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Envisioning Resilient Electrical Infrastructure

A Policy Framework for Incorporating Future Climate Change

into Electricity Sector Planning

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Abstract

Climate change needs to be incorporated in future designs of the electricity sector. This paper argues for a policy framework in which utilities take the lead by performing an electrical climate change impact assessment that evaluates to what extent utilities' electrical assets are vulnerable to future climate change. Based on this assessment, electrical climate change adaptation plans should be formulated by the utility in cooperation with utility regulators, municipalities and supralocal governments. A collaborative process is essential, because adaptation measures need to be tailored to the regional circumstances and many types of adaptation measures require governmental approval. In order for the most sustainable and cost-efficient measures to be selected, cooperation between governments, utilities and utility regulators is necessary.

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1 Introduction

Recently, a powerful storm left thousands without access to electricity across Europe.[1] Last year, Hurricane Sandy left more than 8 million people without power in the Northeastern United States.[2] The electricity sector needs to protect itself against future climate impacts, as scientific research projects that some form of climate change due to anthropogenic emissions of greenhouse gases will be unavoidable.[3] Maintaining energy security is of vital importance to society, because electricity infrastructure powers consumers, businesses and other critical infrastructure such as the IT, health and food sectors. Climate change therefore needs to be considered in future designs of the electricity sector.[4]

This paper presents a policy framework for incorporating future climate change into electricity sector planning. The framework is based on two interrelated observations: first, climate change impacts on electrical infrastructure vary considerably according to regional circumstances. This means that adaptation should be based on a specific climate change impact assessment that incorporates regional climatic, geographical and socio-economical conditions. Second, climate change adaptation measures are very diverse, and potential measures are under the jurisdiction of various public and private entities. In order for climate change adaptation plans to work effectively, cooperation between governments and utilities is necessary.

Section 2 elaborates on the first observation, by providing a general overview of the climatic variables projected to change in the coming decades and their impacts on electricity supply and demand, with specific attention to urban areas. Section 3 deals with the second observation, as it considers what are the available adaptation measures and who is primarily responsible for implementing them. In section 4, employing these two observations, I suggest a policy framework that could be utilized to integrate climate change considerations in electricity sector planning. Section 5 summarizes and concludes the paper.

2 Consequences of Climate Change

2.1 Introduction

Weather impacts are not new to the electricity sector, as facilities and infrastructure operate under differing climatic circumstances throughout the year.[5] Nonetheless, climate change could pose additional challenges not yet accounted for in current planning. This section gives a general

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[1] BBC News, *Deadly Storm And Tidal Surge Batter Northern Europe*, Dec. 6, 2013, http://www.bbc.co.uk/news/world-europe-25243460.

[2] U.S. Department of Energy, *Hurricane Sandy Situation Report # 5* Oct. 30, 2012.

[3] IPCC, *Working Group I Contribution To The IPCC Fifth Assessment Report. Climate Change 2013: The Physical Science Basis. Summary For Policymakers* (Intergovernmental Panel on Climate Change, Switzerland), Sept. 27, 2013; IPCC, *Managing The Risks Of Extreme Events And Disasters To Advance Climate Change Adaptation* (A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change, Cambridge University Press, New York, NY), Apr. 1, 2012.

[4] Jane Ebinger & Walter Vergara, *Climate Impacts On Energy Systems* (World Bank 2011).

[5] EURELECTRIC, Comments On The Green Paper On Adaptation To Climate Change (2007).

overview of the relevant climatic variables projected to change in the coming decades (section 2.2); the impacts they could have on electricity generation, transmission and consumption (sections 2.3-2.5); and the urban dimension of climate change impacts (section 2.6).[6]

2.2 Climatic Variables

Anthropogenic climate change could impact the electricity sector through changes in the average climate, as well as changes in the frequency and intensity of extreme weather events.[7] One of the most important climatic variables is temperature. First, the average global temperature will continue to increase in the coming decades.[8] On the one hand, this could decrease the frequency and intensity of ice and snow storms in colder regions, although changes in ocean currents might produce cooling effects in certain Northern regions.[9] On the other hand, summer temperatures will be considerably higher for periods of time, increasing the number of heat waves.[10] Lack of precipitation could combine with longer periods of higher temperatures to produce decreased water availability, droughts and wildfires.[11] More generally, regional and global precipitation patterns could change, in some cases causing excessive rainfall leading to river flooding.[12] In coastal regions, global sea level rise in combination with more ferocious storms could lead to heightened storm surges and more extensive coastal flooding. Significantly harder to predict is how wind speeds and cloud cover will change due to climate change, although these could also be altered.

2.3 Climate Change Impacts on Electricity Generation

2.3.1 Thermal Power[13]

Thermo-electric power plants, which include nuclear power plants and fossil fuel-based plants, need cooling water to function. In recent summers, power plants in the United States and Europe were forced to reduce their operations due to cooling water scarcity in combination with

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[6] For overviews of the climate change impacts on energy systems, see: U.S. Department of Energy, *U.S. Energy Sector Vulnerabilities To Climate Change And Extreme Weather* Jul. 2013; Roberto Schaeffer et al., *Energy Sector Vulnerability To Climate Change*, 38 ENERGY 1 (2012); L.A. Bollinger et al., *Climate Adaptation Of Interconnected Infrastructures*, REGIONAL ENVIRONMENTAL CHANGE (2013); Ebinger & Vergara, *supra* note 4.

[7] S.A. Hammer et al., *Responding To Climate Change In New York State: The ClimAID Integrated Assessment For Effective Climate Change Adaptation In New York State: Chapter 8 Energy*, 1244 ANNALS OF THE NEW YORK ACADEMY OF SCIENCES 255, 259 (2011).

