RD&D Needs for Energy System Climate Preparedness and Resilience

Workshop Summary

13-14 November 2013

IEA Experts' Group on R&D Priority Setting and Evaluation
Utrecht, The Netherlands

International Energy Agency

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its mandate is two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply and to advise member countries on sound energy policy.

The IEA carries out a comprehensive program of energy co-operation among 28 advanced economies,[1] each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency aims to:

- Secure member countries' access to reliable and ample supplies of all forms of energy—in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context, particularly in terms of reducing greenhouse gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organizations, and other stakeholders.

IEA Experts' Group on R&D Priority Setting and Evaluation

Research, development and deployment of innovative technologies is crucial to meeting future energy challenges. The capacity of countries to apply sound tools in developing effective national research and development (R&D) strategies and programs is becoming increasingly important. The Experts' Group on R&D Priority Setting and Evaluation (EGRD) was established by the IEA Committee on Energy Research and Technology (CERT) to promote development and refinement of analytical approaches to energy technology analysis, R&D priority setting, and assessment of benefits from R&D activities.

Senior experts engaged in national and international R&D efforts collaborate on topical issues through international workshops, information exchange, networking, and outreach. Nineteen countries and the European Commission participate in the current program of work. The results and recommendations provide a global perspective on national R&D efforts that aim to support the CERT and feed into analysis of the IEA Secretariat.

For information specific to this workshop, including the agenda, background information, and presentations, see www.iea.org/workshop/name,43381,en.html. For information on further EGRD activities, see www.iea.org/aboutus/standinggroupsandcommittees/egrd/.

This document reflects key points that emerged from the discussions held at this workshop. The views expressed in this report do not represent those of the IEA or IEA policy nor do they represent consensus among the discussants. This report has been prepared by the U.S. Department of Energy's Office of Climate Change Policy and Technology, in the Office of International Affairs, and may be consulted at http://www.energetics.com/resourcecenter/products/studies/Documents/EGRD-Climate-Resilience.pdf.

[1] Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Republic of Korea, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States; the European Commission also participates in the work of the IEA.

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Executive Summary

The IEA Experts' Group on R&D Priority-Setting and Evaluation (EGRD) convened a workshop on 13-14 November 2013 in Utrecht, The Netherlands, in support of the Forum on the Climate-Energy Security Nexus (the Nexus Forum), focussing on the technology RD&D aspects related to climate resilience of the energy system. Some forty participants met to discuss how climate trends are currently impacting energy systems and how to protect energy systems from future climate changes. Workshop participants identified climate change challenges, highlighted a broad sampling of activities underway in various countries and industries, and identified high-priority gaps and opportunities for RD&D planners. Particular emphasis was placed on opportunities for accelerating technology progress and reducing costs.

Attendees included selected experts from the Nexus Forum and representatives from the IEA energy technology network. In addition to EGRD national experts, the workshop sought input from RD&D decision makers, strategic planners, and program managers from industry concerned with energy systems and climate preparedness and resilience.

Overview

All energy systems, ranging from traditional fossil fuels to renewable energy, are vulnerable to the impacts of climate change. Increasing temperatures, decreasing water availability, extreme weather events, and sea level rise, separately or in combination, will affect important elements of nearly all energy systems. Projected impacts include damage to critical infrastructure, decreased power generation capacity, increased electricity demand, logistical challenges to the transport of critical goods, and other disruptions to a reliable supply of affordable energy. Some of these impacts will be localised, while others are likely to affect broad geographic areas. The interconnectivity of the energy sector increases the likelihood that local events will have wider repercussions, including cascading impacts on other sectors (e.g., transportation, communication, water, health). Industries with operations concentrated in vulnerable regions will be particularly susceptible to these impacts.

Current energy systems need to be strengthened and made more resilient. Future energy systems need to be designed and built to operate reliably under the full range of projected climate changes. Successful solutions necessitate a clearer understanding of the array of projected impacts, the greatest risks and needs for adaptation, and current opportunities to develop more climate-resilient energy technologies.

Current Efforts Underway to Build Climate Resilience of Energy Systems

Industry, government, and other entities are undertaking efforts to assess energy sector vulnerabilities to climate change and develop appropriate response strategies. The private sector has begun to conduct vulnerability assessments and, to develop and deploy climate resilience technologies. The oil and gas industry, for example, held workshops to help companies plan for projected climate impacts and build resiliency into their long-term business models. Entergy, a U.S.-based power and gas company, launched a project to quantify climate risks on the Gulf Coast and identify economically sensible and prioritised approaches to address them. EDF, a French utility company, is investing in dikes, moving its aerial lines underground and rescheduling planned outages for maintenance and refuelling to accommodate changing weather patterns.

Governments are also working to develop better climate data, making such data more available to local and regional authorities, improving decision making and climate response frameworks, identifying technologies for climate proofing physical infrastructure, and defining smart resilience strategies. Government efforts also focus on developing policy frameworks that remove market barriers and encourage market preparedness and resiliency. Research is underway to develop innovative climate-resilient technologies like green adsorption chillers, thermosyphon cooling, and heat absorption nanoparticles for coolants. While these efforts indicate a growing recognition of climate impacts, the pace, scale, and scope of these efforts is inadequate and must increase, given the widespread and pervasive nature of the challenge.

Major Barriers to Climate Resilience

Efforts to strengthen the climate preparedness and resilience of energy systems are severely hampered by the lack of supporting information, technologies, and policies. Climate change has produced fundamental shifts from historical experience. Previous assumptions need to be reconsidered and validated. Inadequate information on climate change, impacts, and interactions impedes the development of useful models and can contribute to ineffective or misinformed planning policies and response strategies. In addition, the risks and opportunities may vary by region and locality, significantly compounding the challenges of effective design and planning.

The failure to carefully consider climate change impacts in all aspects of energy project design, planning, and management presents a considerable hurdle to building resilience into energy systems. Energy practitioners, especially planners, must be encouraged to incorporate climate proofing in all decision-making processes. Climate response strategies need to be developed at every scale, from the entire system level down to the individual asset. Full buy-in on this strategy is essential—from top management to facility operator.

While some climate resilience technologies are being developed, most are still in their infancy. Stakeholders tend to have competing incentives, and no enabling framework has been established to guide energy or climate policymaking to support development of the needed technologies. Lack of a sound investment environment, relevant information, and suitable financial vehicles further impedes progress.

