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ELECTRICITY SECTOR ADAPTATION TO HEAT WAVES

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EXECUTIVE SUMMARY

Electricity is very important for human settlements and a key accelerator for development and prosperity. As heat waves become more frequent and intense the reliability and efficiency of the electricity systems is threatened. Increased temperatures have adverse effects on electricity generation, transmission, distribution and demand. The high temperatures cause intentional or unintentional brownouts and blackouts, which come at high costs for people and economies. The case studies in this analysis highlight the importance of heat wave impacts to the electricity sector and the need for adaptation. The electricity sector requires a holistic approach for adaptation that comprises technological, behavioral and institutional approaches. All actors, governments, electricity companies and individuals need to collaborate in order to secure electricity supply in future heat waves.

CONTENTS

GLOSSARY

Adaptation: The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.

Adaptive capacity: The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.

Resilience: The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation.

Sensitivity: The degree to which a system or species is affected, either adversely or beneficially, by climate variability or change.

Sustainability: A dynamic process that guarantees the persistence of natural and human systems in an equitable manner.

Vulnerability: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.[1]

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[1] *Adopted by* Intergovernmental Panel on Climate Change [Hereinafter IPCC], Annex II: Glossary [Agard, J., E.L.F. Schipper, J. Birkmann, M. Campos, C. Dubeux, Y. Nojiri, L. Olsson, B. Osman-Elasha, M. Pelling, M.J. Prather, M.G. Rivera-Ferre, O.C. Ruppel, A. Sallenger, K.R. Smith, A.L. St. Clair, K.J. Mach, M.D. Mastrandrea, and T.E. Bilir (eds)]. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1757-1776, (2014).

ABBREVIATIONS

AB	Assembly Bill
ARENA	Australian Renewable Energy Agency
ASN	Nuclear Safety Authority (Autorité de Sûreté Nucléaire)
CAC	New York State Climate Action Council
CAISO	California Independent System Operator
CaLEAP	California Local Energy Assurance Planning
CEC	California Energy Commission
CEFC	Clean Energy Finance Corporation
CPUC	California Public Utilities Commission
EDF	Electricity of France
EEPS	New York Energy Efficiency Portfolio Standard
ESC	Energy Saving Certificates
ETS	Emission Trading Scheme
FiT	Feed-in Tariffs
ICT	Information and Communication Technologies
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
MW	Megawatt
NYPA	New York Power Authority
NYSERDA	New York State Energy Research And Development Authorit
OECD	Organisation for Economic Co-operation and Development
ONERC	National Observatory for the Effects of Global Warming
PCET	Regional Climate-Energy Plans
PG&E	Pacific Gas and Electric Company
PSC	New York Public Service Commission
PV	Photovoltaic
REC	Renewable Energy Certificate
RPS	Renewables Portfolio Standard
SB	Senate Bill
SBC	Systems Benefit Charge
SRCAE	Regional Climate, Air and Energy Programs
TWh	Terawatt-hours
U.S.	United States
UHI	Urban heat island
WMO	World Meteorological Organization

1. INTRODUCTION

The electricity sector plays a vital role in all human settlements and supports economies, prosperity and well-being.[2] Societies require a reliable electricity generation, transmission and distribution system with fewer environmental impacts but at the same time in ever increasing volume.[3] The failure to ensure a constant electricity supply at the demand rate has negative implications.[4] Heat waves affect and will continue to affect not only the efficacy of electricity systems but also the electricity demand rates constraining those systems.[5] To reduce the vulnerability of the electricity sector there is a need for climate change adaptation measures that will help prevent blackouts and brownouts and build resilience to system failures in the future.[6] Infrastructure investments in combination with governmental and institutional planning with long-term perspectives will play an important role for a heat wave-proof electricity sector.

This White Paper describes and analyzes options available for electricity sector adaptation to the increasing risk and recurrence of heat waves. Section 2 examines the impacts of heat waves on electricity systems and presents four case studies where heat wave events affected large electricity systems, highlighting the need for climate change preparedness. Section 3 analyses technological, behavioral and institutional adaptation options for the electricity sector. Section 4 concludes with the findings of the research. It bears noting at the outset that research on impacts and adaptation measures for heat wave-related mortality is a well-established research issue among scientists and governments, largely because of observed fatalities. Health publications, heat

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[2] Jane Ebinger & Walter Vergara, *Climate Impacts on Energy Systems: Key Issues for Energy Sector Adaptation,* World Bank, 4, (2011).

[3] S. A. Hammer, J. Keirstead, S. Dhakal, J. Mitchell, M. Colley, R. Connell, R. Gonzalez, M. Herve-Mignucci, L. Parshall, N. Schulz, M. Hyams, *Climate change and urban energy systems. Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network*, C. Rosenzweig, W. D. Solecki, S. A. Hammer, S. Mehrotra, (eds), Cambridge University Press, Cambridge, UK, 85-111, 86, (2011).

[4] Union of Concerned Scientists [Hereinafter UCS], *Power Failure, How Climate Change Puts Our Electricity at Risk-and What We Can Do*, Michelle Davis & Steve Clemmer, USA, 2, (2004).

[5] U.S. Department of Energy's Office of Policy and International Affairs [Hereinafter DOE-PI], *Energy Sector Vulnerability to Climate Change and Extreme Weather,* USA, i, (2013).

[6] UCS, *supra* note 4, at 9.

wave plans for the population and heat-warning systems, however, are outside the scope of this research.

2. HEAT WAVE IMPACTS ON THE ELECTRICITY SECTOR

2.1 Introduction

Existing electricity generation, transmission and distribution systems were not designed to endure heat waves of today's magnitude.[7] Also, end users require more electricity during heat waves, further stretching electricity systems' capacity.[8] During a heat wave the electricity sector can suffer problems with generation, transmission and distribution, potentially causing a blackout (the complete failure of electricity distribution) or a brownout (the reduced supply of electricity).[9] Blackouts and brownouts that occur during a heat wave can have detrimental effects on human health and the economy,[10] as modern societies are highly dependent on electricity for all aspects of daily needs, including lighting, transportation, communication, cooling and industrial production.[11] The impacts vary according to the duration of the failure – power interruptions can be "momentary", lasting only a few seconds, or "sustained," meaning the event is longer than five minutes[12] – but of course longer interruptions have greater impacts.

2.2 The Definition of a Heat Wave

A heat wave is characterized as a prolonged period of hot weather in comparison with the anticipated weather conditions of an area at a certain period of time. There is no agreed upon

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[7] *Id.*, at 2; Government Accountability Office [Hereinafter GAO], Energy infrastructure risks and adaptation efforts. Washington, D.C., (2014); DOE-PI, *supra* note 5 at 1.

[8] Asian Development Bank [Hereinafter ADB], *Climate Risk and Adaptation in the Electric Power Sector,* Manila, Philippines, xiii, (2012).

[9] CRO Forum, *Power Blackout Risks - Risk Management Options Emerging Risk Initiative*, Position Paper, Michael Bruch, Volker Münch, Markus Aichinger, Michael Kuhn, Martin Weymann and Gerhard Schmid, 4, (2011); UCS, *supra* note 4, at 2 & 8.

[10] CRO Forum, *supra* note 9, at 4.

[11] *Id.*

[12] Kristina Hamachi LaCommare and Joseph H. Eto, *Understanding the Cost of Power Interruptions to U.S. Electricity Consumers*, Ernest Orlando Lawrence Berkeley National Laboratory, (2004).

global definition of a heat wave,[13] but according to the World Meteorological Organization (WMO) heat waves occur "when the daily maximum temperature of more than five consecutive days exceeds the average maximum temperature by 9°F (5°C), the normal period being 1961-1990".[14] In the United States (U.S.), every region defines heat waves differently; the consensus view, however, requires a minimum of three consecutive days with a temperature above 90°F (32.2°C).[15]

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment states that heat waves are "very likely" to occur in increased frequency and intensity in land areas during this century.[16] Indeed, so-called "mega heat waves," like those experienced in the summer of 2003 in Europe[17] and the summer of 2010 in extended areas of Russia and Eastern Europe,[18] will increase by a factor five to ten over the coming 40 years.[19] Nevertheless, there is a low probability that a heat wave of the same magnitude will occur in the same region before 2050.[20]

2.3 Heat Wave Impacts on Electricity Sector

2.3.1 Impacts on Electricity Generation

Increased air and water temperatures associated with a heat wave can have significant impacts on fossil fuel-fired and nuclear power plants, which account for 78% of the electricity

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[13] Gerald A. Meehl and Claudia Tebaldi, *More Intense, More Frequent, and Longer Lasting Heat Waves in the 21st Century*, 305 Science 994-997, 994, (2004).

[14] Met Office, *Heatwave,* Aug. 2014 A*vailable at* http://www.metoffice.gov.uk/learning/learn-about-the-weather/weather-phenomena/heatwave.

[15] Gail Hartfield, Michael Strickler and Jonathan Blaes, *August 2007 Heat Wave Event,* Aug. 2007 *Available at* http://www4.ncsu.edu/~nwsfo/storage/cases/20070809/.

[16] IPCC, Working Group I *Summary for Policymakers, In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC,* S. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds) Cambridge University Press, Cambridge, UK and New York, NY, USA, (2013).

[17] IPCC, Working Group I *Summary for Policymakers, In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC,* S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds) Cambridge University Press, Cambridge, UK and New York, NY, USA, (2007).

[18] David Barriopedro, Erich M. Fischer, Jürg Luterbacher, Ricardo M. Trigo, Ricardo García-Herrera, *The Hot Summer of 2010:Redrawing the Temperature Record Map of Europe,* 332 Science 220-224, 220, (2011).

[19] *Id.*

[20] *Id.*

production in Europe and 91% in the U.S.[21] High temperatures affect their capacity resulting in a system-wide failure to generate electricity sufficient to meet demand.[22] Heat waves also affect renewable energy generators. When generation facilities operate at lower efficiency or at intentionally decreased capacity, electricity generation slows down; it may even shut down for a short period of time.[23] Under these conditions electricity operators have to replace the amount of electricity needed with alternative sources for the area in need.[24] A common practice to avoid electricity shortages is to acquire electricity from distant regions or import from neighboring countries, but this comes at a higher cost for electricity suppliers.

a. Impacts of Increased Ambient Air Temperature

Increased ambient air temperature affects natural gas, oil and nuclear power plants but not coal and biomass plants.[25,26] A European study reports that higher air temperatures, which cause lower atmospheric pressures, reduce the fuel burning efficiency because of low oxygen concentration.[27] A study for the Caribbean region explains that this decreased difference between combustion and ambient temperature decreases the energy produced by steam extraction and condensing.[28] The ambient temperature affects the efficiency of turbines, boilers and gensets.[29] For nuclear power plants Linnerud et al. specifies that during a heat wave nuclear power output can

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[21] US Energy Information Administration Independent Statistics and Analysis, *International Energy Statistics*, (2011) *cited at* Michelle T. H. van Vliet,, John R. Yearsley, Fulco Ludwig, Stefan Vögele, Dennis P. Lettenmaier & Pavel Kabat, *Vulnerability of US and European electricity supply to climate change,* 2 Nature Climate Change 676-681, 676 (2012).

[22] UCS, *supra* note 4, at 8.

[23] *Id.*, at 6.

[24] *Id.*

[25] Koen Rademaekers, Jeroen van der Laan, Sil Boeve, Wietze Lise, *Investment needs for future adaptation measures in EU nuclear power plants and other electricity generation technologies due to effects of climate change*, Final Report, Commission of the European Communities, Rotterdam, 85, (2010).

[26] Coal and biomass are affected by increased electricity demand during heat wave rather than due to operational inefficiencies. *See* Koen Rademaekers 2010, *supra* note 25, at 85.

[27] Koen Rademaekers et al., *supra* note 25, at 85.

[28] R. Contreras-Lisperguer and K. de Cuba, *The Potential Impact of Climate Change on the Energy Sector in the Caribbean Region,* Department of Sustainable Development, Organization of American States, 6, (2008).

[29] ADB, *supra* note 8, at 9.

be reduced by more than 2% per 1.8°F (1°C) rise in ambient air temperature due to physical constraints for cooling systems combined with environmental regulations.[30]

Heat waves can also affect the generation capacity of hydroelectric power plants, solar and geothermal energy systems.[31] Hydropower generation may be decreased due to increased evaporation of water bodies; this effect may be amplified during a dry season or where water levels are otherwise low. But evaporation is more complicated as it is not solely attributable to heat waves; it also depends on meteorological conditions such as solar radiation, humidity and advection rates.[32] Photovoltaic (PV) generation capacity is negatively impacted by temperature,[33] as cell performance decreases and cooling is necessary above certain temperatures.[34] Pašičko research[35] found that for every 1.8°F (1°C) rise in temperature, cell's efficiency drops by 0.4% to 0.5% in relative terms[36,37] In PV the control system, the cables and the inverters are affected by high temperatures resulting in lower energy output and lower capacity of underground conductors.[38] Finally, geothermal energy production is affected similarly to fossil fuelled generation.[39] The

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[30] K. Linnerud, T.K. Mideksa, and G.S. Eskeland, *The Impact of Climate Change on Nuclear Power Supply*, 32 Energy Journal 1 149–168, 149, (2011).