[8] IPCC, *Working Group I Contribution To The IPCC Fifth Assessment Report. Climate Change 2013: The Physical Science Basis. Summary For Policymakers*, *supra* note 3, at 18.

[9] European Commission, *Adapting Infrastructure To Climate Change*, SWD(2013) 137 final 8 Apr. 16, 2013.

[10] IPCC, *Working Group I Contribution To The IPCC Fifth Assessment Report. Climate Change 2013: The Physical Science Basis. Summary For Policymakers*, *supra* note 3, at 18.

[11] Lisa M. Beard et al., *Key Technical Challenges For The Electric Power Industry And Climate Change*, 25 IEEE TRANSACTIONS ON ENERGY CONVERSION 465, 4 (2010).

[12] IPCC, *Working Group I Contribution To The IPCC Fifth Assessment Report. Climate Change 2013: The Physical Science Basis. Summary For Policymakers*, *supra* note 3, at 21.

[13] For an overview, see: Jeannette Sieber, *Impacts Of, And Adaptation Options To, Extreme Weather Events And Climate Change Concerning Thermal Power Plants*, CLIMATIC CHANGE (2013).

regulatory restrictions on cooling water discharge temperatures.[14] Decreased river runoff and higher river water temperatures due to climate change could lead to an increasing shortage of cooling water.[15]

Thermo-electric power plants are generally sited near water bodies, either seas or large rivers, which provide them with cooling water.[16] Consequently, rising sea levels due to climate change, along with more extreme weather events, could make these power plants more vulnerable to coastal flooding.[17] Not much attention has been paid in the literature to this trade-off between cooling water requirements and flooding vulnerability.[18]

Moreover, higher ambient air and water temperatures could negatively affect the technical efficiency of electricity conversion, and droughts increase the potential danger of bushfires to power stations.[19] Finally, some fossil fuels might become (temporarily) unavailable as climate change hampers off-shore exploration and extraction of oil and gas, and work on coal mines is minimized on high risk days due to coal's combustibility.[20]

2.3.2 Hydropower

Changes in precipitation patterns and temperature could alter the amount of river runoff available for hydroelectric power generation both in terms of seasonal patterns and total river flow, but the effects vary according to regional circumstances.[21] In some countries, the overall impacts are likely to be positive, while in others they are expected to be negative. For example, climate change will likely require preventive investments in hydropower plants in the Mediterranean region, while hydroelectricity production in Nordic countries might conversely increase.[22] In extreme precipitation events, dam safety could be in jeopardy if the runoff exceeds the dam capacity.[23]

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14 Michelle T.H. van Vliet et al., *Vulnerability Of US And European Electricity Supply To Climate Change*, NATURE CLIMATE CHANGE (2012). Regulations to protect the aquatic environment restrict the amount of water that can be withdrawn and the temperature at which it can later be discharged.

15 *Id.*; Dirk Rübbelke & Stefan Vögele, *Impacts Of Climate Change On European Critical Infrastructures*, 14 ENVIRONMENTAL SCIENCE & POLICY 53 (2011).

16 European Commission, *Adapting Infrastructure To Climate Change*, *supra* note 9, at 35.

17 U.S. Department of Energy, *U.S. Energy Sector Vulnerabilities To Climate Change And Extreme Weather*, *supra* note 6.

18 S.A. Hammer et al., *Climate Change And Urban Energy Systems*, *in* CLIMATE CHANGE AND CITIES: FIRST ASSESSMENT REPORT OF THE URBAN CLIMATE CHANGE RESEARCH NETWORK 85, 95 (C. Rosenzweig et al. eds., Cambridge, UK 2011).

19 Torben K. Mideksa & Steffen Kallbekken, *The Impact Of Climate Change On The Electricity Market*, 38 ENERGY POLICY 3579, 3581 (2010); Rosemary Lyster & Rebekah Byrne, *Climate Change Adaptation And Electricity Infrastructure*, RESEARCH HANDBOOK ON CLIMATE ADAPTATION LAW, J. VERSCHUUREN, ED., EDWARD ELGAR PUBLISHING: CHELTENHAM 8 (2013).

20 Frauke Urban & Tom Mitchell, *Climate Change, Disasters And Electricity Generation* 12 (2011); Lyster & Byrne, *supra* note 19, at 8.

21 IPCC, *Chapter 7: Industry, Settlement And Society*, *in* CLIMATE CHANGE 2007: IMPACTS, ADAPTATION AND VULNERABILITY. CONTRIBUTION OF WORKING GROUP II TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 357, 367 (Cambridge, UK 2007).

22 Rolf Golombek et al., *Climate Change*, 113 CLIMATIC CHANGE 357 (2011); Koen Rademaekers et al., *Investment Needs For Future Adaptation Measures In EU Nuclear Power Plants And Other Electricity Generation*

2.3.3 Wind Power

Wind speeds both on-shore and off-shore could locally change in the coming decades.[24] Higher wind speeds would be beneficial for wind energy production, although extreme wind speeds are detrimental due to more frequent standstills or possibly even destruction.[25] Moreover, higher waves could threaten the structural integrity of off-shore wind turbines.[26] However, the reduction of atmospheric icing in colder regions could enhance the aerodynamic performance and the lifetime of wind turbines.[27]

2.3.4 Solar Power

The efficiency of electricity generation based on solar power could be negatively affected due to higher temperatures, while increasing cloud cover could decrease the solar radiation available.[28] The extent of these impacts power is, however, highly uncertain.[29]

2.3.5 Bioenergy

Electricity generation from biomass draws on a variety of resources, such as wood residues, agricultural residues and animal husbandry residues.[30] Climate change influences biomass resources from forests and agriculture, as it affects land use patterns, biological productivity and disease distribution.[31] The impact of climate change on certain trees will be a function of the level of temperature change, vulnerability to vectors, and level of drought conditions, all of which depend on regional circumstances.[32]

2.4 Climate Change Impacts on Electricity Transmission and Distribution

Electricity transmission and distribution facilities are also vulnerable to direct damage from extreme weather events. Substations and underground electricity networks can be inundated during floods which could lead to short-circuiting, explosions and fires.[33] Excessive precipitation

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Technologies Due To Effects Of Climate Change (European Commission: Directorate-General for Energy), Mar. 2011 7.