Approaches Needed to Build Climate Resilience and Preparedness

Society will be grappling with climate adaptation, specifically preparedness and resilience, for decades or even centuries. As a result, efforts to build resilience must consider actions to address both near-term and long-term needs, as climate change impacts can be expected to vary over time. A flexible, risk-informed approach will enable all stakeholders to adapt as new climate information and data are made available. New information will need to be rapidly translated into actionable plans and policies so that stakeholders can anticipate new challenges and act accordingly.

Climate resilience strategies must be tailored for implementation at the local and regional levels as climate vulnerabilities may vary by country and locality. While private companies will need to understand and address climate vulnerabilities, this process can be technically challenging, time-consuming, and data-intensive. Companies need both resources and expertise to clearly understand the risks to their assets and thoroughly assess appropriate actions. Communication of climate adaptation needs and strategies to both the public and private sectors will be critical in building support for policies and eliciting action.

To encourage innovation and accelerate implementation of climate resilience measures, governments must build enabling policy and institutional frameworks that support such efforts. In market-based economies, financial vehicles and incentives, like carbon prices, loan guarantees, subsidies, and similar instruments, can provide an important boost to building climate change resilience.

RD&D Needs

RD&D needs for building climate change resilience and preparedness will vary for different countries, regions, technologies, and energy systems. The workshop identified some overarching needs for technology development and for building enabling frameworks for climate resilience and preparedness.

Technology

RD&D needs differ for various energy technologies with a focus required on developing energy technologies that are more resilient to droughts, wildfires, storms, floods and sea level rise, including "hardening" of existing energy infrastructure (e.g., transmission and distribution lines, power plants, oil and gas refineries and offshore and onshore oil and gas platforms). Specific technology needs identified include the following:

- For thermoelectric power plant cooling systems (coal, natural gas, nuclear, geothermal, concentrated solar) and oil and gas production, improvements in cost-effective and more energy- and water-efficient technologies are needed, including enhanced water capture/reuse, and use of non-traditional waters.
- With an increase in intermittent renewable energy (solar, wind), developing resilient smart grid technologies is becoming increasingly critical. Smart grid technology needs include distribution automation, automated service restoration, robust communications systems, and advanced metering infrastructure (AMI) integrated with outage management systems (OMSs).
- Technologies for farming climate-robust crops that can increase biofuel production is another area that requires further investigation.
- Technologies that help in preventing damage from an extreme weather event or assist in damage assessment need to be developed as well. These include unmanned aerial vehicles (UAVs), selective undergrounding of transmission and distribution lines, and vegetation management.

Enabling Frameworks

Successful development and deployment of advanced technologies in this area require supportive and enabling frameworks that can assist in ensuring that the technologies are effective, affordable and accessible to the energy sector. Specific needs identified in this area include:

- Holistic approaches to explore and address needs for technology solutions and related RD&D, made available to and adapted to support all stakeholders (government, private, and financial sectors).
- Models that illuminate impacts and vulnerabilities and provide meaningful specificity at the regional and local levels across a range of varied energy systems.
- Risk assessments that cover entire energy systems and take into account the interconnected nature of current energy systems with other sectors.
- Metrics to measure progress and common definitions for such terms as climate preparedness and climate resilience are needed to drive improvements in climate resilience of energy systems.
- Cost-benefit analyses to evaluate climate resiliency measures in existing and new systems (e.g., retrofits in power plants) will point to the most effective risk reduction investments.
- Tools to assist in the incorporation of climate impacts and vulnerabilities into the design, planning, and management procedures of vulnerable energy system components.

Roles of the Different Actors

To address energy sector climate vulnerabilities and develop effective response strategies, action is required in both the near-term and long-term from all stakeholders: government, the private sector, academia, and others. Companies have already started undertaking vulnerability assessments and implementing win–win, “no regrets” measures. Such measures could be undertaken at a broader scale and at an accelerated pace. Government and the private sector could expedite RD&D activities by identifying the top priorities for climate resilient investments, developing enabling policies and incentives, and developing better analytical and technical information. Government could play an important role in developing and disseminating tools and information to support such activities.

Conclusions and Path Forward

The workshop identified critical RD&D needs related to the climate vulnerabilities of energy systems and associated climate resilience technologies and strategies. Results and presentations of the workshop will be made available, broadly, and key findings will be communicated to the IEA Committee on Energy Research and Technology, and the IEA energy technology network to help inform the development of national RD&D agendas on this topic.

In the long term, there is a need for stakeholders to develop robust resilience and preparedness strategies with more innovative and transformative solutions. An emphasis on basic and applied energy-related R&D can help to ensure that relevant technologies and climate response strategies are developed. Expanding communications into regular dialogues or other mechanisms will encourage information exchange between governments and institutions working in this area. Establishing new policy and institutional frameworks can incentivise development of solutions and broaden the suite of advanced technologies. Further, such frameworks can spur deployment and accelerate improved resilience in the design, siting and operation of energy infrastructure. The key is to implement measures that promote the integration of energy sector climate risks into all levels of system planning.

The workshop concluded by noting that relevant RD&D activities need more focus and a concerted push by the international community. Organised sharing of knowledge; ensuring that information is public and accessible; and establishing partnerships among governments, private sector and academia can mobilise the attention and resources needed. A strong and meaningful RD&D agenda can give rise to solutions that will help avoid high consequences and save costs in the long term, while assuring a safe, affordable, sustainable and secure energy system for the future.

Background

Rationale

Local effects of the changing global climate are increasingly apparent and well documented. Many of the changes are accompanied by heightened risks and vulnerabilities for energy infrastructure. The consequences of these changes, including extreme weather events, when combined with vulnerable energy systems, result in large-scale societal impacts. These impacts are increasingly disruptive and costly. As a result, it is now widely accepted that strategies to address climate change must focus on both mitigation and adaptation.

For energy infrastructure, this means identifying actions to enhance climate preparedness and expanded efforts to develop and deploy clean, sustainable, and climate-resilient energy technologies. Extreme weather events threaten electricity generation and transmission and distribution, as well as oil and gas production and delivery. Warmer air, warmer water temperatures, and heat waves result in short-term peaks in energy demand for cooling, while at the same time diminishing electricity supply. Droughts affect water availability required for cooling thermoelectric power plants. Sea level rise and flooding also pose risks for energy infrastructure, as evidenced by 2012's Hurricane Sandy, which caused more than $65 billion (in U.S. dollars, or USD) in damages along the East Coast of the United States and resulted in the loss of electricity for more than 8.5 million people.