[31] Edward Vine, *Adaptation of California's Electricity Sector to Climate Change,* 111 Climatic Change 75-99, 78, (2012).

[32] S. R. Bull, D. E. Bilello, J. Ekmann, M. J. Sale, and D. K. Schmalzer, Effects of Climate Change on Energy Production and Distribution chapter 3 *in the United States in Effects of Climate Change on Energy Production and Use in the United States*. A Report by the U.S. Climate Change Science Program and the subcommittee on Global change Research. Washington, DC, 67, (2007).

[33] DOE-PI, 2013 *supra* note 4, at 12.

[34] Swapnil Dubey, Jatin Narotam Sarvaiya, Bharath Seshadri, *Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World – A Review*, 33 Energy Procedia 311–321, 311, (2013); David Meneses-Rodríguez, Paul P. Horley, Jesús González-Hernández, Yuri V. Vorobiev, Peter N. Gorley, *Photovoltaic Solar Cells Performance at Elevated Temperatures*, 78 Solar Energy Issue 2 243-250, 243, (2005).

[35] This research was conducted for crystalline silicon based cells, a widely used technology, and for the climate of Mediterranean region.

[36] R. Pašičko, *Impacts of Climate Change on Renewable Energy Sources in Croatia*, Joint ICTP-IAEA Workshop on Vulnerability of Electricity Systems to Climate Change and Extreme Events, UNDP Croatia, (2010) *cited at* Koen Rademaekers et al., *supra* note 25, at 140.

[37] A research in performance of different PV module technologies reported that some perform outstandingly even under very high ambient temperatures *at* C. Protogeropoulos, I. Klonaris, C. Petrocheilos, I. Charitos, I. Martinac, *Performance Evaluation of Different PV Module Technologies in a Grid-Connected Pilot Project in Greece*, Paper presented at the 25nd European Photovoltaic Solar Energy Conference. Valencia, Spain. 6–10 September, (2010).

[38] ADB, *supra* note 8, at 29.

[39] R. Contreras -Lisperguer and K. de Cuba, *supra* note 28, at 13.

efficiency of turbines and boilers drops when the difference between ambient temperature and combustion temperature decreases.[40]

b. Impacts by Increased Water Temperature

Higher water temperatures create cooling constraints and affect all fossil fuels, geothermal, biomass and nuclear power plants.[41] The electricity produced per unit of fuel is lower and high temperatures can also create unsafe conditions for the overall operation of a unit.[42] In nuclear power plants, Rademaekers et al. points out that there is 1% efficiency loss for every 9°F (5°C) in water temperature.[43] Van Vliet et al. states that fossil-fuelled and nuclear power plants that have once-through cooling systems are more vulnerable than the ones that recirculate the water using cooling towers.[44] Once-through plants withdraw water from water bodies in the vicinity and return them back usually at higher temperatures. Regulations on water temperature discharges require power plants to slow down operations and thus avoid fines and other penalties.[45] Nevertheless, during extreme heat waves the discharge of warmer water may be allowed for the sake of maintaining electricity supply, despite undeniably harmful impacts to the environment.[46]

2.3.2 Impacts on Electricity Transmission and Distribution

Grid systems obtain high voltage electricity from power plants and transmit it to neighboring, long distant or cross border substations. At substations, high voltage current alternates to low voltage current for distribution to local distribution grids.[47] The grid system is comprised mainly by overhead systems rather than underground for both transmission and distribution of electricity. This is usually due to lower costs in installation and maintenance but at

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[40] *Id.*

[41] Koen Rademaekers et al., *supra* note 25, at 85; R. Contreras-Lisperguer and K. de Cuba, *supra* note 28, at 13.

[42] *Id.*; *UCS*, *supra* note 4, at 6.

[43] Koen Rademaekers et al., *supra* note 25, at 56.

[44] Michelle T. H. van Vliet et al., *supra* note 21, at 676.

[45] *Id.*

[46] DOE-PI, *supra* note 5, at 11.

[47] David M. Ward, *The effect of weather on grid systems and the reliability of electricity supply*, 121 Climatic Change 103-113, 103, (2013); Lawrence Berkeley National Laboratory, *Estimating Risk to California Energy Infrastructure From Projected Climate Change,* Jayant Sathaye, Larry Dale, Peter Larsen and Gary Fitts, Berkeley, CA, USA, 19, (2012).

the same time make them more susceptible to climate.[48] A heat wave-proof transmission and distribution system is fundamental for a reliable electricity supply. If a power plant fails to operate efficiently there are alternative solutions to cover the demand, but alternative grid routes are not usually available.[49]

Transmission and distribution systems, like generation facilities, lose efficiency in high temperatures.[50] High temperatures limit the power rating of transformers, underground cables and overhead lines.[51] It is possible that a system's operating capacity declines as the resistance of metals increases.[52] Larger transmission lines are usually surrounded by aluminum strands that expand with heat; as a consequence, the lines can hang lower, resulting in decreased flow.[53] The transformers' capacity declines 1% for every 1.8°F (1°C) and in copper lines for every 1.8°F (1°C) temperature increase the resistance increases 0.4%. Overall, network losses increase 1% for every 5.4°F (3°C); these increases occur in systems that already have initial losses of 8%.[54] Also, if lines hang low vegetation beneath could also be a threat as there is the risk of flashovers to vegetation.[55]

2.3.3 Impacts by End Users

End users have a significant role to play in power shortages. While heat waves occur demand for cooling increases, most commonly with an increase in the use of air conditioning. Electricity demand reaches its highest values and stresses the capacity of electricity generation and distribution systems.[56] The combination of low output from power plants and the increased

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[48] Parsons-Brinkerhoff, *Electricity Transmission Costing Study*, Institution of Engineering & Technology, 2012 *Available at* http://www.theiet.org/factfiles/transmission-report.cfm?type=pdf.

[49] Koen Rademaekers et al., *supra* note 25, at 34.

[50] David M. Ward, *supra* note 47, at 106; Lawrence Berkeley National Laboratory, *supra* note 47, at 11 & 19.

[51] David M. Ward, 2013 *supra* note 47, at 107 & 110.

[52] Koen Rademaekers et al., *supra* note 25, at 35.

[53] Darryn McEvoy, Ifte Ahmed and Jane Mullett, *The impact of the 2009 Heat Wave on Melbourne's Critical Infrastructure*, 17 Local Environment 783-796, 787, (2012).

[54] Koen Rademaekers et al., *supra* note 25, at 35.

[55] David M. Ward, *supra* note 47, at 107.

[56] ADB, *supra* note 8, at xiii.

demand exacerbates the situation and affects the overall reliability of the power systems, often resulting in brownouts or blackouts.[57]

2.4 Post-2001 Case Studies

The decade spanning from 2001 to 2010 has been characterized as the warmest decade since the beginning of meteorological records.[58] Many countries suffered one or more heat waves during that period, and more have done so in the four years since, with notable numbers of casualties, infrastructure failures and economic losses. During these events, generation, transmission and distribution systems failed to deliver electricity at demand, resulting in many rolling or unintentional blackouts. Blackouts combined with high temperatures intensified the impacts to vulnerable populations, especially in urban centers. This section examines some of the most noticeable incidents of heat wave-induced electricity system breakdown worldwide, with a particular focus on incidents in developed countries where electricity supply is well established. It also assesses the heat wave-preparedness and adaptation planning of each case.[59] The preparedness of each case study includes a mix of legislative, regulatory and energy specific measures, which are not geared particularly towards heat wave adaptation for the electricity sector, but nonetheless have positive impact for adaptation. Usually, GHG emission reduction goals and broader climate change planning drove these measures.

2.4.1 France

a. Heat Wave Impacts

France was severely affected by the heat waves of 2003, one of the worst heat waves in history, and 2006. In both events shortages in electricity were avoided. Nonetheless, these events

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[57] G. Franco and A. Sanstad, *Climate change and electricity demand in California*, 87 Climatic Change 139-151, (2008) *cited at* Lawrence Berkeley National Laboratory, *supra* note 47, at 11.

[58] World Meteorological Organization [Hereinafter WMO], *The Global Climate 2001 - 2010 A Decade of Climate Extremes Summary Report*, Geneva, Switzerland, 3, (2013).

[59] Criteria for case study selection were two: first, the heat wave affected regions to have had heat wave-induced problems to their electricity generation and supply and second, data availability primarily in English.

highlight the threat that heat waves pose to future energy security and the particular susceptibility of the nuclear power sector to extreme heat events.[60]

- During the summer of 2003, Europe and specifically France experienced one of the hottest summers ever recorded with temperatures 20% to 30% higher than average mean temperatures for that period.[61] The maximum temperature recorded in France was 104°F (40°C) and unusual high temperatures persisted for two weeks during August.[62] The low precipitation during July and high temperatures caused water deficits and made conditions even worse.[63] Between August 1 and 20, the country suffered approximately 14,800 casualties, according to a government report.[64] A combination of factors contributed to this excess mortality, mainly attributed to aging population, limited access to cool areas and lack of preparedness.[65]

  Nineteen nuclear plants provide 80% of the country's electricity and they rely on water temperatures from natural water bodies to cool their reactors.[66] Fourteen out of the nineteen plants are located next to inland water bodies; the remaining five are by the sea.[67] During the heat wave, the rivers scored new highs in temperature and the power plant cooling process slowed down.[68] France had to lower its electricity generating capacity by 4,000 megawatts (MW), the equivalent of four nuclear power stations.[69] Seventeen reactors were

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[60] Marc Poumad`ere, Claire Mays, Sophie Le Mer, and Russell Blong, *The 2003 Heat Wave in France: Dangerous Climate Change Here and Now*, 25 Risk Analysis No.6 1483-1494, 1492, (2005).

[61] Jennie Cohen, *Heat Waves Throughout History*, Jun. 25 2013 *Available at* http://www.history.com/news/history-lists/heat-waves-throughout-history; United Nations Environment Programme [Hereinafter UNEP], *Impacts of summer 2003 heat wave in Europe*, 1, (2004).

[62] *Id.*

[63] *Id.*

[64] P. Pirard, S. Vandentorren, M. Pascal, K. Laaidi, A. Le Tertre, S. Cassadou, M. Ledrans, *Summary Of The Mortality Impact Assessment Of The 2003 Heat Wave In France*, Eurosurveillance, Volume 10, Issue 7, (2005).

[65] Jennie Cohen *supra* note 61.

[66] The Guardian, *Heatwave hits French power production*, Aug. 12 2003 *Available at* http://www.theguardian.com/world/2003/aug/12/france.nuclear.

[67] The New Republic, *Can Nuclear Power Take The Heat?*, Jul. 7 2009, *Available at* http://www.newrepublic.com/blog/the-vine/can-nuclear-power-take-the-heat.

[68] The Guardian, *supra* note 66.

[69] *Id.*

forced to shut down or reduce their production due to water withdrawal and discharge restrictions.[70] In total, during the whole summer nuclear power reduction was 5.3 terawatt-hours (TWh).[71] The nuclear safety authority allowed water discharges of 86°F (30°C), far higher than the standard limit of 75.2°F (24°C).[72] The electricity supply in the country did not experience any shortages even though demand increased. But Electricity of France (EDF), a key European electricity producer, had to halve the exporting volume to Switzerland, Britain, Italy, Belgium, and Spain during peak hours.[73]

- In July 2006, France experienced the second most severe heat wave in recorded history. Minimum and maximum temperatures observed were lower than those of August 2003 heat wave, but July was the warmest month of July since 1950 in the country. Mortality rates were much lower this time but the electricity sector was again affected.[74] The Nuclear Safety Authority (ASN) authorized nuclear plants to discharge warmer water to rivers and, unlike 2003, power was imported in order to avoid shortages.[75]

b. *Heat Wave Preparedness*

The French government initiated climate change adaptation actions by establishing a National Observatory for the Effects of Global Warming (ONERC) in 2001.[76] In 2006, the government adopted the first National Adaptation Strategy, which is a set of 84 actions and 230 measures.[77] The adaptation plan was published on July 20, 2011 and during these past years more

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[70] ADB, *supra* note 8, at 15.

[71] N. Kopytko & J. Perkins, *Climate Change, Nuclear Power, and the Adaptation-Mitigation Dilemma*. 39 Energy Policy 1 318-333, 322, (2010).

[72] The Guardian, *supra* note 66; Joe Romm, *France imports UK electricity as summer heatwave puts a third of its nukes out of action, Climate Progress,* Jul. 6 2009 *Available at* http://thinkprogress.org/climate/2009/07/06/204331/france-imports-uk-electricity-summer-heatwave-puts-nuclear-power-plants-out-of-action/.

[73] The Guardian, *supra* note 66; UNEP, *supra* note 61, at 3.