23 Mideksa & Kallbekken, *supra* note 19, at 3582.

24 *Id.*

25 Urban & Mitchell, *supra* note 20, at 20.

26 S.C. Pryor & R.J. Barthelmie, *Climate Change Impacts On Wind Energy*, 14 RENEWABLE AND SUSTAINABLE ENERGY REVIEWS 430 (2010).

27 Mideksa & Kallbekken, *supra* note 19, at 3582.

28 European Commission, *Adapting Infrastructure To Climate Change*, *supra* note 9.

29 Hammer et al., *Climate Change And Urban Energy Systems*, *supra* note 18, at 97.

30 Urban & Mitchell, *supra* note 20, at 22.

31 Mideksa & Kallbekken, *supra* note 19, at 3583.

32 Hammer et al., *Responding To Climate Change In New York State: The ClimAID Integrated Assessment For Effective Climate Change Adaptation In New York State: Chapter 8 Energy*, *supra* note 7, at 268.

33 The City of New York, *PlaNYC: A Stronger, More Resilient New York. Chapter 6: Utilities* 105, 114 Jun. 11, 2013, at 105; Nicholas Walliman, *Assessment Of The Vulnerability Of Critical Infrastructure Buildings To Floods*, WP02–01–12–05 (FloodProBE), Nov. 2012 15.

could lead to mass movements (landslides, mud and debris flows) causing damages.[34] Substations in northern regions could be exposed to subsidence risk from thawing permafrost.[35] Finally, overhead cables can be destroyed in violent storms due to extreme wind speeds, either by trees or other debris falling on the cables.[36]

Furthermore, transmission infrastructure works less efficiently during periods of higher temperature because of the additional resistance induced.[37] If equipment cannot cool off sufficiently during nighttime, this could in some cases even lead to a breakdown of the equipment and service disruption. Instead, electric equipment might need to operate at less than the maximum power in order to prolong the equipment life span.[38] The sagging of power lines due to higher temperatures might also be hazardous, as well as bushfires caused by faulty electricity assets.[39] On the other hand, issues related to colder temperatures, such as ice storms or extreme snowfall, might be alleviated due to milder temperatures.[40]

2.5 Climate Change Impacts on Electricity Consumption

Regional and seasonal shifts in electricity demand for heating and cooling are among the most significant impacts of climate change on electricity infrastructure.[41] Due to rising temperatures, it is generally expected that the number of cooling degree days will increase and the amount of heating degree days will decrease.[42] This will have different consequences depending on the current temperatures in a region, the sensitivity of electricity demand to temperature changes and the amount of electricity used for heating and cooling.[43] In colder countries for instance, global temperature rise will likely cause the annual electricity consumption to fall in the short term due to a lower heating demand. Nevertheless, electricity savings might be modest because many other sources of energy are relied upon for heating, such as oil, gas and biomass.[44]

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[34] European Commission, *Adapting Infrastructure To Climate Change*, *supra* note 9, at 34.

[35] Frederick E. Nelson et al., *Subsidence Risk From Thawing Permafrost*, 410 NATURE 889 (2001).

[36] Primary examples are the 1999 storms across France: J. ABRAHAM, F. BENDIMERAD ET AL., WINDSTORMS LOTHAR AND MARTIN. DECEMBER 26-28, 1999 (Newark, CA, Risk Management Solutions 2000); See also Gibson Peters et al., *Transmission Line Reliability*, ELECTRICAL TRANSMISSION LINE AND SUBSTATION STRUCTURES, PROC., ELECTRICAL TRANSMISSION CONF., AMERICAN SOCIETY OF CIVIL ENGINEERS (ASCE), RESTON, VA 12 (2006).

[37] U.S. Department of Energy, *U.S. Energy Sector Vulnerabilities To Climate Change And Extreme Weather*, *supra* note 6.

[38] Beard et al., *supra* note 11, at 3.

[39] Lee Godden & Anne Kallies, *Electricity Network Development: New Challenges For Australia*, *in* ENERGY NETWORKS AND THE LAW: INNOVATIVE SOLUTIONS IN CHANGING MARKETS 308 (Martha M. Roggenkamp et al. eds., Oxford University Press 2012).

[40] Hammer et al., *Responding To Climate Change In New York State: The ClimAID Integrated Assessment For Effective Climate Change Adaptation In New York State: Chapter 8 Energy*, *supra* note 7, at 262.

[41] European Commission, *Adapting Infrastructure To Climate Change*, *supra* note 9, at 12.

[42] Heating degrees are those days where heating is deemed necessary, often defined in relation to a base temperature. Conversely, cooling degrees are those days where cooling is deemed necessary.

[43] Daniel R. Klein et al., *Susceptibility Of The European Electricity Sector To Climate Change*, 59 ENERGY 183 (2013).

[44] IPCC, *Chapter 7: Industry, Settlement And Society*, *supra* note 21, at 366.