Some of these effects will occur across all regions, while other effects may vary more by region, but impacts will occur across all regions and energy technologies. In addition, the impacts on the energy sector will in turn impact other dependent sectors, including communications, transportation, and health.

Thus, it is becoming critically important to understand the impact of climate change on existing energy technologies, prioritize risks and adaptation needs, and identify opportunities to develop more climate-resilient energy technologies. These efforts involve assessing the vulnerabilities of existing technologies, monitoring activities to improve them, and identifying the relevant high-priority energy technology research, development and demonstration (RD&D) gaps and opportunities.

Current Activities

Significant actions are being taking by the public and private sector to assess vulnerabilities to the energy sector and develop response strategies. These efforts include assessment of the physical and economic vulnerabilities of the energy sector, adaptation planning efforts, development and deployment of energy technologies that are more climate-resilient, and development of policies that can facilitate these efforts. The pace, scale, and scope of these efforts, however, is inadequate and must increase, given the challenge.

In November 2012, the IEA initiated a dialogue through its Climate–Energy Security Nexus (the Nexus Forum) on energy security impacts of climate change. Participants included representatives of a select group of companies from the energy and manufacturing sectors, other sectors such as insurance and banking, and governments. The purpose was an exploratory discussion on the threats climate change posed to energy systems. The International Energy Agency (IEA) has expanded upon this initial meeting with a subsequent meeting in June 2013 focused on issues for cities and for the insurance industry, a third forum in October 2013 focused on electricity, and the November workshop on climate resilience discussed in the present report.

Introduction

In conjunction with the Nexus Forum, the Expert Group on Energy R&D and Priority Setting (EGRD) hosted a workshop on 13–14 November 2013 in Utrecht, the Netherlands, that focused on the technology RD&D aspects related to climate resilience of the energy system. Participants discussed how climate trends are currently impacting energy systems and how to protect energy systems from future climate changes. Workshop participants identified climate change challenges, highlighted a broad sampling of activities underway in various countries and industries, and identified high-priority gaps and opportunities for RD&D planners. Particular emphasis was placed on opportunities for accelerating technology progress and reducing costs.

Attendees included selected experts from IEA's Climate–Energy Security Nexus Forum and representatives from the IEA energy technology network: Working Parties, Experts' Groups, and the Implementing Agreements. In addition to EGRD national experts, the workshop sought input from RD&D decision makers, strategic planners, and program managers from industry concerned with energy systems and climate preparedness and resilience. Key questions discussed by participating technology experts include the following:

- What components of your country's energy system have shown to be vulnerable to climate change and extreme weather? Are there data available?
- Given increasing climate change impacts on the energy system, what are the key steps towards developing and deploying climate-resilient energy technologies, and increasing climate preparedness and resilience in the energy system for different zones (e.g. coastal, semi-arid/desert, permafrost)?
- What are the major barriers inhibiting greater development and deployment of climate-resilient energy technologies? Can these be characterized by categories such as (a) policy, (b) socio-economic, and (c) technical and/or cost?
- What are the most important actions that IEA member countries might take to address barriers and enhance climate preparedness and resilience of the energy systems?
- What are the highest priority energy technology RD&D gaps and opportunities to address energy system vulnerabilities?
- What is the proper role of government versus the private sector in developing, demonstrating, and deploying climate-resilient and flexible energy technologies?
- What programs, policies, or incentives are needed to accelerate the pace at which climate-resilient technologies are developed and/or deployed?

Additional questions addressed by workshop experts include the following:

- How would you define climate preparedness and resilience for energy systems?
- Is climate resilience a factor in prioritization of RD&D portfolios and funding?
- What tools, data, and information would be helpful in evaluating climate preparedness and resilience?
- What lessons can be learned from the private sector, or from public–private partnerships, in developing response strategies and deploying climate-resilient energy technologies?
- What are the elements of an effective, integrated framework for monitoring, evaluating, and communicating progress towards a climate-resilient energy system?

- What approaches would be most effective to communicate results of energy sector vulnerability assessments to climate change, and to inform decision-making for prioritization or restructuring of research investments and related policies, and achieve desired outcome?

Report structure

The report provides an overview of energy sector vulnerabilities to climate change followed by a summary of presentations delivered by representatives of selected countries. The presentations cover climate resilience strategies for energy production, distribution, and demand; RD&D activities, gaps, and opportunities; and thoughts on frameworks for accelerating RD&D investment in climate-resilient energy technologies. Discussion and conclusions follow the presentation summaries. Appendices to the report provide a list of acronyms, workshop speakers, the meeting agenda, and some useful references.

Energy Sector Vulnerabilities to Climate Change: An Overview

A Long-Term Challenge

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) recently reconfirmed that the warming of the climate system is unequivocal. The report states that "the atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen." A study, undertaken by MIT in 2005 (Figure 1), found that even when greenhouse gas (GHG) emissions are curtailed, their effects on the environment will continue to be felt for hundreds, if not thousands, of years. As a result, climate adaptation, and building climate resilience of our systems, will continue to be a challenge that our society will need to address for the foreseeable future.

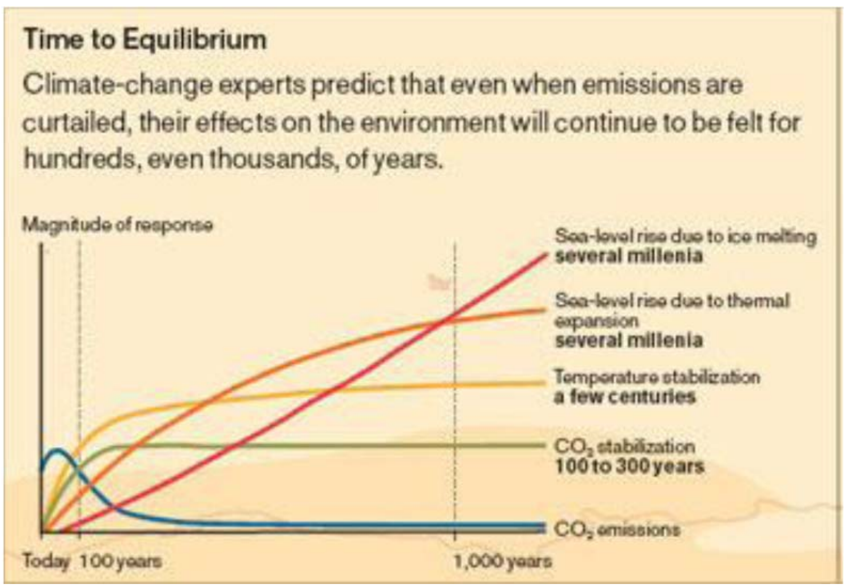

Figure 1. Time taken to reach an equilibrium state can range from decades to centuries

Source: Jones-Thompson, Maryanne, "Engineering Climate", Technology Review, MIT, March 2005

Implications on the energy sector in the near- to mid-term

As climate-related events increase in frequency and intensity, an issue of growing importance is the climate vulnerability of the energy sector. In particular, it is essential to get a better understanding of the impacts of climate change on energy demand, supply, infrastructure, and related assets.