[74] Mathilde Pascal, Alain Le Tertre and Abdessattar Saoudi, *Quantification of the heat wave effect on mortality in nine French cities during summer 2006*, PLOS Currents Disasters, (2012).

[75] Juliette Jowit and Javier Espinoza, *Heatwave shuts down nuclear power plants*, The Guardian, Jul. 29 2006 *Available at* http://www.theguardian.com/environment/2006/jul/30/energy.weather.

[76] Ministry of Ecology, Sustainable Development, Transport and Housing, *French National Climate Change Impact Adaptation Plan 2011 - 2015*, Direction générale de l'Énergie et du Climat, Arche Nord, La Défense cedex, 7, (2011).

[77] *Id.*, at 15.

than 90% of identified actions have started and some have already been completed.[78] The horizon of implementation is 2011 to 2015.[79] For the energy sector and industry the adaptation plan develops four main actions:

1. *Manage the emergence of peaks in summer energy consumption via an electrical capacity obligation mechanism.*
2. *Promote the use of more efficient cooling equipment (air conditioning) or equipment using renewable or recoverable energy.*
3. *Make all hydrogeological and climate data available.*
4. *Integrate climate change into the monitoring indicators of the Water Framework Directive.*[80]

Since 2006, the government has initiated Energy Saving Certificates (ESC), otherwise named "White Certificates," a scheme that imposes obligations on energy suppliers for energy efficiency, replacement of energy-intensive cooling equipment and the promotion of renewable energy sources with planning that considers the projected climate change for 2030 and 2050.[81] The adaptation plan also initiated the "Heating Fund". This is available for financing renewable or recoverable energy projects that alleviate the grid during extreme events and it is responsible for keeping renewable energy prices lower than conventional energy sources for the users.[82]

At the regional level the Regional Climate, Air and Energy Programs (SRCAE) and the Regional Climate-Energy Plans (PCET) are responsible for developing climate change planning in accordance with the provisions of Law 2010-788, enacted on July 12, 2010.[83] PCETs are mandatory for authorities covering more than 50,000 inhabitants and voluntary for authorities covering less

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[78] European Commission and European Environmental Agency [Hereinafter EC and EEA], *European Climate Adaptation Platform - France,* Climate-Adapt, 2014 *Available at* http://climate-adapt.eea.europa.eu/countries/france.

[79] Ministry of Ecology, Sustainable Development, Transport and Housing, *supra* note 76, at 6.

[80] Framework Water Directive (2000/60/EC) commits European Union members to achieve good qualitative and quantitative status of all water bodies by 2015.

[81] *Id.*, at 38 & 39; Organisation for Economic Co-operation and Development and International Energy Agency [Hereinafter OECD and IEA], *Policies of IEA Countries, France 2009 Review*, 44, 2010 *Available at* http://www.iea.org/publications/freepublications/publication/france2009.pdf.

[82] Ministry of Ecology, Sustainable Development and Energy, Le fonds chaleur (The heat fund), France, Sep. 4 2014 *Available at* http://www.developpement-durable.gouv.fr/Presentation-generale,25027.html; Ministry of Ecology, Sustainable Development, Transport and Housing, *supra* note 76, at 38.

[83] EC and EEA, *supra* note 78.

population.[84] Five hundred authorities are obliged to develop the plans and 200 smaller authorities have agreed to develop them voluntarily.[85] The plans are compatible with national and European commitments and aim to reduce GHG emissions, improve air quality and develop actions for climate change adaptation.[86] The regional authorities together with local stakeholders are responsible to develop SRCAE and they are obliged to pass them through a public consultation stage before they get finalized.[87]

Other related actions have also been initiated for the residential and the tertiary sector in order to increase energy efficiency.[88] A new thermal regulation RT 2012 established in January 2013 sets new limits on energy consumption in new buildings.[89] According to RT 2012, from 2020 new buildings should be positive energy, producing more energy from renewables than they consume.[90] The use of low carbon energy will benefit the electricity sector.[91] Cross-sectoral measures promote the development of renewable energy sources with several instruments including tax credits for individuals to invest in renewable energy equipment (measures extended until 2015), consumer financing measures in favor of renewable energy sources and regulatory measures.[92]

In 2004, the ASN recommended additional actions for mitigating the magnitude of future heat waves including plant ventilation, air conditioning, optimised monitoring and alert systems.[93] EDF after the 2003 experience also put forward several provisions. They installed a weather

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[84] French Environment and Energy Management Agency [Hereinafter ADEME], *Memorandum on Action: Good practices to be shared in the run-up to Rio +20, Territorial Energy & Climate Plans (TECP) Focus on local territories*, Paris.

[85] Ministry of Ecology, Sustainable Development and Energy, *The Sixth National Communication of France to the United Nations Framework Convention on Climate Change*, Direction générale de l'Énergie et du Climat, Arche Nord, La Défense cedex 16, (2013).

[86] *Id.*, at 16.

[87] *Id.*, at 16.

[88] *Id.*, at 11.

[89] *Id.*, at 12.

[90] *Id.*, at 12.

[91] *Id.*, at 12.

[92] *Id.*, at 13.

[93] Marc Poumad`ere, Claire Mays, Sophie Le Mer, and Russell Blong, *The 2003 Heat Wave in France: Dangerous Climate Change Here and Now*, 25 Risk Analysis No.6 1483-1494, 1492, (2005).

warning system where warning levels apply to site-specific features of technical characteristics, organizational structures and regulations.[94] EDF also took actions to identify which facilities operated in low safety margins in order to make alternations considering increased air and water temperatures. For this reason they conducted impact analysis for identifying possible hazards.[95] In 2004, Electricity Transmission Network began publishing daily, summer, annual and ten-year electricity demand forecasts to ensure balance in supply-demand and provide the essential information for decisions makers.[96]

2.4.2 California

a. Heat Wave Impacts

Beginning in 2001, the State of California experienced a series of heat waves that culminated in the second half of July 2006 in a two-week long heat wave.[97] The increased need for air conditioning drove electricity consumption up in the state.[98] Many heat waves have followed since, with demand ever increasing and electricity end users suffering power failures in most cases. The most profound electricity-related impacts were noted on 2010.

- In July 2002 there was an all-time single day electricity record of 52,863 MW. Average demand during that summer was between 40,000 MW to 45,000 MW for the whole state. The heat wave affected the electricity supply and many regions were without power for periods ranging from hours to days.[99]

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[94] G. Thuma, J. Rodriguez, F. Bigot, Y. Guigueno, *Experience with the Influence of Both High Summer Air and Cooling Water Temperatures and Low River Levels on the Safety and Availability of German and French NPP*, EUROSAFE forum 2004: Learning from experience - A cornerstone of nuclear safety, INIS Collection, 4, (2004).

[95] *Id.*, at 6.

[96] Réseau de Transport d'Electricité [Hereinafter RTE], *France's Power Supply Guaranteed in the Event Of A Heatwave This Summer*, Press Release , (2014).

[97] California Climate Change Center, *Our Changing Climate 2012: Vulnerability & Adaptation to the Increasing Risks from Climate Change in California,* A Summary Report on the Third Assessment, California, 2, (2012).

[98] California Global Warming Solutions Act of 2006 AB 32; Edward Vine, *supra* note 31, at 76.

[99] Edward Vine, *supra* note 30, at 77.

- In July 2006, in a two-week event, temperatures soared during the day and remained high at night, accompanied by consistently high humidity levels.[100] The event was characterized as the biggest heat wave recorded between the years 1948 and 2006 for the region.[101] Statewide the estimated heat related deaths were 650.[102] The excess visits in the emergency department were 16,166 and excess hospitalizations were 1,182 during the heat wave.[103] Pacific Gas and Electric Company (PG&E), the biggest power company in California, reported that heavy electricity use and ambient temperature heated the transformers and they failed to cool; this in turn tripped circuit breakers, broke fuses and burned the insulation, causing short circuits inside the transformers.[104] In Los Angeles Department of Water and Power service territory, more than 80,000 people were left without electricity for several days and 860 transformers were malfunctioning or stopped operating.[105] In the north of the state, 1.2 million PG&E customers experienced electricity shortages when 1,150 distribution line transformers failed to cool down and stopped operating.[106]
- In September 2007, southern California experienced a week of high temperatures, with the death toll from heat-related causes surpassing 20.[107] On two separate days Los Angeles

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[100] Alexander Gershunov, Zane Johnston, Helene G. Margolis and Kristen Guirguis, *2006 California Heat Wave High Death Toll: Insights Gained from Coroner's Reports and Meteorological Characteristics of Event*, 31 Geography Research Forum 6-31, 6, (2011).

[101] Alexander Gershunov and Daniel Cayan, *Recent Increase in California Heat Waves: July 2006 and the Last Six Decades, Climate*, Prepared For: Public Interest Energy Research Program California Energy Commission, Atmospheric Science and Physical Oceanography, Scripps Institution of Oceanography University of California, San Diego, vii, (2009).

[102] Heat Adaptation Workgroup, *Preparing California for Extreme Heat: Guidance and Recommendations*, California, 2, (2013).

[103] K. Knowlton, M. Rotkin-Ellman, G. King, H.G. Margolis, D.Smith, G. Solomon, R. Trent and P. English, *The 2006 California heat wave: Impacts on hospitalizations and emergency department visits*, 117 Environmental Health Perspectives 61-67, (2009).

[104] Edward Vine, *supra* note 31, at 84.

[105] Sharon Bernstein, *DWP Scrambles to Gauge Power Needs Before the Next Heat Wave*, Los Angeles Times, Aug. 9 2006 *Available at* http://articles.latimes.com/2006/aug/09/local/me-dwp9.

[106] Rick Jurgens, *Outages Identify PG&E's Limits: After Heat Wave Caused 1.2 Million Customers to Lose Power, Experts Assess Utility's Vulnerabilities,* Contra Costa Times (Walnut Creek, CA), Jul. 30 2006 *Available at* http://www.highbeam.com/doc/1G1-148827202.html; Scott DiSavino, *California Power Grid Survives Heat Wave, Nuclear Outage*, Chicago Tribune, Jul. 3 2013 *Available at* http://articles.chicagotribune.com/2013-07-03/news/sns-rt-utilities-californiaheatwave-20130701_1_grid-operator-power-grid-california-iso.

[107] Jennifer Steinhauer, *California Heat Wave Ends With a Death Toll Near 25*, The New York Times, Sep. 7 2007 *Available at* http://www.nytimes.com/2007/09/07/us/07heat.html?_r=1&.

recorded a high temperature of 112°F (44.4°C).[108] Southern California Edison officials announced that 20,000 customers were left without electricity in Los Angeles, Ventura, Orange, Riverside and San Bernardino Counties.[109]

- In June 2008, southern California experienced a week-long heat wave, with maximum daily temperatures exceeding 100°F degrees (37.7°C).[110] San Jose reached 95°F (35°C), San Diego 105°F (40.6°C), Burbank and San Luis Obispo 107°F (41.7°C).[111] Los Angeles County had prepared 42 cooling centers during the day and warned all citizens to take precautions.[112] In Los Angeles city electricity consumption reached 5,854 MW, an all time record for the month of June. Many electricity disruptions occurred and 8,000 customers experienced blackouts that in some cases lasted more than a day.[113]
- In September 2010, an all-time record high temperature of 113°F (45°C) was recorded in downtown Los Angeles.[114] More than 30,000 Southern California Edison customers and 5,400 Los Angeles Department of Water and Power costumers experienced power cuts during the heat wave caused by the high electricity demand.[115]
- In mid-September 2014, temperatures reached 102°F (38.9°C) in down town Los Angeles.[116] The electricity demand for the whole state was 45,090 MW, which was the highest of the year and in Los Angeles city the Los Angeles Department of Water and Power reported

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[108] *Id.*

[109] The New York Times, *California: A Weeklong Heat Wave*, Sep. 4 2007 *Available at* http://www.nytimes.com/2007/09/04/us/04brfs-AWEEKLONGHEA_BRF.html?fta=y.

[110] USA Today, *Relief in sight from California heat wave*, Jun. 22 2008 *Available at* http://usatoday30.usatoday.com/news/nation/2008-06-21-2589594867_x.htm.

[111] *Id.*

[112] Allison Hoffman, *Heat Wave Continues to Blister SoCal*, USA Today, Jun. 20 2008 *Available at* http://usatoday30.usatoday.com/weather/news/2008-06-19-socal-heat-wave_N.htm.

[113] USA Today, *supra* note 110.

[114] John Antczak, *Los Angeles Heat Wave Bakes At Record 113 Degrees*, HUFF POST, Los Angeles, updated post May 25 2011 *Available at* http://www.huffingtonpost.com/2010/09/27/los-angeles-heat-wave-bak_n_740936.html.