As electricity is the dominant means to operate cooling devices in most countries, higher temperatures will result in a global increase in summer electricity consumption, both by an intensified usage and an increased adoption rate of air conditioners.[45] In addition, more frequent and intense heat waves will increase peak demand and produce periods of sustained high electricity usage. Tourists from colder areas that tend to travel to warmer areas could augment summer peak demand further in these areas, while demand in colder areas is reduced.[46] Nonetheless, cooling demand is also significantly affected by other climatic variables, such as relative humidity, and by other non-climatic variables, such as income, demography and technology.[47]

2.6 Urban Dimension of Climate Change Impacts

Even though electricity infrastructure is not exclusively located in urban areas, it is important to consider climate impacts in an urban context, as some of the issues are especially pronounced in these areas.

Urban areas represent a very concentrated demand for electricity, which poses infrastructural challenges to avoid load pockets during summer peak demand. Moreover, the urban heat island effect exacerbates heat wave impacts in urban areas by significantly increasing local electricity demand for space cooling.[48] As a result, blackouts could occur or corresponding urban electricity prices could rise considerably. This latter effect could make lower-income consumers with air conditioners more reluctant to use them because they cannot afford the electricity, with possible health consequences.[49] In impoverished urban neighborhoods, this problem is often compounded by a higher settlement density, a lack of open space and more sparse vegetation, which contributes to a more pronounced urban heat island effect.[50]

Furthermore, a breakdown of electricity supply in urban areas due to extreme weather events has major impacts among commercial, industrial and residential sectors.[51] During blackouts, not only the utility companies[52] and their investors often suffer wide-spread economic losses, but other businesses also incur loss of income due to forced closures. In that

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[45] Mideksa & Kallbekken, *supra* note 19, at 3580.
[46] Klein et al., *supra* note 43, at 189.
[47] Hammer et al., *Responding To Climate Change In New York State: The ClimAID Integrated Assessment For Effective Climate Change Adaptation In New York State: Chapter 8 Energy*, *supra* note 7, at 273; Gunnar S. Eskeland & Torben K. Mideksa, *Electricity Demand In A Changing Climate*, 15 MITIGATION AND ADAPTATION STRATEGIES FOR GLOBAL CHANGE 877 (2010).
[48] Urban heat islands refer to the fact that cities are full of impervious surfaces that trap heat, leading to elevated air temperatures: Hammer et al., *Climate Change And Urban Energy Systems*, *supra* note 18, at 92.
[49] Hammer et al., *Responding To Climate Change In New York State: The ClimAID Integrated Assessment For Effective Climate Change Adaptation In New York State: Chapter 8 Energy*, *supra* note 7, at 287.
[50] *Id.*
[51] Future Cities, *Adaptation Compass. Guidance For Developing Climate-Proof City Regions* (2012) 22; Hammer et al., *Climate Change And Urban Energy Systems*, *supra* note 18, at 92.
[52] Acclimatise, *Building Business Resilience To Inevitable Climate Change* (Carbon Disclosure Project Report. Global Electric Utilities, Oxford 2009).

case, infrastructure providers may even face liability for these damages.[53] In addition, other critical infrastructure requires electricity in order to function.[54] This interrelatedness of infrastructure is especially pronounced in urban areas, where infrastructure is often "co-located (e.g. power cables laid below roads and beside communications cables, adjacent to water and gas mains and above sewers)."[55] Transit infrastructure such as trains, subways and traffic lights, runs on electricity, which means that during a black-out employees often cannot get to work, leading to additional economic losses.[56] Personal computers and mobile phones need electric power to run or to charge and telecommunication networks require electricity.[57] Food infrastructure needs electricity for refrigeration purposes and electricity is sometimes also used for cooking food. Moreover, power is required to pump gas and operate district heating systems.[58] During flooding events, a loss of electricity means that pumping equipment cannot be operated to dewater tunnels and to clean up damaged subway stations, or to pump stormwater, wastewater or drinking water.[59] Electricity infrastructure is often vital to accommodate an adequate emergency response to an extreme event.[60] Power outages at hospitals, nursing homes and adult-care facilities directly threaten the lives of their inhabitants who are often in fragile conditions. Blackouts during a heat wave are especially dangerous for vulnerable people, such as the elderly and the disabled.[61] If they live in high-rise buildings, failing elevator services mean that they could be stranded in their high-temperature apartments for extended periods of time, without any water from the tap because pumping equipment is failing.[62] Future trends in population growth and urbanization will exacerbate these impacts and exert significant additional stress on electricity infrastructure.[63]

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[53] Jan McDonald, *Paying The Price Of Climate Change Adaptation*, *in* ADAPTATION TO CLIMATE CHANGE 234 (Tim Bonyhady eds., Federation Press 2010).

[54] FloodProBE, *Identification And Analysis Of Most Vulnerable Infrastructure In Respect ToFloods*, WP2–01–12–04 5 Jan. 18, 2013.

[55] European Commission, *Adapting Infrastructure To Climate Change*, *supra* note 9, at 5; See also Nikolai Bobylev, *Urban Physical Infrastructure Adaptation To Climate Change*, *in* 2 GLOBAL CHANGE, ENERGY ISSUES AND REGULATION POLICIES 77, 128 (Jean Bernard Saulnier & Marcelo D. Varella eds., Dordrecht, Springer Netherlands 2013).

[56] The City of New York, *PlaNYC: A Stronger, More Resilient New York. Chapter 6: Utilities*, *supra* note 33, at 107.