Climate change is expected to affect every aspect of the energy system—oil and gas production systems, thermal and renewable energy systems, electric grids, and fuel distribution systems. Increased frequency and magnitude of weather-related events, changing patterns of precipitation and water availability, increased air temperatures, and increasing sea levels will all have impacts on a country's energy systems. Projected impacts could include damages to critical infrastructure, decreased power production and generation capacity, increased electricity demand, decreased efficiency in transportation of critical goods, and other disruptions. Having a better understanding of the sector's vulnerabilities, and the measures that it can undertake to enhance its climate preparedness and resilience, will be crucial for a country's economic prosperity. Energy sector vulnerabilities will be unique to every country and locality, and while international energy and economic interdependencies reflect a need for cross-border collaboration, implementation of climate preparedness measures will be best undertaken at the local or regional level.

Climate resilience strategies as varied as the energy systems they are designed to protect will need to be deployed. For example, energy demand can be reduced by investing in energy-efficient infrastructure, appliances, and equipment; freshwater availability issues can be addressed by recycling water or using brackish water for power plant cooling and other processes; and levees, dikes, or flood-proofing can be built into systems to build coastal resiliency of energy assets. Climate-resilient energy technologies will need to be developed while increasing the climate preparedness of the current systems. First and foremost, the RD&D needs of this challenge will need to be identified. The major barriers deterring development of climate-resilient energy systems will need to be addressed. Most importantly, being armed with better information will help in the design and planning phases of such systems, and partnerships among governments and the private sector can enhance the RD&D of climate-resilient energy technologies. Policies, programs, and incentives that build climate resilience in the energy systems will need to be encouraged.

Climate Energy and Security Nexus: Improving Energy Resilience to a Changing Climate

Takashi Hattori, Unit Head, Environment and Climate Change Unit, International Energy Agency

- Link to presentation slides: http://www.iea.org/media/workshops/2013/egrdutrecht/1.Hattori.pdf

From 1980 to 2011, the world experienced an increasing number of climate-related disasters: 3,455 floods, 2,689 storms, 470 droughts, and 395 extreme temperature events. An issue of growing importance is the impact of the changing climate on world's energy systems—in particular, energy demand, supply, infrastructure, and related assets—and the measures that the energy sector can take to enhance its climate resilience. The "Nexus Forum," an IEA initiative established in November 2012, provides a platform to consider this critical issue.

The Nexus Forum recognizes that the energy sector will be impacted by climate change. The Forum's first workshop focused on implication of climate change for energy suppliers and users. Key takeaways from the workshop included lack of data to quantify the impacts of climate change, need for regional and local approaches, importance of energy sector's flexibility and responsiveness, lack of a narrative on energy system resilience, and the need for a systematic and pragmatic approach.

The Nexus Forum has also hosted workshops on cities and the insurance industry, and the resilience of the electricity sector. Participants in the first workshop highlighted the importance of a fundamental shift in mindset, strong local action plans that can guide infrastructure planning, and development of new risk models. The participants also cautioned that climate change can cause substantial gross domestic product (GDP) decline if adequate insurance is not made available. In the electricity sector resilience workshop, the main takeaways were the importance of communication, building upon synergies between energy security and climate resilience, and quantification of energy and financial impacts for sound decision making. Action areas and RD&D needed to address the challenges were discussed (Figure 2).

Figure 2. Spheres of action to that are needed to address climate vulnerability

Energy Preparedness and Resilience: A Netherlands Perspective

Pieter Boot, Head of Department, Netherlands Environmental Assessment Agency, Netherlands

- Link to presentation slides: http://www.iea.org/media/workshops/2013/egrdutrecht/2.Boot.pdf

The National Adaptation Strategy of 2007 lays the policy framework for addressing climate change impacts in the Netherlands. This framework is implemented through the 2010 Delta Programme on Water, which was adopted without opposition in 2011. In 2013, the government released a climate report that takes a joint approach to mitigation and adaptation. As per this report, the government plans to undertake risk analyses for the transport, energy, agriculture and fisheries, and other sectors. This updated adaptation strategy will be integrated with the Delta Programme and presented before 2017. Table 1 gives an overview of projected impacts of climate change on the energy supply in Europe.

Climate vulnerabilities in the energy sector exist primarily in the offshore wind sector and the grid networks, which are mainly affected by floods. While The Netherlands has no formal adaptation approach for its energy sector, some trends are noticeable. Due to local opposition, high-voltage grid networks were placed below the ground. Following a storm in 2010 a comprehensive assessment was conducted by the operator and in the subsequent storm in 2012, no substantial blackouts were experienced. The main challenge remains smart grids, decentralization of the grid, and grid resilience. New infrastructure along the coast has started taking into account sea level rise estimates over the next 50 years. However, progress in some areas remains slow. For example, sea level rise remains the responsibility of investors in offshore wind development.

Table 1. Projected impacts of climate change on energy supply in Europe

Qualitative link between technologies and climate change effect

Technology	Δ air temp.	Δ water temp.	Δ precip.	Δ wind speeds	Δ sea level	Flood	Heat waves	Storms
Nuclear	1	2		-	-	3	1	-
Hydro	-	-	2	-		3	-	1
Wind (onshore)	-	-	-	1	-	-	-	1
Wind (offshore)	-	-	-	1	3	-	-	1
Biomass	1	2	-	-	-	3	1	-
PV	-	-	-	-	-		1	1
CSP	-	-	-	-	-	1	-	1
Geothermal	-	-	-	-	-	1	-	-
Natural gas	1	2	-	-	-	3	1	-
Coal	1	2	-	-	-	3	1	-
Oil	1	2	-	-	-	3	1	-
Grids	3	-	-	-		1	1	3

Note: 3 = Severe Impact, 2 = Medium Impact, 1 = Small Impact, - = No Significant Impact;

Source: Ecorys, Investment needs for future adaptation measures in EU, 2011

The primary issue related to climate change adaptation in the Netherlands is the risk of flooding by sea and rivers. Climate models show that from 1990 to 2100, sea levels could rise 35 to 85 centimeters (Figure 3). The Rhine River is expected to have instances of high discharge 4 to 40 times more often than at present. Cost estimates of climate change impacts in Central Northern Europe—mainly due to flooding—show that losses up until 2080 could amount to 1.5% to 1.7% of GDP. For the Netherlands, while climate adaptation needs to be addressed, the focus will remain on mitigation.