[115] *Id.*

[116] Joseph Serna, *Power grid groans, blackouts roll through L.A. area as heat wave nears peak*, Los Angeles Times, Sep. 16 2014 *Available at* http://www.latimes.com/local/lanow/la-me-ln-ladwp-power-demand-heat-wave-20140916-story.html.

that the demand was 6,196 MW higher than the highest demand in 2010 of 6,177MW.[117] In Los Feliz and Hollywood, 3,300 customers experienced intermittent blackouts.[118]

b. *Heat Wave Preparedness*

California has sought to address climate change through the California Global Warming Solutions Act of 2006, Assembly Bill (AB) 32.[119] This law established reductions of GHG emissions to the 1990 limits by 2020.[120] In 2002, the State of California introduced the Renewables Portfolio Standard (RPS) Program articulated by the Senate Bill (SB) 1078 which aims to increase the share of renewables in the electricity mix to 20% of retail sales by 2017.[121] In 2003 the Integrated Energy Policy Report suggested 20% by 2010 and the update of 2004 increased the target to 33% by 2020.[122] In 2011, the 33% target was codified (SB X1-2) and applied to all electricity retailers, publicly owned utilities, investor-owned utilities, electricity service providers, and community choice aggregators.[123] The California Public Utilities Commission (CPUC) and the California Energy Commission (CEC) together implement the RPS program.[124] The CEC also assists local governments in developing energy assurance plans within the framework of the California Local Energy Assurance Planning (CaLEAP) program.[125] CaLEAP's target is to prepare plans that ensure key assets are resilient to disaster events and secure reliable energy supply.[126] On the other hand,

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[117] *Id.*; Bloomberg, *Los Angeles Power Jumps as Heat Wave Boosts Demand to Record*, Sep. 16 2014 *Available at* http://www.bloomberg.com/news/2014-09-16/los-angeles-power-jumps-as-heat-wave-boosts-demand-to-record.html.

[118] Joseph Serna, *supra* note 116; Ann Carlson, *Los Angeles Heat Waves, Electricity Use and Climate Change*, Legal Planet UCLA Law, Sep. 16, 2014 *Available at* http://legal-planet.org/2014/09/16/los-angeles-heat-waves-electricity-use-and-climate-change/.

[119] Edward Vine, *supra* note 31, at 75.

[120] *Id.*; U.S. Department of State, *the Sixth National Communication of the United States of America*, U.S. Climate Action Report 2014 under the United Nations Framework Convention on Climate Change, Washington, Chapter 4 Policies and Measures, 129, 2014.

[121] California Energy Commission, California Renewable Energy Overview and Programs, 2014 *Available at* http://www.energy.ca.gov/renewables/.

[122] *Id.*

[123] *Id.*

[124] California Public Utilities Commission, *RPS Program Overview*, 2013 *Available at* http://www.cpuc.ca.gov/PUC/energy/Renewables/overview.htm.

[125] California Local Energy Assurance Planning, 2014 *Available at* http://www.caleap.org

[126] *Id.*

the SB 1368 of 2006 might be a challenge for peak electricity demand during heat waves.[127] This bill limits California's electricity imports from other states generated by non-clean energy in an effort to reduce GHG emissions.[128] During a heat wave back-up electricity from fossil fuelled sources will not be a solution.[129]

In 2009, the California Climate Adaptation Strategy was directed by Executive Order S-13-08 and prepared by five state agencies and nine departments.[130] The Climate Adaptation Strategy has three relevant key strategies for the energy sector that develop in six near-term and long-term actions. CEC and several other agencies have the responsibility to implement those actions.

1. *Increase energy efficiency efforts in climate vulnerable areas.*
    a. *Meet the energy efficiency goals outlined in AB 32 scoping plan.*
    b. *Facilitate access to local, decentralized renewable resources.*
2. *Assess environmental impacts from climate change in siting and re-licensing of new energy facilities.*
    a. *Assess power plants vulnerable to climate impacts, and recommend reasonable adaptation measures.*
    b. *Encourage expansion of renewable energy resources.*
    c. *Assess the impacts of climate change on energy infrastructure.*
3. *Identify how state renewable energy goals could be impacted from future climate impacts.*
    a. *Assess climate impacts on energy.*[131]

In June 2012, the State of California developed the plan "Electric Power Disruption Toolkit for Local Governments" for managing heat wave stresses on communities.[132] This tool identifies actions that city and county government can take to protect people and provides preparedness,

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[127] Edward Vine, *supra* note 31, at 87.

[128] *Id.*

[129] *Id.*

[130] California Natural Resources Agency, *2009 California Climate Adaptation Strategy*, A report to the Governor of the State of California, (2009).

[131] *Id.*, at 131 & 132.

[132] California Governor's Office of Emergency Services [Hereinafter, Cal OES] Cal OES, *Contingency Plan for Excessive Heat Emergencies*, A Supporting Document to the State Emergency Plan, 3, (2014).

response, recovery and mitigation actions when electric disruptions occur.[133] The California Independent System Operator (CAISO), which manages 80% of California's grid except some areas that are served by municipal utilities, employs alerts for demand and supply service forecasts during heat waves.[134] These alerts are for increased electricity loads and are separated into 3 stages:

1. *When the reserve margin falls below 7%.*
2. *When the reserve margin falls below 5%.*
3. *When the reserve margin falls below 1.5% (rolling blackouts occur).*[135]

Regarding air conditioning systems, in 2008 CEC developed the "Strategic Plan to Reduce the Energy Impact of Air Conditioners" as directed by AB 2021, a law aiming to improve energy efficiency and decrease the peak electricity demand.[136] Complementary to this, California's building codes (latest update 2013 and in effect July 2014) aim to make new and existing residential and commercial buildings more energy efficient.[137] Finally, Flex Alerts, a voluntarily program issued by the CAISO, provides early warnings of possible electricity shortages.[138] This program, allows the public to be prepared for interruptions and also to encourage them to conserve energy.[139] Similarly, the Demand Response Program aims for electricity conservation by providing incentives and other benefits to customers. This is mostly for commercial customers and some residential customers ensuring affordable and reliable power supply.[140]

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[133] Cal OES, *Electric Power Disruption Toolkit for Local Government*, (2012).

[134] Cal OES 2014, *supra* note 131, at 45.

[135] *Id.*

[136] California Energy Commission, *Strategic Plan To Reduce The Energy Impact of Air Conditioners*, Staff Report, State of California, 1, Jun. 2008 *Available at* http://www.energy.ca.gov/2008publications/CEC-400-2008-010/CEC-400-2008-010.PDF.

[137] California Energy Commission, *2013 Building Energy Efficiency Standards*, 2013 *Available at* http://www.energy.ca.gov/title24/2013standards/index.html.

[138] California's Energy Conservation Network, Flex Alert, 2014 *Available at* http://www.flexalert.org/what-is-flex-alert.

[139] *Id.*

[140] *Id.*

2.4.3 New York City

a. Heat Wave Impacts

New York City has often experienced heat waves in the past and is likely to experience more intense and frequent heat waves in the future. The urban heat island (UHI) effect and high temperatures affect the electricity demand and challenge the efficiency of electricity generation and supply systems.[141] New York City has suffered many heat waves with many electricity related failures, with the most intense one coming in July 2006.

- In July 2002, two separate week-long heat waves occurred with average daily temperatures above 90°F (32.2°C).[142] On July 31, Con Edison[143] asked its big customers to reduce power use in order to avoid failures.[144] The Metropolitan Transportation Authority reduced the subway service on a number of lines and eliminated its air conditioning use on some trains. [145] This decision created many delays for commuters.[146]
- In July 2006, New York City experienced a serious heat wave that caused around 140 casualties.[147] There were two events of high temperature, one from July 16 to 18 and a longer one from July 27 to August 5.[148] Elderly people and other vulnerable groups were the main victims.[149] Heat wave-related electricity disruptions in Long Island City and

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[141] C. Rosenzweig, W. Solecki, A. DeGaetano, M. O;Grady, S. Hassol, P. Grabhorn (eds), *Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation*, Technical Report, New York State Energy Research and Development Authority [Hereinafter NYSERDA], Albany, New York, 286 & 287, (2011).

[142] National Oceanic and Atmospheric Administration [Hereinafter NOAA], *National Weather Service New York, NY NYC Heatwaves Page*, Mar. 12 2010 *Available at* http://www.weather.gov/okx/heatwaves; 4 NBC New York, *Heat Wave Longest Recorded in New York City in Over a Decade*, Jul. 20 2013 *Available at* http://www.nbcnewyork.com/news/local/Heat-Wave-New-York-CIty-Longest-Since-2002-Storm-Team-4-Forecast-216279211.html.

[143] Con Edison is a subsidiary of Consolidated Edison. Con Edison delivers energy to approximately 9 million New York City and Westchester County residents. Consolidated Edison is one of the largest energy companies in the U.S.

[144] Jayson Blair, *Power Cuts Put M.T.A. And Con Ed At Odds*, The New York times, Aug. 1 2002 *Available at* http://www.nytimes.com/2002/08/01/nyregion/power-cuts-put-mta-and-con-ed-at-odds.html.

[145] *Id.*

[146] *Id.*

[147] Richard Pérez-Peña, *Heat Wave Was a Factor in 140 Deaths, New York Says*, The New York Times, Nov. 16 2006 *Available at* http://www.nytimes.com/2006/11/16/nyregion/16heat.html.

[148] Department of Health and Mental Hygiene, *Deaths Associated with Heat Waves in 2006*, New York City, Nov. 2006 *Available at* http://www.nyc.gov/html/doh/downloads/pdf/survey/survey-2006heatdeaths.pdf.

[149] *Id.*

Queens affected 115,000 customers for more than a week.[150] Con Edison urged its 3.2 million customers to stop using any unnecessary electrical appliances and save energy during the heat waves; it also had to lower the voltage in Brooklyn and Queens.[151] An all-time peak electricity demand was recorded that reached 13,141 MW[152] at 5 p.m. on August 2.[153]

- In July 2010, the maximum temperature reached 103°F (39.5°C) in Central Park.[154] Con Edison reduced voltage in Brooklyn and Queens due to problems with electrical cables, and customers received automated calls in order to conserve electricity.[155] Approximately 52,000 Con Edison customers were without electricity during the heat wave and 400 cooling centers opened for people who required air conditioning.[156]
- In July 2011, the City of New York experienced high temperatures and high humidity. On July 22, the U.S. National Weather Service issued an excessive heat warning for the city lasting until 10 p.m.[157] Con Edison recorded a new all-time peak in electricity use of 13,189 MW at 4 p.m. surpassing the record of August 2, 2006.[158] Con Edison had to reduce the voltage in many neighbourhoods in Queens and Brooklyn (121,000 customers in an afternoon) and in Westchester and Queens (139,000 customers overnight) due to equipment

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[150] PlaNYC, *A Stronger More Resilient New York City*, The City of New York, 120, 2013.

[151] Con Edison, *Con Edison Eyes Record Electric Use; Urges Conservation*, Jul. 30 2006 *Available at* http://www.coned.com/newsroom/news/pr20060730.asp.

[152] This number is ever increasing. Con Edison first reached the 10,000 MW in 1988, 11,000 MW in 1997, 12,000 MW in 2001 and 13,000-megawatts in 2005.

[153] Con Edison, Con Edison Sets New Record For Electric Usage, Aug. 2 2006 *Available at* http://www.coned.com/newsroom/news/pr20060802_3.asp.

[154] Patrick McGeehan and Fernanda Santos, *New York Wilts Under Record-Breaking Heat Wave*, The New York Times, Jul. 6 2010 *Available at* http://www.nytimes.com/2010/07/07/nyregion/07heat.html?pagewanted=all.

[155] *Id.*

[156] Thom Patterson, *U.S. electricity blackouts skyrocketing*, CNN, Oct. 10 2010 *Available at* http://www.cnn.com/2010/TECH/innovation/08/09/smart.grid/.

[157] Scott DiSavino, U.S. *Heatwave Causes Brownouts in NYC as Power Use Spikes*, Reuters Jul. 22 2011 *Available at* http://www.reuters.com/article/2011/07/22/us-utilities-conedison-heatwave-idUSTRE76L44A20110722.

[158] Con Edison, *Con Edison Peak Demand Hits All-Time High*, Jul. 22 2011 *Available at* http://www.coned.com/newsroom/news/pr20110722_5.asp.

failures. The brownouts were not always noticeable but it was an important measure for precaution due to on-going repairs to the electricity system.[159]

- In July 2013, a seven-day heat wave hit New York City, the longest in duration since 2002.[160] In certain areas the temperature reached 107°F (41.6°C).[161] The electricity demand within the city reached another all-time high record in electricity of 13,322 MW at 5 p.m., on July 19.[162]

b. *Heat Wave Preparedness*

Climate change planning for New York City was reinforced in 2006 when the Office of Long-Term Planning and Sustainability was created and later in 2007 when the sustainability plan PlaNYC was released. PlaNYC set GHG emission targets and recognised the importance of climate change adaptation and mitigation.[163] PlaNYC brought together 25 agencies from various sectors, including the energy sector, and suggested 23 initiatives that create a regulatory framework for utilities and regulators for cooperation and building resiliency. The initiatives include cost-effective measures, energy efficiency standards, planning for avoiding outages, upgrading technology and improving back up generation.[164] In 2008, the Office of Long-Term Planning and Sustainability created the NYC Climate Change Adaptation Task Force, which works with several stakeholders on the development of an integrated climate change risk assessment and adaptation plan for the critical infrastructure of the metropolitan region.[165] In 2009, Executive Order no. 24

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[159] Scott DiSavino 2011, *supra* note 157.