[57] The City of New York, *PlaNYC: A Stronger, More Resilient New York. Chapter 1: Sandy And Its Impacts* 9, 16 Jun. 11, 2013, at 9; FloodProBE, *Identification And Analysis Of Most Vulnerable Infrastructure In Respect ToFloods*, *supra* note 54, at 28.

[58] The City of New York, *PlaNYC: A Stronger, More Resilient New York. Chapter 6: Utilities*, *supra* note 33, at 117.

[59] The City of New York, *PlaNYC: A Stronger, More Resilient New York. Chapter 1: Sandy And Its Impacts*, *supra* note 57, at 17.

[60] IPCC, *Chapter 7: Industry, Settlement And Society*, *supra* note 21, at 371; FloodProBE, *Technologies For Flood Protection Of The Built Environment*, WP05–01–13–03 94 Sept. 18, 2013.

[61] IPCC, *Managing The Risks Of Extreme Events And Disasters To Advance Climate Change Adaptation*, *supra* note 3, at 257.

[62] The City of New York, *PlaNYC: A Stronger, More Resilient New York. Chapter 6: Utilities*, *supra* note 33, at 107.

[63] Beard et al., *supra* note 11, at 4; N. Jollands et al., *The Climate's Long-Term Impact On New Zealand*

3 Climate Change Adaptation Measures

3.1 Introduction

Section 2 has made it clear that climate change impacts on electricity infrastructure are diverse. This means that in one region, droughts and heat waves might be most critical, while in another region flooding might be the more serious issue. Corresponding measures to adapt electricity infrastructure to climate change are therefore necessarily just as varied. In most cases the employment of a range of adaptation strategies will be most effective.

Due to the nature of the electricity sector, only a few actors are in a position to implement climate change resilience measures.[64] I distinguish here between *utilities & utility regulators (*section 3.2)*, local governments (*section 3.3) and *supralocal governments (*section 3.4). Electricity sector regulators are included here with utilities, as these regulators can only demand or allow those adaptation measures that the utility is actually able to implement. Supralocal governments include all those governments that have jurisdictions larger than single cities, which might be regional, provincial, state or national governments, depending on the country.

Certain adaptation measures can only be carried out by one of these three actors – for instance, utilities will be in charge of making electric equipment water-proof, while many planning decisions are made by governments. It is useful to investigate what type of measures generally can be carried out by utilities themselves and what measures need governmental authorization, because the most optimal adaptation options might not be selected if a utility only considers the options it can carry out by itself. Effective climate implementation calls for cooperation among utilities and governments.

3.2 Utilities & Utility Regulators[65]

The first adaptation strategy available for utilities is *"hardening",* either by constructing new reinforced infrastructure or retrofitting existing infrastructure.[66] Flood damage can be prevented by elevating critical infrastructure or by using submersible, saltwater-resistant equipment which is less susceptible to damage resulting from inundation. Floodwalls can be established around substations, and floating or amphibious concepts could also be potentially used.[67] Storm impacts to overhead lines can be prevented by burying electric power lines. Nonetheless, undergrounding is only suitable in some cases, as it is expensive and might make

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Infrastructure (CLINZI) project—A Case Study Of Hamilton City, New Zealand, 83 JOURNAL OF ENVIRONMENTAL MANAGEMENT 460 (2007).

[64] About the term "resilience": Miles Keogh & Christina Cody, *Resilience In Regulated Utilities* (The National Association of Regulatory Utility Commissioners), Nov. 2013.

[65] For a recent example of a utility taking resiliency measures, see: Consolidated Edison Company of New York Inc., *Storm Hardening And Resiliency Collaborative Report* Dec. 4, 2013.

[66] U.S. Department of Energy, *U.S. Energy Sector Vulnerabilities To Climate Change And Extreme Weather*, *supra* note 6.

[67] Rutger de Graaf, *Technologies For Flood-Proofing "hotspot" Buildings*, WP4–01–12–01 28–30 (FloodProBE), Jun. 7, 2012.

cables more vulnerable to flooding.[68] In addition, storm and flood hardening might reduce the ability of equipment to dissipate heat, so that the implementation of one hardening measure needs to consider the possible amplification of other vulnerabilities. Utilities have to make sure that solutions to one problem do not cause other problems. Cooling water scarcity issues can be addressed by installing new cooling systems for thermoelectric plants that use less water or reuse process water.[69] Hardening measures could also include long-term career training of utility personnel, so that a skilled energy workforce could help to operate, maintain and upgrade ageing electrical infrastructure properly.

Hardening requirements could be formalized in the form of *technical standards.* Technical standards have an important impact on the resilience of electric products, processes and construction, as they are used in every phase during the lifetime cycle of infrastructure.[70] Organizations establishing reliability standards for electric apparatus and power system design could incorporate climate change considerations, but utilities could also update their network and reliability codes to reflect climate change resiliency.[71]

Second, utilities can improve resiliency by making grids *smarter* and *more decentralized.* One of the properties that makes electrical infrastructure especially vulnerable to climate change impacts is that it is traditionally centralized: one big generation facility produces electricity that is further transmitted and distributed to a large number of people.[72] If one link in the chain breaks, the whole system falls apart. Distributed generation and storage would create a more resilient electricity system, particularly when combined with microgrids. In these decentralized networks, a failure of one component would not lead to cascading blackouts. Placing generation closer to consumption might also reduce distribution and transmission losses and reduce constraints on power lines.[73] Furthermore, smart grids could help to pinpoint malfunctioning parts of the systems, so that staff can be dispatched promptly to damaged equipment.[74] Finally, intermittent renewable energy sources such as solar PV and wind energy, as well as the use of electric cars, could be more easily incorporated in these smart grids, diversifying electricity generation sources and exploiting additional synergies between adaptation and mitigation goals.[75]