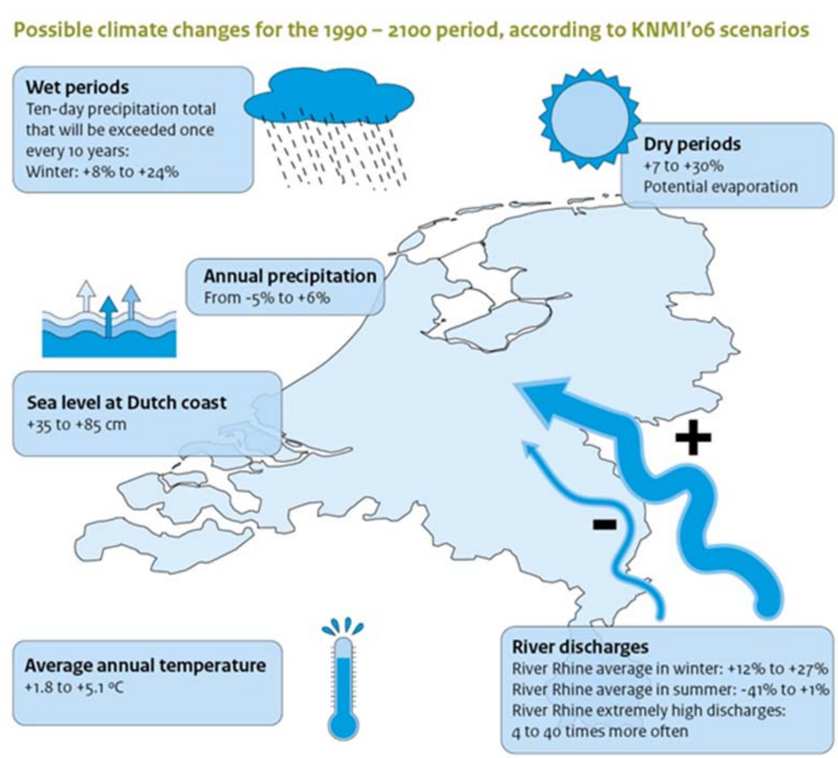

Figure 3. Examples of projected climate impacts in the Netherlands

U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather

Craig Zamuda, Senior Advisor, Office of Climate Change Policy and Technology, U.S. Department of Energy, United States of America

- Link to presentation slides: http://www.iea.org/media/workshops/2013/egrdutrecht/3.Zamuda.pdf

In July 2013, the U.S. Department of Energy (DOE) released a report entitled *U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather*. The purpose of the report is to provide an objective analysis of vulnerabilities to the U.S. energy sector and identify opportunities for future actions. The report recognizes that climate change impacts are already affecting the U.S. energy sector; and the current pace, scale, and scope of climate preparedness and resilience efforts are insufficient and need to be escalated. Governments can play a critical role by partnering with the private sector, academics, and other stakeholders to help enhance RD&D of climate-resilient energy technologies, foster enabling policies at all levels that encourage building resiliency in our energy system, and provide technical information and assistance. The report describes the vulnerabilities of the energy sector to various impacts of climate change, including increasing temperatures, water availability, storms, flooding, and sea level rise (Figure 4).

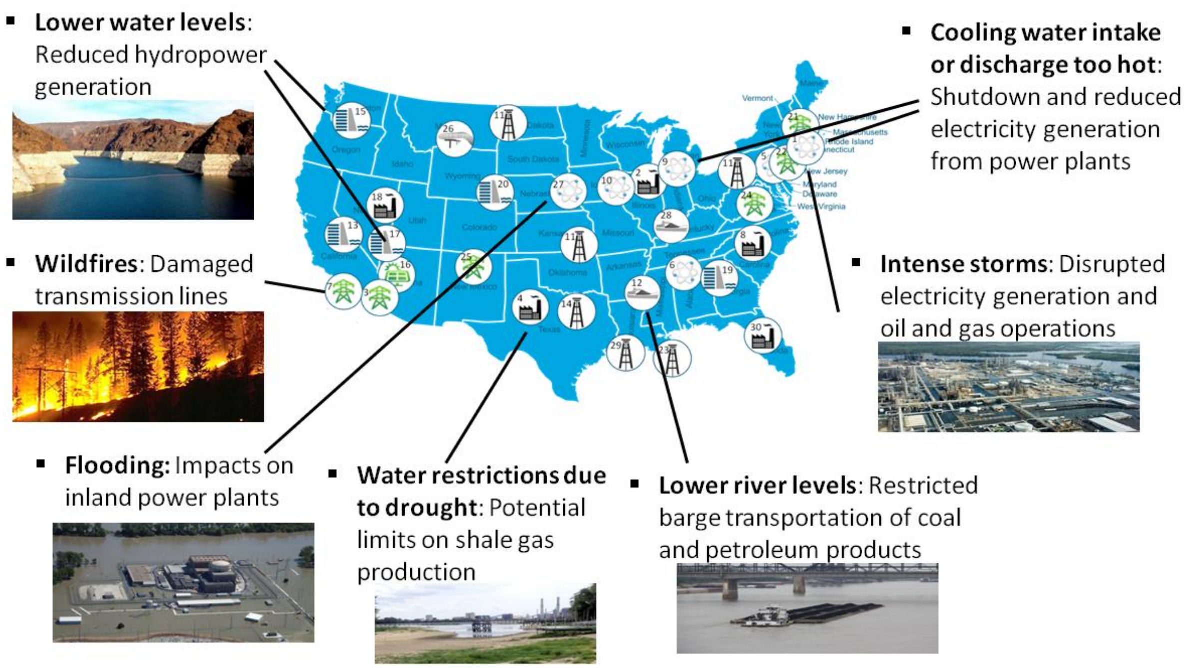

Figure 4. Recent events illustrate U.S. energy sector vulnerability to climate conditions

Over the last 100 years, average temperatures have increased across the United States. Heat waves and wildfires have become more intense and frequent, and a decrease in sea ice cover has been observed in the Alaskan Arctic. All these climatic changes are affecting the U.S. energy sector by increasing electricity demand, decreasing available thermoelectric generation capacity and efficiency, reducing transmission efficiency, and damaging critical infrastructure.