[160] 4 NBC, *supra* note 142.

[161] Katie Valentine, *New York City Breaks Its Energy Use Record During Brutal Week-Long Heat Wave*, Climate Progress, Jul. 21 2013 *Available at* http://thinkprogress.org/climate/2013/07/21/2333821/new-york-city-breaks-its-energy-use-record-during-brutal-week-long-heat-wave/.

[162] Con Edison, *Another New Electric Peak Reached, Con Edison Stressing Conservation*, Jul. 19 2013 *Available at* http://www.coned.com/newsroom/news/pr20130719_2.asp.

[163] C. Rosenzweig, C. and Solecki, W., *Chapter 1: New York City adaptation in context*. 1196 Annals of the New York Academy of Sciences, 19–28, 19, (2010).

[164] PlaNYC, *supra* note 150, at 122-129.

[165] Shagun Mehrotra, Claudia E. Natenzon, Ademola Omojola, Regina Folorunsho, Joseph Gilbride and Cynthia Rosenzweig, *Framework for City Climate Risk Assessment, Buenos Aires, Delhi, Lagos, and New York*, World Bank Commissioned Research, Fifth Urban Research Symposium Cities and Climate,Change: Responding to an Urgent Agenda, Marseille, France, 36, Jun. 2009 *Available at* http://uccrn.org/documents/Framework_for_City_Risk_Assessment-June17.pdf.

created the New York State Climate Action Council (CAC) with the purpose to prepare a climate action plan by 2010.[166] In 2010, CAC released an Interim Report of the New York State Climate Action Plan, which focuses mainly on reduction of GHG emissions and suggests a preliminary list of policy options. Policy options include improving energy efficiency for state buildings, promoting renewable energy sources and improving the electricity grid.[167] In 2011 a state-level assessment for climate change impacts named ClimAID was prepared for the New York State Energy Research And Development Authority (NYSERDA) with the purpose of encouraging the development of climate adaptation strategies. ClimAID identified temperature as an important risk for critical infrastructure and suggested a framework for managing the climate risks across sectors[168] (NYSERDA is responsible to develop and implement programs for energy efficiency initiatives and renewable energy sources funded through the Systems Benefit Charge (SBC)[169]). In 2008, the New York Public Service Commission (PSC) established the New York Energy Efficiency Portfolio Standard (EEPS), which aims to achieve 15% reduction in electricity usage from the forecasted levels by 2015 with comparable results in natural gas conservation.[170] PSC also adopted a RPS in September 2004, which seeks to increase the electricity share produced by renewable sources that is used by retail customers.[171] New York Power Authority (NYPA) since 1999 has developed the Peak Load Management program developed to reduce electricity demand. With this, customers agree to participate on electricity reduction while gaining benefits and contributing to the reliability of the electricity grid.[172]

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[166] Department of Environmental Conservation, *Energy/Climate Programs New York's Energy and Climate Portfolio*, New York State, 2014 *Available at* http://www.dec.ny.gov/energy/43384.html.

[167] *Id.*

[168] *Id.*

[169] NYSERDA, *System Benefits Charge Technology and Market Development Program*, New York State, 2014 Available at http://www.nyserda.ny.gov/Energy-Data-and-Prices-Planning-and-Policy/Program-Planning/System-Benefits-Charge.aspx.

[170] New York State Public Service Commission, *Energy Efficiency Portfolio Standard*, New York State, Sep. 24 2014 *Available at* http://www3.dps.ny.gov/W/PSCWeb.nsf/All/06F2FEE55575BD8A852576E4006F9AF7?OpenDocument.

[171] NYSERDA, *New York Renewable Portfolio Standard, A Clean, Green Tomorrow Starts Today*, Aug. 14 2014 *Available at* http://www.nyserda.ny.gov/Energy-Data-and-Prices-Planning-and-Policy/Program-Planning/Renewable-Portfolio-Standard.aspx.

[172] New York Power Authority, *About Peak Load Management*, 2012 *Available at* http://www.nypa.gov/plm/default.htm.

2.4.4 Australia

a. Heat Wave Impacts

In Australia, over the last decades heat waves[173] have increased both in frequency and duration. Since 1950 the annual number of record hot days has more than doubled.[174] The number of heat wave days each year has been increasing across the country.[175] A 2014 report published by the Climate Council in Australia highlights the urgent need for changes in the electricity sector due to old and inefficient power infrastructures.[176]

- In March 2008, South Australia experienced its longest ever recorded heat wave lasting 15 consecutive days with a maximum daily temperature of 104.4°F (40.2°C).[177] This prolonged event caused several problems to electricity transmission and distribution resulting in seven short blackouts while the need for cooling was constant.[178] On three separate occasions the demand for electricity reached a new all-time record and electricity retail prices went up on six occasions during the 15-day period.[179]
- In the beginning of 2009 a very long and intense heat wave hit South-Eastern Australia starting on January 27 and lasting until February 8.[180] Over the five days between January 27 and 31 the maximum temperatures were 53.6°F to 59°F (12°C to 15°C) above normal in

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[173] A heatwave is defined as a period of at least three days where the combined effect of high temperatures and excess heat is unusual within the local climate according to Bureau of Meteorology cited at Will Steffen, Lesley Hughes and Sarah Perkins, *Heatwaves: Hotter, Longer, More Often*, Climate Council of Australia Limited, Australia, 3, (2014).

[174] *Id.*

[175] *Id.*, at 7.

[176] Andrew Stock, *Australia's Electricity Sector: Ageing, Inefficient and Unprepared*, Climate Council of Australia Limited, iii, 2014.

[177] Bereau of Meteorology [Hereinafter BoM], *Monthly Climate Summary for Adelaide Metro*, Australian Government, Apr. 7 2008 *Available at* http://www.bom.gov.au/climate/current/month/sa/archive/200803.adelaide.shtml.

[178] Watt Clarity, *Effects of the Heatwave of March 2008 on the South Australian Region*, Australia, 7 and 8, May 16 2008 *Available at* http://www.wattclarity.com.au/files/documents/march08heatwave.pdf.

[179] *Id.* at 6 & 8.

[180] Australian Bureau of Statistics, *Feature Article: The Exceptional Heatwave of January-February 2009 in South-Eastern Australia,* Jan. 21 2013 *Available at* http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/1301.0Chapter1042009%E2%80%9310.

many areas in Victoria.[181] The maximum daytime temperature in Melbourne reached 109.4°F (43°C) for three consecutive days and the maximum daily temperature recorded was 113.2°F (45.1°C), the second highest on record.[182] There were 374 excess deaths noted over of what it would be expected comparing to mortality rates for the same days over the past five years.[183] In central and western Melbourne on January 30, 500,000 residents had blackouts lasting from one hour up to two days.[184] In Victoria rolling blackouts were driven by the increased demand of air conditioning and the shutdown of the Basslink interconnector cable.[185] The heat-induced shutdown of the Basslink, which gives to Victoria 6% of the power supply, compromised the capacity of the electricity supply.[186] The Basslink connects Tasmania to Victoria.[187] This happened when Tasmania was also experiencing similar weather to Victoria and South Australia and when high temperatures made converters to operate at their maximum operating temperature.[188]

- In the summer of 2014, heatwaves in southeast Australia were particularly intense, mainly due to their duration.[189] Between December 30 and January 4, 34 locations mostly in New South Wales and Queensland had their hottest day ever recorded within the past 40 years or more.[190] In Victoria State increased temperatures started on January 13 and lasted until the 17, where the state-wide average maximum temperature exceeded the 105.8°F (41°C)

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[181] Victorian Government Department of Human Services Melbourne, *January 2009 Heatwave in Victoria: An Assessment of Health Impacts*, Melbourne, Australia, 1, (2009).

[182] *Id.*, at 4.

[183] *Id.*, at iv.

[184] Will Steffen et al., *supra* note 174, at 33.

[185] Queensland University of Technology [Hereinafter QUT], *Impacts and adaptation response of infrastructure and communities to heatwaves: The southern Australian experience of 2009*. Report for the National Climate Change Adaptation Research Facility, Gold Coast, Australia, 57, (2010).

[186] *Id.*, at 4.

[187] *Id.*, at 4.

[188] *Id.*, at 19 & 60.

[189] Climate Council of Australia, *Angry Summer 2013/2014*, 3, 2014.

[190] BoM, *Special Climate Statement 47 - an intense heatwave in central eastern Australia*, 2, Jan. 21 2014 *Available at* http://www.bom.gov.au/climate/current/statements/scs47.pdf.

for the last four days.[191] Big cities experienced very high temperatures for several days in a row, Canberra had four consecutive days of daily maximum temperature 102.2°F (39°C), Melbourne four days of 105.8°F (41°C) and Adelaide five days of 107.6°F (42°C).[192] On January 14, the electricity prices raised 7% and reached their highest since January 30, 2012.[193] The electricity demand stretched the national grid.[194] In Melbourne, 10,000 homes experienced power outages as electricity demand raised.[195] In addition, in Victoria and South Australia electricity consumption was at its highest level since 2009, though it did not exceed that record.[196]

b. *Heat Wave Preparedness*

Australia's climate change actions focus on mitigation and GHG emission targets. At the national scale, in November 2010 the Legislative Assembly passed the Climate Change and Greenhouse Gas Reduction Act 2010, which established GHG emission reduction targets of 40% below 1990 levels by 2020, and 80% below 1990 levels by 2050.[197] In 2012, the Australian Renewable Energy Agency Act 2011 (ARENA Act) established the Australian Renewable Energy Agency (ARENA) as a Commonwealth Authorities and Companies Act 1997 authority. ARENA's two objectives are to improve the competitiveness of renewable energy technologies, and to increase the supply of renewable energy in Australia. The Clean Energy Act 2011 established an Emission

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[191] BoM, *Special Climate Statement 48 – one of Southeast Australia's most Significant Heatwaves*, Australian Government, Aug. 21 2014 *Available at* http://www.bom.gov.au/climate/current/statements/scs48.pdf.

[192] Climate Council of Australia, *supra* note 189, at 2.

[193] Jason Scott and Ben Sharples, *Australia Heat Wave Strains Power Supplies, Sparks Wildfires*, Bloomberg, Jan. 16 2014 *Available at* http://www.bloomberg.com/news/2014-01-16/heatwave-strains-australia-power-supply-with-mercury-set-for-115.html.

[194] ABC, *More power cuts on cards as south-east Australia sizzles in heatwave*, Jan. 16 2014 *Available at* http://www.abc.net.au/news/2014-01-15/fire-crews-on-alert-as-south-east-australia-sizzles-in-heatwave/5200424.

[195] *Id.*

[196] Brian Robins, *Power blackouts tipped for industry in heatwave,* The Sydney Morning Herald, Jan. 16 2014 *Available at* http://www.smh.com.au/business/power-blackouts-tipped-for-industry-in-heatwave-20140115-30v5y.html#ixzz3Cjm1iD6o; Alexander White, The blackouts during Australia's heatwave didn't happen by accident, The Guardian, Jan. 17 2014 *Available at* http://www.theguardian.com/environment/southern-crossroads/2014/jan/17/heat-wave-australia-record-breaking-climate-change-bushfires-melbourne.

[197] Australian Capital Territory, *A new climate change strategy and action plan for the Australian Capital Territory,* Environment and Sustainable Development Directorate, Canberra, vii, 2012 *Available at* http://www.environment.act.gov.au/__data/assets/pdf_file/0006/581136/AP2_Sept12_PRINT_NO_CROPS_SML.pdf.

Trading Scheme (ETS) and a Clean Energy Finance Corporation (CEFC) to encourage and support clean energy projects only to be repealed in September 2013 when the dismantling of climate change programs started which included the Clean Energy Act 2011.[198] Earlier the same year the department of Climate Change was disbanded distributing some of its functions to other departments.[199]

Since 2008, feed-in tariffs (FiT) that promote renewable electricity generation sources have been initiated in all the Australian states.[200] The Renewable Energy Target (RET) requires that 20% of the county's electricity be produced by renewable energy sources by 2020. For this goal the government set annual targets and obliges Australian electricity retailers and large wholesale purchasers to demonstrate compliance by submitting renewable energy certificates (RECs). If the RECs are not adequate charges apply.[201] Electricity retailers and wholesale buyers either generate the electricity from renewable sources or purchase the RECs from others that have done so.[202] But there is not a national adaptation plan for the electricity sector with specific targets and planning nor any policy explicitly focusing on heat waves.[203] In 2011, PricewaterhouseCoopers Australia, supported by the government, published the report "Protecting Human Health and Safety During

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[198] Australian Government, *Adapting to climate change - Government actions*, 2013 *Available at* www.climatechange.gov.au/climate-change/adapting-climate-change/adaptation-framework/government-actions; Parliament of Australia, *Australian Climate Change Policy: a Chronology*, Parliament Library, Research Publications, 2013 *Available at* http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/rp1314/ClimateChangeTimeline.