Third, utilities could implement measures to reduce energy consumption during peak demand. In particular, demand response programs help to 'shave' the peak off the energy demand during

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68 Sieber, *supra* note 13, at 9.
69 *Id.* at 7.
70 European Commission, *Adapting Infrastructure To Climate Change*, *supra* note 9.
71 Beard et al., *supra* note 11.
72 Lyster & Byrne, *supra* note 19, at 13.
73 *Id.* at 16.
74 *Id.* at 17.
75 Lesley K. McAllister, *Adaptive Mitigation In The Electric Power Sector*, 2011 BRIGHAM YOUNG UNIVERSITY LAW REVIEW 2115 (*in* ABI/INFORM Complete; ProQuest Central; ProQuest Research Library, 922047419, 2011).

heat waves. Demand side management, facilitated by smart grids, could also lead to energy reduction.

Fourth, utilities could facilitate additional generating or transmission capacity in order to prevent blackouts during peak demand.[76] For example, the implementation of solar powered cooling and distributed cooling could help to provide additional energy for air conditioning during summer periods.[77] Temporary capacity increases could also be achieved by changing water management practices to secure hydroelectricity production during critical periods.[78] New generation facilities might also be based on fossil fuels, but this would be at odds with climate change mitigation goals.

Finally, utilities could prepare emergency response plans with future climate change in mind. Temporary, mobile substations could be installed which could be deployed in case of emergency.[79] Employees trained to understand climate risks could be more able to restore service in a timely manner after a storm hits. Moreover, early warning systems that link information about the physical climate system with the energy system could be established, which would communicate anticipated blackouts or brownouts to the general public, response agencies and other utilities.[80]

3.3 Local Governments

As noted in section 2.6, urban areas pose special challenges for electrical infrastructure. Municipalities therefore play an important role in implementing climate change resilience. This is evidenced by multiple initiatives that seek to strengthen local climate resilience.[81] Many cities around the world have already developed local adaptation strategies. Local governments have multiple tools to improve climate change resilience of electrical infrastructure.

First of all, local governments are often in charge of *spatial planning.* Zoning plans could incorporate certain elevation requirements when building or rebuilding infrastructure. They could prevent the construction of electrical facilities in flood-prone areas, and could even potentially require older infrastructure to relocate to safer, higher altitude areas.[82] Land-use planning can also include zoning provisions to mitigate the urban heat island effect, for instance

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76 James E. Neumann & Jason C. Price, *Adapting To Climate Change. The Public Policy Response* Jun. 2009 23.

77 European Commission, *Impact Assessment - Part 2. Accompanying The Document: An EU Strategy On Adaptation To Climate Change*, SWD(2013) 132 final 27 Apr. 16, 2013.

78 *Id.*

79 The City of New York, *PlaNYC: A Stronger, More Resilient New York. Chapter 6: Utilities*, *supra* note 33, at 127.

80 Michael Kintner-Meyer & Ian Kraucunas, *The Growing Footprint Of Climate Change;Can Systems Built Today Cope With Tomorrow's Weather Extremes?*, PUBLIC UTILITIES FORTNIGHTLY, Jul. 2013.

81 C40 Cities: Climate Leadership Group, http://www.c40cities.org/; World Mayors Council on Climate Change, http://www.worldmayorscouncil.org/; Durban Adaptation Charter, http://www.durbanadaptationcharter.org/about.

82 European Commission, *Impact Assessment - Part 1. Accompanying The Document: An EU Strategy On Adaptation To Climate Change*, SWD(2013) 132 38–39 Apr. 16, 2013.

by incorporating green infrastructure.[83]

Second, local governments are often responsible for *building regulations.* Flood resiliency can be improved by adjusting building standards, for instance by requiring electric equipment to be elevated or to use flood-resilient materials.[84] Especially in high-rise buildings, equipment is often responsible for delivering electricity to a great number of people, but placed in basements where they are vulnerable to flooding. Critical facilities such as hospitals could also be required to install backup generators. Furthermore, building regulations can help to reduce energy consumption, which would help to moderate the peak demand during heat waves. Energy reduction can be achieved through energy conservation (e.g. less intensive usage of air conditioners) or energy efficiency (e.g. newer, more efficient air-conditioning systems).[85] The design of buildings is important in reducing energy usage, for instance by improving insulation or using green roofs.[86]

Finally, local governments could provide assistance to utilities in the implementation of climate change resilience, for instance by facilitating smart grids and renewable energy.[87] They could also be instrumental in organizing effective emergency response plans.

3.4 Supralocal Governments

Supralocal governments – such as countries, states or provinces – often have broad legislative powers, which could indirectly facilitate the implementation of climate change resilience. Electricity laws could facilitate smart grids, renewable energy and energy efficiency, while building laws could promote flood-resiliency of electric equipment. Moreover, supralocal adaptation strategies could create awareness for climate change impacts on the electricity sector, promote infrastructure resilience and fund research on climate change vulnerabilities.

Besides these indirect powers, supralocal governments are often more directly involved in providing general protection against flooding that could prevent storm surges from damaging electricity infrastructure. Protection can utilize man-made structures such as dykes, but natural areas could also act as buffers to mitigate the impacts of storms and floods. Ecosystem based approaches include afforestation, extending sand banks and limiting soil sealing. Such green infrastructure solutions could be cheaper than purely technical protection and include other

[83] European Commission, *Adapting Infrastructure To Climate Change*, *supra* note 9, at 16; Brian Stone & John M. Norman, *Land Use Planning And Surface Heat Island Formation*, 40 ATMOSPHERIC ENVIRONMENT 3561 (2006).