Similarly, changes in precipitation, more frequent and severe droughts, lower summer stream flows, and declines in ground and surface water levels can affect the energy sector. Impacts include reductions in available generation capacity, decreased bioenergy production, impacts on oil and gas production, and decreased efficiency in transportation of critical products (e.g., crude oil, coal, and petroleum products).

Additional climate events that are being felt by the U.S. energy sector include rising sea levels, more intense hurricanes, and increased flood magnitudes. Resulting impacts include increased risk of damage or disruption of coastal and offshore infrastructure; greater risk of damage to electric transmission and distribution lines; and greater risk to inland thermoelectric facilities and to rail and barge transport of crude oil, petroleum products, and coal.

DOE plans to develop a response framework that will further develop tools to address climate impacts for the energy sector. The main goals of the framework will be to enhance research, development, demonstration and deployment of climate-resilient energy technologies (Figure 5); develop enabling policies to remove market barriers and encourage building resiliency; provide assistance and technical information; and partner with stakeholders. These goals will be achieved through various actions, including using existing mechanisms (such as national laboratories) to support efforts; examining innovative and effective public policies to support and replicate on a national scale; facilitating access to higher resolution data, models, and tools; and developing guidance and best practices for energy system resiliency. DOE also plans to work with states and the private sector to build partnerships.

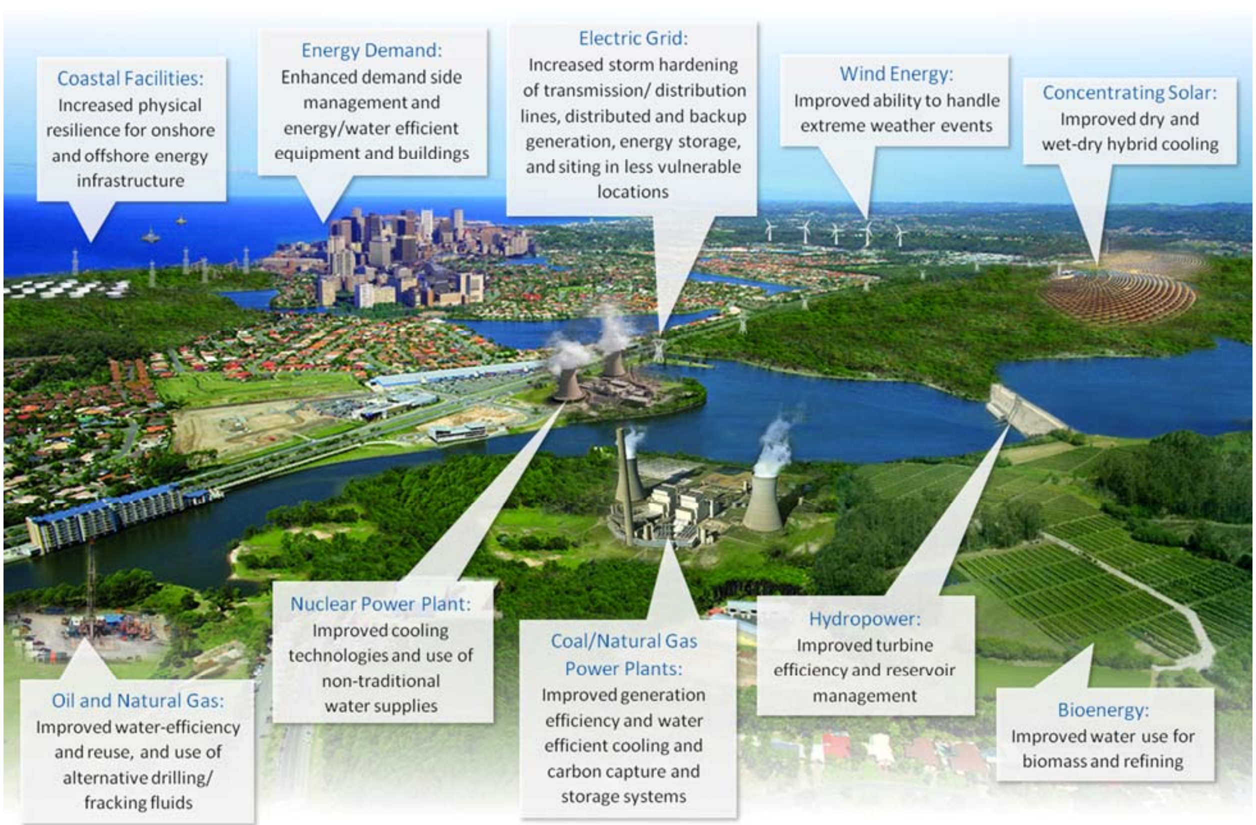

Figure 5. Illustrative opportunities: building a climate-resilient energy system

Climate Change Impacts on Renewable Energy Sources in the Nordic and Baltic Countries until 2050

Arni Snorrason, Director-General, Icelandic Meteorological Office, Iceland

- Link to presentation slides: http://www.iea.org/media/workshops/2013/egrdutrecht/4Snorrason.pdf

The Nordic "Climate and Energy Systems" Project is a part of the Nordic Energy Research's 2007–2010 Strategy and Action Plan. The primary objective of this project is to improve the decision framework of the energy sector with regard to climate change impact on renewable energy resources and the energy system. With a focus on hydropower, wind energy, and biomass, the € 2.15 million research program was supported by Nordic Energy Research and the Nordic energy industry. The program was followed up by the 2009 to 2014 Top Research Initiative, which has a € 53 million budget. The project has eight focus areas: statistical analysis group; climate modelling and scenarios group; hydropower, snow and ice group; hydropower and hydrology group; wind energy group; biofuels group; risk analysis group; and energy systems analysis group.

The statistical analysis group focuses its work on future climate scenarios through studying patterns of change in historical data. The group conducts trend analysis of various climate parameters for individual countries, changes in the occurrence of extreme events, and interactions between atmospheric processes and aspects of the energy sector. For example, a study in Sweden shows the time series for runoff and temperature between 1901 and 2009, highlighting changes to the climate system.

The climate modeling and scenarios group uses output from global Atmosphere Ocean General Circulation Models (AOGCMs) to forecast the climate of the Nordic region. The study developed regional climate scenarios at 25-kilometer resolution as well as high-resolution climate change scenarios at 1 to 3 kilometers. The probability of climate variability was analyzed for the period from 2010 to 2050 and the impact-relevant indices.