[199] Parliament of Australia, *supra* note 198.

[200] Parliament of Australia, *Feed-in Tariffs*, 2011 *Available at* http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/Browse_by_Topic/ClimateChange/Governance/Domestic/national/tariffs.

[201] Parliament of Australia, *Mandatory renewable energy target*, 2010 *Available at* http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/Browse_by_Topic/ClimateChange/Governance/Domestic/national/Mandatory.

[202] *Id.*

[203] Martin Rice, *Australia's ancient electricity sector urgently needs a new plan*, The Conversation, Jun. 18 2014 *Available at* http://theconversation.com/australias-ancient-electricity-sector-urgently-needs-a-new-plan-28085; PricewaterhouseCoopers Australia [Hereinafter PwC] and Department of Climate Change and Energy and Efficiency, Protecting human health and safety during severe and extreme heat events A national framework, prepared in collaboration with the Australian Government, 42, 2011 *Available at* http://www.pwc.com.au/industry/government/assets/extreme-heat-events-nov11.pdf.

Severe and Extreme Heat Events: A National Framework," which gives advice on the effectiveness of heat wave response systems and highlights the vulnerability of the electricity sector.[204] This report does not provide any binding actions - its purpose is only to raise awareness for heat wave events. At a city level there many examples of actions for reducing the overall temperature of urban areas. In the City of Melbourne, actions include tree planting by implementing the Urban Forest Strategy where they plan to increase the canopy to 40% by 2040 and development of cool roof technology, shading devices and permeable pavements.[205]

3. ADAPTATION TO HEAT WAVES

3.1 Introduction

According to the IPCC "adaptation is the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities" and adaptive capacity is "the ability of systems, institutions and humans to adjust to potential damage, to take advantage of opportunities, or to respond to consequences".[206] The Organisation for Economic Co-operation and Development (OECD) defines adaptation as an ongoing practice that requires the development and re-development of strategies, policies and plans, climate understanding, investment, and technology advances considering socio-economic changes.[207] Adaptation depends on various conditions such as time, motivation for action and the goals of the main stakeholders. It can be either anticipatory or reactive. Anticipatory is when actions take place before a climate impact becomes evident; reactive adaptation refers to

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[204] PwC and Department of Climate Change and Energy and Efficiency, *supra* note 203, at 42.

[205] City of Melbourne, *Heatwaves and days of extreme heat*, 2014 *Available at* http://www.melbourne.vic.gov.au/Sustainability/AdaptingClimateChange/Pages/Heatwaves.aspx#actions.

[206] IPCC, *Annex II: Glossary* [Agard, J., E.L.F. Schipper, J. Birkmann, M. Campos, C. Dubeux, Y. Nojiri, L. Olsson, B. Osman-Elasha, M. Pelling, M.J. Prather, M.G. Rivera-Ferre, O.C. Ruppel, A. Sallenger, K.R. Smith, A.L. St. Clair, K.J. Mach, M.D. Mastrandrea, and T.E. Bilir (eds)]. *In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1757-1776, (2014).

[207] OECD, *Integrating Climate Change Adaptation Into Development Co-Operation: Policy Guidance*, 56, (2009).

when action takes place after an impact.[208] For heat waves, anticipatory adaptation is not common as governments and utilities are not willing to expend effort or money without clear warnings of risks or obvious losses. Usually preparedness is triggered by events with significant impacts. In this section the focus is on reactive adaptation, which is more relevant for the electricity sector. Reactive adaptation refers both to long-term and short-term planning; the latter refers to measures that take place just before and during heat waves. Under this scope the section first examines adaptation barriers in order to identify why adaptation is not facilitated and then continues with adaptation options looking at technological, behavioural and institutional approaches. Technological adaptation refers to retrofitting and replacement of existing electricity systems and integration of energy efficient infrastructures and technologies. Behavioral adaptation refers to electricity conservation and control of electricity consumption from utilities' and end users' perspectives. Finally, institutional adaptation refers to methods and actions taken by governments of all levels and cross-sector collaboration. The section closes by explaining how investments and transparency support adaptation goals and what are the complexities in institutional adaptation.

3.2 Adaptation Barriers

Up until now, mitigation has been the main climate change-related effort.[209] The limited scientific literature of impacts on utilities, compared to other sectors and systems, increases uncertainty and creates an environment of reluctance.[210] Adaptation exists in corporate and public sector agendas but there have not been many concrete actions.[211] There a number of reasons that help explain this. First, any changes to electricity systems and institutions come with large investments, increasing the tendency toward inaction.[212] Usually, relatively inexpensive measures are easier to be implemented, as they need less investment and fewer approvals. A new power

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[208] Richard J.T. Klein, *Adaptation To Climate Variability And Change: What Is Optimal And Appropriate?*, Potsdam Institute for Climate Impact Research, Potsdam, Germany, 3, (1999).

[209] Jane Ebinger & Walter Vergara, *supra* note 2, at 84.

[210] Rebecca Stecker, Anna Pechan, J. Micha Steinhaüser, Maja Rotter, Gerd Scholl, Klaus Eisenack, *Why are Utilities Reluctant to Adapt to Climate Change?* Chameleon Research Group Report, 2, (2011).

[211] *Id.*, at 4.

[212] Gregory C. Unruh, *Escaping Carbon lock-in*, 30 Issue 4 Energy Policy, 317-325, 317, (2002); Gregory C Unruh, *Understanding Carbon lock-in*, 28 Issue 12 Energy Policy 817-830, 817, (2000).

plant, or new transmission and distribution lines, takes years to be approved and start operating.[213] Second, the electricity sector is highly regulated, which makes changes more difficult; the lack of coordination between governments and private businesses exacerbates the problem.[214] Decision-making processes are even more complex due to multiple actors that come from different sectors and different perspectives.[215] In addition, political turnover makes action more unlikely, as new governments do not necessarily follow the same lines for climate change action as their predecessors. Finally, planning and management practices for increasing resilience over-rely on existing practices without incorporating innovative thinking and re-conceptualize adaptation, and therefore fail to address the seriousness of climate change.[216]

The case studies in Section 2 provide several instances where governments and other actors have begun to overcome these barriers. France, in particular, has had an exceptional evolution and heat waves have been treated as a major risk for both society and the electricity sector, and have been dealt separately from other climate impacts. The movement in these case studies may be attributed to the experience of heat wave impacts, which were massive and continuous over the years, and the available capacity to invest, which made policy makers more willing and able to adopt measures.

3.3 Technological Adaptation

3.3.1 Electricity Generation Plants

The efficiency and reliability of thermal power plants may be improved through heat-related efficiency standards, cooling technology standards, and siting requirements. As mentioned above (see Section 2) air and water temperatures affect electricity generation capacity, lowering the output and making facilities operate in low safety margins. Likewise regulations for water temperature discharges limits in natural water bodies from power plants make electricity systems work below their full capacity. Technological changes are necessary to safeguard existing

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[213] Edward Vine, *supra* note 31, at 94.

[214] Rebecca Stecker et al., *supra* note 210, at 2 & 3.

[215] Edward Vine, *supra* note 31, at 95.

[216] Darryn McEvoy et al., *supra* note 53, at 793.

electricity generation and increase energy efficiency before utility companies consider expanding electricity generation plants due to increasing electricity demand. New and retrofitting technologies may include changing the types of turbines and using heat-resistant technology. For example in PV systems heat-resistant cells and modules improve the airflow in systems and keep them cooler.[217] Technology should adapt to projected local climate changes and should be designed to operate at higher temperatures to avoid compromising the power output during heat waves. Current electricity generation plants in most cases are older than 30 years old and retrofitting is necessary.[218] However, retrofitting investments for cooling should be justifiable due to electricity efficiency gains; alternatively, decommissioning of old plants and their replacement by new, more heatproof plants [219] should be considered.[220]

Water regulations drive choices of technology towards more environmentally friendly choices such as water recirculating systems or air-cooling technology.[221] Change in cooling technology is not always feasible as it increases costs. Recirculating systems maximize water use and have a lower operating cost, but they have approximately 40% higher installation costs than once-through cooling systems. Moreover, plants with cooling towers using recirculating water have lower power efficiency by 2% to 3% because they consume more energy internally to operate the water pumps and ventilators.[222] These are all crucial aspects that should be considered by operators before changing their technology.

Cooling constraints are related to all power plants located inland but are not relevant to those located by the coast using seawater.[223] New power plants could be placed close to the sea or

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[217] ADB, *supra* note 8, at 29.

[218] EIA, *Age of Electric Power Generators Varies Widely*, Jun. 16 2011 *Available at* http://www.eia.gov/todayinenergy/detail.cfm?id=1830; Nina Chestney And Susanna Twidale, *Insight - The Cost Of Caring for Europe's Elderly Nuclear Plants*, REUTERS UK Edition, Aug. 17 2014 *Available at*

http://uk.reuters.com/article/2014/08/17/uk-europe-nuclear-power-insight-idUKKBN0GH05S20140817.

[219] New plants should consider all climate change impact spectrum they should be climate-proof.

[220] ADB, *supra* note 8, at 7.

[221] World Energy Council, *Water for Energy*, (2010) cited at ADB, *supra* note 8, at 11.

[222] S. Greis, J. Schulz, and U. Muller, *Water Management of a Thermal Power Plant - A Site Specific Approach Concerning Climate Change*, in A. Troccoli (ed.), Management of Weather and Climate Risk in the Energy Industry. Dordrecht (The Netherlands): Springer Academic Publisher, (2010) cited at ADB, *supra* note 8, at 11.

[223] Koen Rademaekers et al., *supra* note 25, at 27.

where climate is projected to be cooler and water availability adequate.[224] [225] But in this case new locations that have cooling capacity should also be close to where electricity is needed or where adequate resources for electricity production exist. The new locations should have more benefits than losses and the costs of electricity transmission should not surpass the generation efficiency gains.[226]

3.3.2 Electricity Mix Diversification

Expanding the variety of power plant sources in the electricity mix and having both centralised and decentralised options increases the energy security and the flexibility of the electricity sector.[227] Diversifying the electricity generation mix by increasing the renewable energy share is a commonplace practice for building electricity sector resilience. Renewable energy sources not only reduce GHG emissions and mitigate climate change but also can possibly back up electricity when big fossil-fueled plants fail to generate at demand rate.[228] Diversification helps to avoid the overreliance to one type of source located in a certain area. Therefore, in case a type of source is severely affected by a heat wave the electricity losses will not affect consumers and businesses at a large-scale. Diversification minimises the magnitude of impacts and makes electricity systems less prone to failures.[229]

Centralised systems of various sources including large-scale renewables are usually located outside of the urban centers, and they serve large areas. In case of a heat wave, when these systems fail to operate or operate below their capacity, potentially vast areas that depend on them lose their electricity supply. So not only various types of generation systems are needed but also decentralised generation systems. Decentralised systems can continue to operate in the event of

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[224] ADB, *supra* note 8, at 12.

[225] Flooding and sea level rise risk should be considered as they threaten plants located close to the sea.

[226] ADB, *supra* note 8, at 12.

[227] B. Rothstein, S. Mimler, U. Múller, and L. Ottenschläger, *The electricity industry as stakeholder of climate change*, Contribution to the Second National Workshop of EPA, Adaptation to Climate Change in Germany, Regional Scenarios and National Tasks, Berlin, (2006) *cited at* Jane Ebinger & Walter Vergara, *supra* note 2, at 64.

[228] California Climate Change Center, *supra* note 97, at 14.

[229] Jane Ebinger & Walter Vergara, *supra* note 2, at 64; Executive Office of Energy and Environmental Affairs and the Adaptation Advisory Committee, *Massachusetts Climate Change Adaptation Report*, Boston U.S., 57, (2011).

failure and also can lower peak demand as a whole. These types of facilities can also mean less need for cooling water as the need is disaggregated to more areas, minimising water related risks.[230] Decentralised generation systems can serve individual buildings or local networks, covering energy needs by using heat pumps, rooftop PV generators and other technologies based on local available sources.[231] Additionally, the consumption of electricity is very close to the generation point, which accordingly minimises the losses and risks of transmission and distribution systems.[232]

Renewables are the only sustainable solution for both diversification and decentralization but there are some concerns regarding their integration to existing systems. In 2012, renewable sources added 20.8% to the grid of all electricity generation sources, with the two major contributors being hydropower (16.2%) and wind (2.4%).[233] However, further integration of renewables requires contemplating some risks such as voltage fluctuations, inefficiencies, outages and waste.[234] A recent report by the International Energy Agency (IEA) indicates that there are two primary obstacles of integrating wind and solar energy at large scale, into the grid.[235] First, these sources are variable, depending on weather conditions, such as wind patterns and daylight and constant supply is uncertain.[236] Currently, to balance this variability and back up electricity in times of need in most cases the solution is supply from conventional generation sources.[237] Second, the location of a source might be distant from the demand and the transmission and distribution

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[230] ADB, *supra* note 8, at 12.