[84] FloodProBE, *Technologies For Flood Protection Of The Built Environment*, *supra* note 60, at 96.

[85] Energy reduction strategies often also have the co-benefit of contributing to climate change mitigation goals, as energy production is closely associated with greenhouse gas emissions: McAllister, *supra* note 75; nonetheless, energy rebound effects need to be considered, as indirect energy use effects often undo some of the energy reductions seemingly achieved: Jeroen C.J.M. Bergh, *Energy Conservation More Effective With Rebound Policy*, 48 ENVIRONMENTAL AND RESOURCE ECONOMICS 43 (2010).

[86] Hammer et al., *Responding To Climate Change In New York State: The ClimAID Integrated Assessment For Effective Climate Change Adaptation In New York State: Chapter 8 Energy*, *supra* note 7, at 279.

[87] Hammer et al., *Climate Change And Urban Energy Systems*, *supra* note 18, at 89.

co-benefits generated by healthy ecosystems.[88] Therefore it is important that these options are considered in resiliency planning.

Supralocal governments often also have spatial planning powers on larger scales. This is important in particular for the planning of high-voltage transmission infrastructure. Supralocal spatial planning can be used similarly to local spatial planning, by including elevation requirements and obliging the construction of electrical facilities in safer, higher altitude areas.

4 Policy Integration of Climate Change Adaptation

4.1 Introduction

Sections 2 and 3 have established what are the main climate change impacts on electricity infrastructure and who are the main actors and their roles in climate change adaptation. In this section, I present a policy framework to incorporate these observations. First, section 4.2 examines the role of uncertainty in electricity sector planning for future climate change. Then, the main instruments to enact climate resilience in the electricity sector are discussed: electrical climate change impact assessments and electrical climate change adaptation plans (section 4.3 and section 4.4). Section 4.5 briefly mentions how this process could be supported by legislation.

4.2 Role of Uncertainty

Uncertainty about future climate change in electrical sector planning revolves around two issues, namely the timing and extent of climate change.

The timing of climate change determines if current decisions on capital investments and replacement need to incorporate the climatic situation at the end of the useful life of infrastructure.[89] If extreme weather changes are projected to occur on a timescale slower than the lifetime of infrastructure, the power system will be able to adapt by designing expansion and equipment according to the current weather extremes.[90] On the contrary, if climatic changes are projected to occur rapidly, planning decisions need to be made keeping future climate in mind. For instance, power plants must then be sited based not only on current flood maps, but also on maps depicting expected future flood levels including the effects of climate change.[91]

The extent of climate change impacts determines to what degree adaptive action is warranted. A key question is "whether climate change will require a significant shift in energy planning or will remain a small demand driver relative to population and economic growth, and other factors."[92]

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[88] European Commission, *Adapting Infrastructure To Climate Change*, *supra* note 9, at 16.

[89] Kelly Harrington-Andrejasich, Con Edison infrastructure plan needs work, groups say (Jun. 4, 2013), http://www.snl.com/Interactivex/article.aspx?CdId=A-17879657-10277.

[90] Beard et al., *supra* note 11, at 3.

[91] Harrington-Andrejasich, Con Edison infrastructure plan needs work, groups say, *supra* note 89.

[92] Hammer et al., *Responding To Climate Change In New York State: The ClimAID Integrated Assessment For*

Both types of uncertainty make it complicated to base investments on future climate projections.[93] I am not arguing here that the impact of climate change will always be considerable compared to other factors and that measures should be taken regardless of the uncertainty involved. On the contrary, climate change adaptation should take regional circumstances into account, which means that in some regions the conclusion could be that no adaptive action is necessary. However, what is important is that future climate risks and uncertainties are actually *assessed*, since the lifetime of electrical infrastructure is often long, "15–40 years for power plants and 40–75 years for transmission lines."[94] This means that electrical infrastructure should be able to cope with future climatic circumstances. What is vital then, is that an informed decision is made based on an *electrical climate change impact assessment.*

4.3 Electrical Climate Change Impact Assessment

An electrical climate change impact assessment is an assessment that investigates the possible impacts of future climate change on electricity infrastructure.[95] This assessment should be based on the best available data suited to the particular geographic area. I would argue that utilities (or a cooperation of utilities) should have primary responsibility for carrying out this assessment for their own assets. These could be stand-alone investigations, such as the initial climate risk assessments carried out by utilities in the United Kingdom.[96] Utilities could also incorporate these assessments into regular reports on infrastructure reliability and investments.[97] This could help to evaluate the impact of climate change against other drivers of infrastructure investment, such as the incorporation of renewable energy and socio-economic developments.[98]

Nonetheless, the utility might not have the climate-related knowledge to carry out the vulnerability study alone. Cooperation with weather agencies or environmental departments in the government could prove useful here to fill this knowledge gap. Alternatively, data on climate impacts, such as future flooding maps, could be made available in publicly accessible databases.

Effective Climate Change Adaptation In New York State: Chapter 8 Energy, *supra* note 7, at 271.

[93] European Commission, *Adapting Infrastructure To Climate Change*, *supra* note 9, at 6.

[94] Ebinger & Vergara, *supra* note 4, at xxi. According to EURELECTRIC, "new power stations typically have a life of up to 50 years and beyond." EURELECTRIC, *supra* note 5.

[95] See also: Michael B. Gerrard, Post-Hearing Brief Of The Columbia Center For Climate Change Law In State Of New York Public Service Comission Case No. 13-E-0030 (2013); Schaeffer et al., *supra* note 6; Rabindra Nepal & Tooraj Jamasb, *Security Of European Electricity Systems*, INTERNATIONAL JOURNAL OF CRITICAL INFRASTRUCTURE PROTECTION (2013).