The hydropower, snow and ice group used the climate scenarios developed for Scandinavia and Iceland to model future changes in glacier volume and melt water delivery from glaciers. Scientists concluded that many glaciers and ice caps, with the exception of the Greenland ice sheet, will likely disappear in the next 100 to 200 years; and runoff from ice-covered areas could increase between 2020 and 2051, which can have huge impacts on hydroelectric power plants.

The same climate scenarios were used by the hydropower and hydrology group to predict runoff changes and to investigate their impact on hydropower with respect to production, dam safety, lake and river regulation, and flooding risks. For example, one of the studies focuses on five areas in Finland where the scenarios indicate a 5% to 10% increase in annual runoff and a clear increase in winter runoff. The group has also mapped the changes in 100-year floods in Sweden, comparing the 1963–1992 time period to 2021–2050. The group concluded that hydropower systems in the Nordic and Baltic regions will definitely be affected by climate change; opportunities for hydropower production will increase, but there will be considerable uncertainty and regional variability.

The wind energy group modeled future wind climates, analyzed climate change impacts of extreme wind, and contributed to forecasts of the Nordic electricity system's development in the coming 20 to 30 years. The biofuels group focuses its work on evaluating the potential production of forest biomass for energy and understanding the natural variability and predictability of bioenergy production.

The risk analysis group provides the tools required to enable decision making in an increasingly uncertain environment. The group is focused on developing a risk assessment framework (RAF) for the energy sector and providing support for adaptation planning efforts.

The energy systems analysis group ran simulations of the electricity system in 2020, quantifying changes in generation of and demand for electricity resulting from changing climatic conditions. Results indicate that hydro production is likely to replace thermal production and that there will be more exports (and fewer imports) to continental Europe.

A specific study in Iceland found that increased runoff could translate to a 20% increase in potential energy in river flows of existing hydropower plants by 2050 (Figure 6). These findings are being used for redesign and upgrade of current hydropower plants. Operations and planning of hydropower in Iceland is increasingly being based on scenarios rather than past statistics, and this approach has already generated operational and financial benefits.

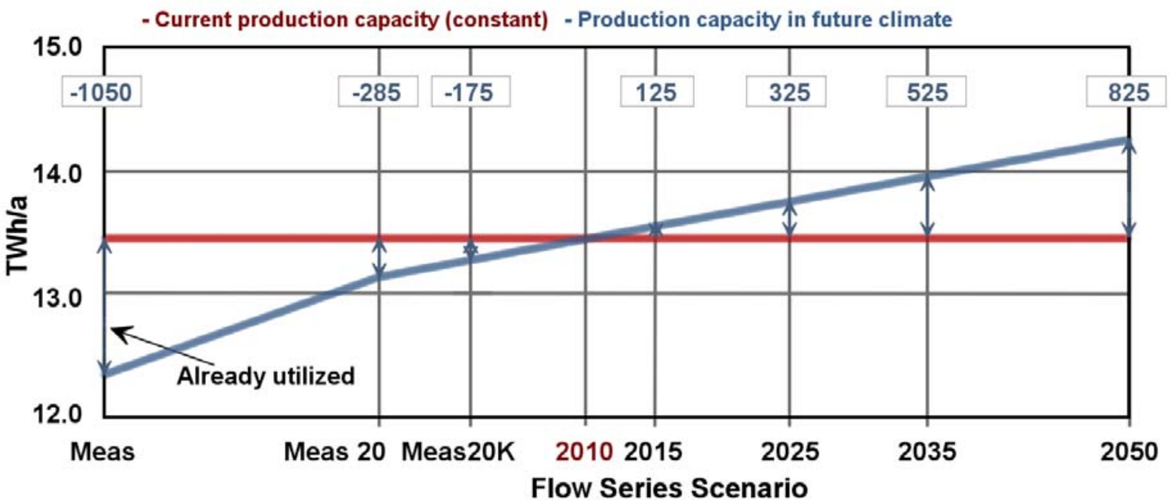

Figure 6. Because of a warming climate, hydropower production in Iceland may increase.

The numbers in boxes show the difference between 2010, future, and past in GWhe/a.

Climate Resilience Strategies in the Energy Production Sector

Building climate preparedness and resilience of energy production systems will require adopting strategies by governments, private sector and other stakeholders. Climate impacts in certain industries will be felt more acutely than in others, especially where a majority of the operations are in regions that will experience multiple climate impacts, for example, the oil and gas industry. Resilience strategies should be tailored for individual technologies. For example, solar and wind equipment should be made more resistant to extreme weather, and wind turbines should be dispersed over a larger geographical region. Climate preparedness needs vary at the local level, and assessments should be made accordingly.

Key consideration should be given to incorporating climate forecasting in systems management and planning processes. Integrated modeling for whole systems and regional markets will enable energy practitioners to better understand the challenges that the sector is facing, and it will give them the ability to better design and plan their climate resilience strategies. Climate proofing should be mainstreamed, and climate risk considerations should be integrated in all decision making processes.

Private sector engagement will be crucial in ensuring that the energy systems of the future are climate-resilient and climate-proofed. Adoption of such measures has been slow to date, as the energy sector continues to improve understanding of climate change's implications for operations and assets. RD&D needs for the private sector include developing modeling scenarios that enable a better understanding of its climate risks, conducting cost–benefit analyses of potential climate-resilient strategies, and developing planning and management practices to integrate climate considerations in day-to-day operations.

Integrating Climate Resilience in Renewable Energy Investments in the North Sea

Kirsten Halsnaes, Professor, Management Engineering, Technical University of Denmark (DTU), Denmark

- Link to presentation slides: http://www.iea.org/media/workshops/2013/egrdutrecht/5.Halsnaes.pdf

Renewable energy production is increasing in the North Sea region and is expected to take over fossil energy by 2050. For example, offshore wind farm development is growing at a rapid rate in the region. Renewable energy systems of the future will need to cope with both climate change and extreme weather (Table 2).

Integrated systems will have additional challenges in the case of extreme weather events. For example, synchronic shocks can have a system-wide impact; storms can hit several plants and sources, including nuclear and thermal, with wide repercussions. Strategies to cope with climate change should be for individual technologies and at the system level. For example, when considering dam construction for hydropower generation, the private sector should take into account the extreme and mean values of climate forecasts during the project planning phase that could alter the availability of water. Wind energy development should be spread over a large geographical base, and construction should be strengthened to withstand extreme events. Solar power panels should be made more resistant to hail, storms, and precipitation, and climate-robust crops (e.g., drought-resistant) should be introduced for biofuel production.