[231] Jane Ebinger & Walter Vergara, supra note 2, at 61; S. A. Hammer et al., *supra* note 3, at 87.

[232] U.S. Department of Energy, *The Potential Benefits Of Distributed Generation And Rate-Related Issues That May Impede Their Expansion,* A Study Pursuant To Section 1817 Of The Energy Policy Act Of 2005, xvii, Feb. 2007 *Available at* http://www.ferc.gov/legal/fed-sta/exp-study.pdf.

[233] Observe'ER and Foundation Energies pour le Monde, *Worldwide Electricity Production form Renewable Energy Sources, Electricity Production in the World: General Forecasts*, Fifth Inventory, 6, (2013).

[234] International Electrotechnical Commission, *Grid integration of large-capacity Renewable Energy sources and use of large-capacity Electrical Energy Storage*, White Paper, Geneva, Switzerland, 106, Oct. 2012 *Available at* http://www.iec.ch/whitepaper/pdf/iecWP-gridintegrationlargecapacity-LR-en.pdf.

[235] OECD/IEA, The Power Of Transformation: Wind, Sun And The Economics Of Flexible Power Systems, 238, 13, (2014).

[236] *Id.*, at 13.

[237] International Electrotechnical Commission, *supra* note 234, at 58.

costs are high.[238] Existing electricity transmission and distribution systems require technology adjustments for accepting bigger loads from renewable sources.

3.3.3 Electricity Storage

The increase of renewable energy and decentralised systems mandate the use for electricity storage for securing constant electricity supply in order to avoid using fossil fuels for back up. Energy storage technologies are very important during blackouts and can increase the reliability of the supply. The energy can be stored and used when the demand is increased or the production rate decreases. Different technologies are being developed and optimized, including chemical energy storage like advanced batteries, mechanical energy storage such as compressed air energy storage and flywheels, electrical energy storage like capacitors and supercapacitors, and thermal energy storage like steam or hot water accumulators.[239] Further research and advancement of these technologies is still required for their optimisation and commercialization.[240]

3.3.4 Grid Modernization

Improving the grid by retrofitting current structures and introducing new technologies and new design structures is a critical step for heat-proofing the electricity system. The grid is the most weather-exposed part of the electricity supply chain. Overhead lines sag lower during a heat wave diminishing their efficiency.[241] A solution for avoiding that is the replacement of some overhead lines with underground cables.[242] However, underground cables add additional costs for installation and maintenance.[243] Supplementary transmission lines are also an option to increase system's flexibility by providing the ability to re-route electricity in case of a failure and minimize

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[238] OECD/IED, *supra* note 235, at 13.

[239] National Science and Technology Council, *A Policy Framework for The 21st Century Grid: A Progress Report*, Executive Office Of The President, Washington, D.C., 3, (2013); Sandia National Laboratories, *Electricity Storage*, 2014 *Available at* http://www.sandia.gov/ess/tech_batteries.html; Jane Ebinger & Walter Vergara, *supra* note 2, at 65.

[240] International Electrotechnical Commission, *supra* note 234, at 97.

[241] David M. Ward, *supra* note 47, at 107.

[242] *Id.*

[243] Executive Office of the President, *Economic Benefits Of Increasing Electric Grid Resilience To Weather Outages*, Report was prepared by the President's Council of Economic Advisers and the U.S. Department of Energy's Office of Electricity Delivery and Energy Reliability and the White House Office of Science and Technology, Washington D.C., 13, (2013).

the risks of electricity outages.[244] Smart technology also increases the reliability of the electricity grid.[245] Smart grids are designed to control the system remotely and in an automated way. This technology uses sensors to manage the grid in real-time and make corrections when electricity loss is observed.[246] Smart technology can show exactly where an outage occurs as opposed to existing systems where in most cases customers have to inform the utilities for electricity outages.[247] Microgrid technology can contribute to more resilient transmission and distribution systems as well.[248] Microgrids are associated with decentralized electricity systems as they are isolated smaller grid networks that connect to the main grid or function alone in case of a failure when part of the grid faces problems.[249] Finally, new grid structures, such as circular grids, can also allow more flexibility. Circular grids can be considered a better technology than linear networks because their design allows electricity to reach end users through alternative routes and thereby secures supply at times of need.[250]

3.3.5 Adaptation to Built Environment

The building sector is a major electricity consumer globally and accounts for half of all electricity consumed.[251] The projected increase of heat waves will reduce buildings' capacity to maintain stable indoor temperature and thus, air-conditioning use will increase. Alterations to buildings for conserving electricity like introducing new building codes for energy efficiency, passive cooling systems, window shading and insulation are important for decreasing the overall

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[244] *Id.*, at 14.

[245] *Id*.

[246] National Science and Technology Council, *supra* note 239, at 3.

[247] *Id.*; Executive Office of the President, *supra* note 243, at 15.

[248] David Ferris, *Microgrids: Very Expensive, Seriously Necessary*, Forbes, Jul. 31 2013 *Available at* http://www.forbes.com/sites/davidferris/2013/07/31/microgrids-very-expensive-seriously-necessary/; National Science and Technology Council, *supra* note 239, at 4.

[249] Executive Office of the President, *supra* note 243, at 14.

[250] Eric Klinenberg, Adaptation, How can cities be "climate-proofed", The New Yorker, Jan. 7 2013 *Available at* http://www.newyorker.com/magazine/2013/01/07/adaptation-2.

[251] OECD/IEA, *Transition to Sustainable Buildings, Strategies and Opportunities to 2050*, Paris, France, 1, 2013 *Available at* http://www.iea.org/Textbase/npsum/building2013SUM.pdf.

demand.[252] Building codes should be modified to ensure exploitation of bioclimatic design principles and permission for green roofs development, increase of lighter color materials and white roofs that do not absorb much heat.[253],[254]

Buildings together with other infrastructures create the conditions for even further electricity consumption due to the creation of the UHI effect. The UHI effect is created mainly due to lack of vegetation and increase of built environment with dark surfaces that absorb radiation, such as buildings, streets and parking lots.[255] The introduction of green spaces and green roofs is a well-understood approach to counter-acting the UHI effect.[256] During summer the temperature in an afternoon can be 4.5°F (2.5°C) higher in cities than in nearby rural areas [257] and electricity demand rises by 2% to 4% for every 1.8°F (1°C) increase above 59°F - 68°F (15°C - 20°C).[258] Cooling down cities can have positive outcomes for utilities by decreasing the overall demand and securing electricity supply in heat waves with the added value of reducing electricity expenses for households.[259] Lastly, reduced demand can create huge savings for utilities that would be able to meet future demand and possibly postpone expansion costs.[260]

3.3.6 Forecasting

Short-term demand forecasting is already a common tool to control electricity supply but long-term demand forecasting is important for utilities and their future investment plans. There are two important elements to long-term demand forecasting: heat wave predictions and electricity

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[252] Patrick L. Kinney, Marie S. O'Neill, Michelle L. Bell, Joel Schwartz, *Approaches for Estimating Effects of Climate Change on Heat-related Deaths: Challenges and Opportunities*, 11 Environmental Science & Policy Issue 1 87-96, 90, (2008); Frank Stern, *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies - Energy*, Jan F. Feenstra Ian Burton Joel B. Smith Richard S.J. Tol (eds), UNEP, 11-28, (1998).

[253] A. H. Rosenfeld, J. J. Romm, H. Akbari and M. Pomerantz , *Cool Communities: Strategies for Heat Island Mitigation and Smog Reduction*, 28 Energy and Buildings 51-62, 52, (2008).

[254] Lou Chesné, Thierry Duforestel, Jean-Jacques Roux and Gilles Rusaouën, *Energy Saving and Environmental Resources Potentials: Toward New Methods of Building Design*, 58 Building and Environment 199-207, 199, (2012).

[255] H. Akbari , M. Pomerantz and H. Taha, *Cool Surfaces and Shade Trees to Reduce Energy Use and Improve Air Quality in Urban Areas,* 70 Solar Energy No. 3, pp. 295–310, 295, (2001).

[256] A. H. Rosenfeld et al., *supra* note 253, at 52.

[257] H. Akbari et al., *supra* note 255 at 295.

[258] *Id*.

[259] A. H. Rosenfeld et al., *supra* note 253, at 51; OECD/IEA, *supra* note 251, at 1.

[260] OECD/IEA, *supra* note 251, at 1.

demand predictions. Utilities have to collaborate with climate scientists and develop long-term temperature forecasting tools.[261] In regards to demand, utilities need to predict the number of people who will increase their air-conditioning use when temperatures rise.[262] To determine this demand there are many socio-economic factors to consider, such as household income, electricity prices, energy efficient appliances and personal preferences, among others.[263] Another important forecasting tool is for predicting variability of large-capacity renewables. This combines the forecast of weather and generation. The forecasting will improve the supply and demand balance and utilities will be ready to provide more electricity when generation is less than expected and also to obtain more when generation is more than predicted.[264]

3.4 Behavioural Adaptation

3.4.1 Electricity Sector

Behavioral adaptation for utilities refers to modification of emergency, operating and maintenance plans and training of workforce with the aim to minimize risk in operation.[265] Risk identification is the first step. Heat waves should be acknowledged within the spectrum of important risks and included into risk management and emergency plans. Evaluation of heat wave preparedness and response after any severe heat wave is useful for identifying the weak parts of the electricity generation, transmission and distribution systems and for making improvements. In addition, utilities should create dedicated climate change adaptation strategies to assess those risks and identify measures that secure the systems.[266] By changing and improving operation and management methods utilities can cost-effectively reduce the vulnerability of assets without

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[261] Pierre Audinet, Jean-Christophe Amado and Ben Rabb, *Climate Risk Management Approaches in the Electricity Sector: Lessons from Early Adapters*, Weather Matters for Energy, A. Troccoli, L. Dubus and S. E. Haupt (eds), 52, (2014).

[262] European Observation Network, Territorial Development and Cohesion (ESPON) (2010) *Discussion Paper: Impacts of Climate Change on Regional Energy Systems*, 12, 2010 *Available at* http://www.espon.eu/export/sites/default/Documents/Projects/AppliedResearch/ReRISK/RERISK-Discussion-Paper-Climate-Change.pdf.

[263] *Id.*

[264] International Electrotechnical Commission, *supra* note 234, at 26.

[265] Pierre Audinet et al., *supra* note 261, at 33.

[266] *Id.*, at 34.

making any changes in technology.[267] Furthermore, electricity companies can also initiate discussions with governments and regulators for covering adaptation costs in order for the electricity sector to improve their capacity and cope with adverse impacts while reducing some costs when possible.[268]

3.4.2 End Users

End users adaptation refers to consumption adjustments with the purpose to conserve electricity. Adaptation to end users lifestyle can make the difference in heat waves as many electricity systems face blackouts due to increased demand. More aware consumers equipped with more energy efficient appliances can actually affect the overall demand. Usually, end users are encouraged by utilities to moderate their electricity and adjust their thermostats during a heat wave in order to avoid blackouts. However, additional actions should be considered by utilities and policy makers to ensure high electricity conservation and efficiency. For instance, elimination of energy subsidies would reveal the true cost of electricity and could create incentives to reduce consumption.[269] Educational programs that promote a general less energy-intensive lifestyle will be beneficial.[270] Governments' encouragement to equip houses with better windows, shading and other cooling structures can also reduce overall electricity demand. Additionally, smart meters motivate end users to reduce their electricity. Smart meters can record a consumer's energy use hourly or even at 15-minute intervals and allow the user to track her electricity consumption. This information can stimulate users to save electricity and reduce costs, or even to find faulty equipment that consumes significant amounts of electricity and fix or replace it.[271]

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[267] *Id.*, at 37.

[268] *Id.*, at 37.

[269] Frank Stern, *supra* note 252.

[270] S. A. Hammer et al., *supra* note 3, at 106.

[271] National Science and Technology Council, *supra* note 239, at 3-4.

3.5 Institutional Adaptation

3.5.1 Introduction

O'Riordan and Jordan define the role of institutions "as a means for holding society together, giving it sense and purpose and enabling it to adapt".[272] Technology improvements and behavioral change combined with institutional adaptation can create stronger capacity electricity systems that avoid cascading failures. Governments and institutions at all levels—international, national, regional and local—that consider socio-economic conditions in adopting particular strategies determine the success or failure of adaptation.[273] Several important decisions lie with the electricity companies, including operation and maintenance procedures, training for employees and load management. But policies and regulations for energy efficiency and security lie outside of the electricity sector decision-making framework. Governments and institutions are responsible for enacting the appropriate set of policies and regulatory frameworks necessary for maintaining the electricity sector's reliability.[274] Other determinants in the scope of institutional adaptation are cross sector collaboration, transparency of operations, available investment and the complexity of multiple actors.