[96] Department for Environment, Food and Rural Affairs, *Adapting To Climate Change: Helping Key Sectors To Adapt To Climate Change* Mar. 2012.

[97] For example, see: National Grid, *Climate Change Adaptation Report* Sept. 2010 21; cf. Keogh & Cody, *supra* note 64, at 9.

[98] Frans Berkhout et al., *Socio-Economic Futures In Climate Change Impact Assessment*, 12 GLOBAL ENVIRONMENTAL CHANGE 83 (2002).

4.4 Electrical Climate Change Adaptation Plan

If certain vulnerabilities are identified, electrical climate change adaptation plans might be formulated to address the existing weaknesses in the electricity infrastructure. At this point, all the actors identified in section 3 should be included in the planning process. Adaptation plans could be made at multiple scales. National utilities that operate the transmission infrastructure might work together with supralocal governments, while regional utilities that operate distribution infrastructure would additionally focus on local governments. Furthermore, utility regulators should be involved as they might need to approve the recuperation of the utility's investments in climate resiliency. An adaptation plan should evaluate which measures would be most suitable for the specific region.

A collaborative process facilitates the selection of the most sustainable and cost-efficient solutions. Given the wide range of actors involved, measures could range from hardening electric equipment to implementing green infrastructure, and from rolling out smart grids to updating building codes. Moreover, a cooperative process provides widespread support among actors, which might ease the challenge of obtaining funding for resiliency measures, either through electricity rate increases, governmental support or private investments.[99] Finally, a comprehensive adaptation plan would help to firmly establish the future benefits and the avoided costs of resiliency measures, even if these measures do not pay dividends right away.

One example of a collaborative process is the Collaborative in the 2014 rate case procedure in New York City.[100] Con Edison, the biggest utility in New York City, applied for a $1 billion investment in storm hardening measures to reinforce its electrical system after Hurricane Sandy. On the initiative of the New York State Department of Public Service Staff, a Collaborative was formed comprised of parties to the rate case, including the utility, state and local governments and NGOs. This Collaborative addressed climate change impacts on the utility's infrastructure, design standards and resiliency strategies.[101]

Finally, evaluating the implementation and success of an electric climate change adaptation plan is no easy task, since some of the events that it prepares for do not occur frequently.[102] Certain indicators could be developed in order to monitor the climate vulnerability and resiliency of electricity infrastructure.[103]

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[99] European Commission, *Adapting Infrastructure To Climate Change*, *supra* note 9, at 25; Christopher Kennedy & Jan Corfee-Morlot, *Mobilising Investment In Low Carbon, Climate Resilient Infrastructure* (2012).

[100] Consolidated Edison Company of New York Inc., *supra* note 65.

[101] *Id.*

[102] European Commission, *An EU Strategy On Adaptation To Climate Change*, COM/2013/0216 final Apr. 16, 2013.

[103] Axel Michaelowa et al., *Use Of Indicators To Improve Communication On Energy Systems Vulnerability, Resilience And Adaptation To Climate Change*, *in* MANAGEMENT OF WEATHER AND CLIMATE RISK IN THE ENERGY INDUSTRY 69 (Springer 2010); Keogh & Cody, *supra* note 64, at 10.

4.5 Supporting Legislation

Ideally, the process of devising climate change impact assessments and adaptation plans should be enshrined in electricity sector regulation, so that utilities are required to carry out these procedures regularly. Utility regulators could also be instructed to assess the climate preparedness of the utilities under their supervision. Additionally, climate change impact assessments could be incorporated in Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) procedures.[104] This would entail a 'reverse' EIA or SEA, demonstrating that future climate change will not adversely affect the proposed construction, policy or program.[105]

5 Conclusion

This paper has argued that climate change resilience in the electricity sector is best served by a policy process that is led by utilities, but accompanied by intensive cooperation between utilities, utility regulators, local and supralocal governments. The first reason for a collaborative process is that climate change impacts on electricity infrastructure vary considerably according to regional circumstances. This means that adaptation measures need to be tailored to regional conditions. Second, climate change adaptation measures are very diverse and utilities do not have the authority to implement all resiliency measures. Many types of adaptation measures require governmental approval. In order for the most sustainable and cost-efficient measures to be selected, cooperation between governments and utilities is necessary. Moreover, a collaborative process could provide utilities with climate-related knowledge available in governmental departments, as well as facilitate the funding of resiliency measures.

The proposed process would start with electrical climate change impact assessments, in which utilities assess to what extent their assets are vulnerable to climate change. These assessments could be incorporated into regular reports on infrastructure reliability and investments. Based on these assessments, electrical climate change adaptation plans should be formulated through cooperation between utilities, utility regulators, municipalities and supralocal governments. These plans would address the existing weaknesses in the electrical infrastructure and would help to establish the future benefits and avoided costs of resiliency measures. The whole process should be supported by legislation, so that utilities are required to carry out these procedures periodically.

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[104] Shardul Agrawala et al., *Incorporating Climate Change Impacts And Adaptation In Environmental Impact Assessments: Opportunities And Challenges*, OECD Environmental Working Paper 24 (2010) 26; Philip Byer et al., *Climate Change In Impact Assessment* (2012).

[105] Michael B. Gerrard, *Reverse Environmental Impact Analysis: Effect Of Climate Change On Projects*, NEW YORK LAW JOURNAL (2012); European Commission, *Adapting Infrastructure To Climate Change*, *supra* note 9.