3.5.2 Governance

Adaptation is a relatively new issue in governance and is still developing in various countries, at different paces.[275] In many countries international frameworks such as the United

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[272] T. O'Riordan and A. Jordan, *Institutions, climate change and cultural theory: towards a common analytical framework*, 9 Global Environmental Change 81-93, 1999, *cited at* J. E. Thornes, *IPCC, 2001: Climate change 2001: impacts, adaptation and vulnerability*, Contribution of Working Group II to the Third Assessment Report of the IPCC, J. J. McCarthy, O. F. Canziani, N. A. Leary, D. J. Dokken and K. S. White (eds), Cambridge University Press, Cambridge, UK, and New York, USA, (2001).

[273] S. Cutter, B. Osman-Elasha, J. Campbell, S.-M. Cheong, S. McCormick, R. Pulwarty, S. Supratid, and G. Ziervogel, Managing the risks from climate extremes at the local level, in Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds)], A Special Report of Working Groups I and II of the IPCC, Cambridge University Press, Cambridge, UK, and New York, NY, USA, 417, (2012).

[274] ADB, *supra* note 8, at 7.

[275] R. Swart, G.R. Biesbroek, S. Binnerup, T. Carter, C. Cowan, T. Henrichs, S. Loquen, H. Mela, M. Morecroft, M. Reese, and D. Rey, *Europe Adapts to Climate Change. Comparing National Adaptation Strategies*, Vammalan Kirjapaino Oy, Sastamala, (2009) *cited at* Lasse Peltonen, Sirkku Juhola, Philipp Schuster, *Governance of Climate Change Adaptation: Policy Review*, Baltic Sea Region Programme 2007-2013, 4.

Nations Framework for Convention on Climate Change stimulate adaptation actions but in most cases extreme events, economic and human losses make adaptation a high political priority.[276] Successful adaptation depends on governance regimes of all scales: international, national, regional and local. Governments oversee planning regulations, set standards for operations and facilities, integrate policy frameworks in electricity markets and ensure that the electricity sector and end users take all precautionary measures to reduce vulnerability.[277]

At the national level governments can create policy frameworks for, or even require, effective long-term adaptation actions, establish performance standards for the electricity sector, provide quality climate information and prepare plans for emergency situations.[278] National policies and plans also shape national budgets that can allocate sufficient funds for adaptation purposes. Also, national governments have the power to facilitate renewable energy, energy efficient projects, change building codes, set appliance standards and promote heatproof infrastructures.[279] Common practices for establishing action are the adoption of RPS, feed-in tariffs, carbon pollution reduction schemes and quota schemes. National governments are also responsible for developing national adaptation plans and creating measurable targets for heatproof infrastructures, energy efficiency and behavioural changes.

At the regional and local levels, governments control spatial and land-use plans, which give them the ability to change current infrastructures and appraise new options, replace vulnerable systems and select areas for new electricity generation sites.[280] Local governments are also developing plans for greening cities, building green infrastructures and setting building standards. Hence, they can play an essential role in reducing electricity consumption and minimizing UHI. Furthermore, they address local vulnerability and develop plans that consider

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[276] S. Juhola, *Mainstreaming Climate Change Adaptation: The Case of Multilevel Governance in Finland*, Development of Adaptation Policy and Practice in Europe: Multi-level Governance of Climate Change, E.C.H. Keskitalo, Verlag Springer (eds), Berlin, (2010); Lasse Peltonen, Sirkku Juhola, Philipp Schuster, *Governance of Climate Change Adaptation: Policy Review*, Baltic Sea Region Programme 2007-2013, 4.

[277] IEA, Energy Policy Highlights, Paris, 54, 2013; Edward Vine, *supra* note 31, at 84.

[278] Jane Ebinger & Walter Vergara, *supra* note 2, at 57.

[279] Edward Vine, *supra* note 31, at 85.

[280] EC, *Adapting Infrastructure To Climate Change*, Commission Staff Working Document, SWD (2013) 137, 15, Apr. 16 2013 *Available at* http://ec.europa.eu/clima/policies/adaptation/what/docs/swd_2013_137_en.pdf.

local potentials (for instance for exploiting renewables energy sources) and that take into account local socio-economic conditions and climate.[281] Thus, their decisions can greatly affect the local electricity demand.[282] At the local level, governments can also develop emergency plans during heat waves and make sure that some critical facilities like hospitals and cooling rooms for vulnerable groups will have backup electricity facilities. However, even though adaptation planning at regional and local scales is crucial, usually it is constrained by a lack of information and resources, and by conflicting interests associated with local planning. Although mitigation has arguably received greater attention than adaptation even at the local level,[283] mitigation measures in many cases have adaptation benefits – for instance, increase of PV permits decrease electricity demand, which can help minimise electricity shortages.[284]

3.5.3 Cross-sectoral Collaboration

A great challenge when addressing climate change impacts is the consideration and integration of multiple sectors.[285] The electricity sector does not work in isolation and therefore adaptation actions should consider related sectors and their interactions. Hydro-meteorological offices and the electricity sector should work together in order for the latter to obtain high-quality climate data and use them in decision-making and planning processes.[286] Utilities require data not only of climatic averages but also detailed data of various spatial resolutions, timescales and climate scenarios. This information is not readily available to electric utilities and is thus rarely included into planning.[287] The two sectors should closely collaborate, especially before investing in heatproof technologies. Furthermore, utilities and regulators have to ensure that adaptation solutions do not create problems for other economic sectors. Highly water-dependent sectors like

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[281] Jane Ebinger & Walter Vergara, *supra* note 2, at 57.

[282] Edward Vine, *supra* note 31, at 84.

[283] Thomas G. Measham, Benjamin L. Preston, Timothy F. Smith, Cassandra Brooke, Russell Gorddard, Geoff Withycombe, Craig Morrison, *Adapting to climate change through local municipal planning: barriers and challenges*, 16 Mitigation and Adaptation Strategies for Global Change 8, 889-909, (2011).

[284] Edward Vine, *supra* note 30, at 91.

[285] Jane Ebinger & Walter Vergara, *supra* note 2, at 42.

[286] Pierre Audinet et al., *supra* note 261, at 19.

[287] *Id.*

agriculture, domestic water supply and industry have to work in synergy with the electricity sector for agreeing on water use and other priority uses during heat waves.[288] High electricity-dependent industries should collaborate with the electricity sector in order to increase energy efficiency and lower peak demand during heat waves but also during normal temperature days in order to alleviate the grid as a whole and offer opportunities for economic development without further expansion of the electricity systems. Interconnections of sectors should also be considered for understanding vulnerability. For instance as the electricity sector becomes more and more dependent on information and communication technologies (ICT) for monitoring and control operations,[289] their roles and responsibilities during a heat wave should be clearly defined.

3.5.4 Transparency

Creating open and centralised pools of information can enhance effective investments and minimise research repetitions.[290] The dialogue between climate scientists, electricity decision makers, businesses and the public sector is very important for efficiency and reliability issues.[291] Knowledge that supports adaptation goals should be shared between different stakeholders to encourage further actions and behavioral change.[292] This requires shared knowledge to be "relevant, technically sound and user-friendly".[293]

3.5.5 Investment

Sufficient investment is essential for developing heat-resilient and energy efficient systems. Utilities and other stakeholders normally embrace cost-effective upgrades for electricity systems. However, investments to the electricity sector remain very low worldwide. In order to continue providing reliable electricity to end users, sufficient investments are necessary.[294] Experience so far indicates that with the right incentives within a stable investment environment, investors are ready

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[288] Jane Ebinger & Walter Vergara, *supra* note 2, at 42; S. Cutter et al. *supra* note 273, at 307.

[289] ADB, *supra* note 8, at 5.

[290] National Science and Technology Council, *supra* note 239, at 3.

[291] Jane Ebinger & Walter Vergara, *supra* note 2, at 57.

[292] UNEP 2006 *cited at* Jane Ebinger & Walter Vergara, *supra* note 2, at 57.

[293] Jane Ebinger & Walter Vergara, *supra* note 2, at 57.

[294] IEA, Tackling Investment Strategies in Power Generation, OECD/IEA, 3, 2007.

to compete with the needs of increased generation capacity in liberalized markets.[295] Lack of incentives combined with regulatory uncertainties can lead to under-investment and/or short vision investments.[296] It is critical for existing funds and resources to be used now on electric infrastructures due to the growing risk of ageing infrastructures and increasing demand.[297] Additionally, governments should continue to invest in research and development for energy efficient technologies and continue to financially support and facilitate innovation.[298] Only when technology is readily available, more efficient and cheaper, will decision makers in utilities and end users increase their technology investments. However, because technology is changing very rapidly decision makers might hesitate to invest immediately as certain technologies might become outdated soon.[299]

3.5.6 Complexity in Institutional Adaptation

Even though electricity companies and end users understand the benefits of efficient and reliable electricity supply they are not always willing to invest in an environment that lacks incentives to do so and/or regulations requiring action.[300] Thus, prioritizing adaptation measures within government agendas will define to a great degree the level of adaptive capacity of electricity systems. Yet, governments must work through multiple layers of complexity to successfully prioritize and address adaptation. First, as noted above, public and private agents may have conflicting objectives and motivations. The same issue exists also within institutions. Adaptation responses are not a natural procedure that depends only on the factor of risk. Actions are an outcome of the cost and benefits of investing in adaptation or continuing business as usual, and those costs and benefits may viewed differently by different actors operating at a single scale.[301] Thus, adaptation demands a collective effort to achieve the goals of different actors and

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[295] *Id.*, at 13.

[296] *Id.*, at 14.

[297] *Id.*, at 3.

[298] National Science and Technology Council, *supra* note 239, at 3.

[299] *Id.*, at 18.

[300] Jane Ebinger & Walter Vergara *supra* note 2, at 70.

[301] N. Adger, N. Arnell, E. Tompkins E, *Successful adaptation to climate change across scales*. 15 Global Environ Change 77-86, 80, 2005.

institutions, with long-term thinking about how to accommodate conflicting goals.[302] Second, governments have an even more complicated and unclear role in electricity systems due to the existence of both state and private ownership models. Governments have the role of a policy maker, regulator and service provider at the same time.[303] It is vital that governments have a clear and stable position on their adaptation strategies despite their ownership status in both regulated and deregulated markets. Finally, achieving policy coherence and integration of adaptation measures across scales poses another set of challenges. Responsibilities and roles are diffused between national or local actors and across sectors of governance.[304] National adaptation plans usually have a positive contribution for triggering regional and local level adaptation strategies for private and public agents.[305] Yet, local innovations add significant value to the overall effort. Adaptation should combine top-down and bottom-up approaches that complement each other and effectively address conflicting arenas. In order to achieve this, channels of communication, dialogue, information sharing and collective action are essential across scales.[306]

4. CONCLUSIONS

This study examined the impacts on the electricity sector by heat waves. Electricity generation, transmission, distribution and demand are affected by heat waves and existing systems are not designed to withstand high intensity events. The case studies researched showed that heat waves have different impacts in different circumstances. In France the vulnerability was an outcome of an overreliance on a single source for generating electricity – nuclear power that is affected due to water withdrawal and discharge restrictions. In California the ever-increasing demand for cooling was a main factor that caused electricity interruptions. In New York, the increased temperatures combined with high electricity demand challenged the efficiency of

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[302] *Id.*

[303] QUT, *supra* note 185 at 53.

[304] Lasse Peltonen, Sirkku Juhola, Philipp Schuster, *Governance of Climate Change Adaptation: Policy Review*, Baltic Sea Region Programme, 2007-2013, 4.

[305] *Id.*, at 10.

[306] *Id.*, at 4.

generation and supply systems. In Australia old and inefficient power infrastructures resulted in electricity shortages. In all cases there were significant human and economic losses and all events highlighted the need for adaptation. In these situations the majority of adaptation actions that did occur and have occurred since were embedded in a broader agenda of planning and development and they were not the driving force for policies and practice. Adaptation existed within a general framework of greener infrastructures, energy efficiency and climate change agendas. Extensive, dedicated heat wave strategies for electricity systems were not found. Better understanding and knowledge of those impacts is necessary in order to encourage actions that will aim to build more reliable and efficient electricity systems.

The study continued identifying several solutions for adaptation through the examined cases and literature. The adaptation solutions were distinguished in three categories: technological, behavioral and institutional. In these adaptation approaches it was found that technology advancement, technology adoption, awareness among stakeholders, collaboration, transparency and investment facilitation are all very important for successful adaptation. Willingness for actions is also a determining factor for building adaptive capacity. Based on the experiences to date it appears that post-shock entities are more willing to adapt, but again only if benefits of adaptation measures exceed generated costs. Also, adaptation can start from inexpensive solutions that require changes only in management practices of utilities and behavioral changes by end users and continue with more expensive actions that require systemic or technological change or even retirement of old units and complete replacement. The electricity sector must commit to long-term planning for future heat waves by re-conceptualizing and adjusting both management and management systems. Finally, governments of all levels require engagement, communication and open dialogue among them and other relevant stakeholders in order to facilitate, encourage and impose adaptation actions.