Table 2. Key climate vulnerabilities of renewable energy systems

Renewable Energy	Climate Change	Extreme Weather Events
Hydropower	Increases/decreases in potential Changes in seasonal availability	Damages to dams
Wind Power	Less frequent icing Dust from precipitation Flooding at coastal sites	Material damage due to storms
Solar Power	Lower efficiency of photovoltaic (PV) with higher temperature Higher efficiency of Solar Thermal Heating (SH) with higher temperatures	Material damage due to storms, hail, and heavy precipitation
Biofuels	Changed productivity and new crops	Loss of harvest due to draught and storms

At the system level, climate change forecasts should be included in system management and planning, integrated modeling should be conducted for the whole system and regional markets, and energy storage facilities should be created. Uncertainty should be factored in to account for low-probability and high-consequence events. Smart Energy Systems that have high shares of fluctuating energy pose their own unique challenges related to resilience and these will need to be addressed accordingly.

Markets are a major coping mechanism with idiosynchronic shocks on renewable energy sources, but cross-national climate proofing should be considered as well. Public–private partnerships need to consider climate risks in projects, and supply security insurance should be considered.

Additional research is needed to further understand how climate proofing can be mainstreamed, and climate science should be pushed further to enable answering questions such as the probability of extreme weather events.

Petroleum Industry: Adaptation to Projected Impacts of Climate Change

Jan Dell, Supply Chain Sustainability, ConocoPhillips, United States of America

- Link to presentation slides: http://www.iea.org/media/workshops/2013/egrdutrecht/6.Dell.pdf

Practitioners in the oil and gas industry need to be concerned about climate change impacts since a majority of the industry's projects and operations are in areas that will be affected by sea level rise, ocean acidification, shrinking snow cover, and increasing temperatures. It is also an industry that needs large amounts of water for its operations. Figure 7 gives an overview of the impacts of climate change on the industry.

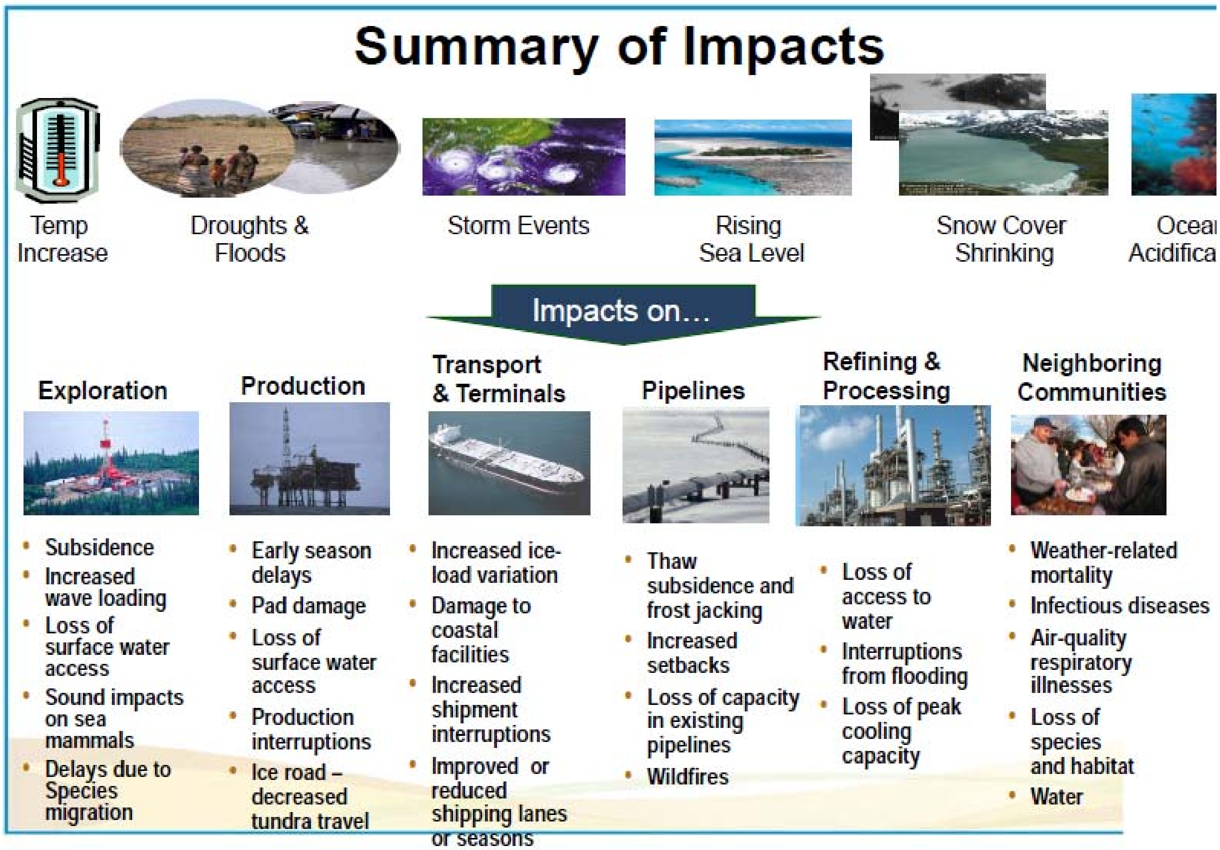

Figure 7. Impact of climate change on oil and gas industry

The U.S. Security and Exchange Commission issued a guidance identifying four areas companies need to consider when assessing whether climate-related disclosure is required under its rules. One of the four areas is "physical risks of floods and other natural disasters that may result from climate change."

In 2009, a consortium for the oil and gas industry conducted workshops to assess the global oil and gas value chain to enable companies to plan for the projected climate impacts and build resiliency into their long-term business models. The main finding from the workshop was that adaptation planning identifies "no-regret" actions and promotes cost-effective resiliency in operations. Physical climate change impacts are local, and projects are unique; as a result, adaptation assessments must be performed at the site level.

A good example of how an industry has built resiliency to climate impacts is the geographical diversification away from coastal and off-shore fossil sources to increased onshore shale gas and oil production. For power plant retrofits, moving away from coal to increased gas combustion and construction of new gas power plants results in lower water intensity, dry cooling, and use of municipal effluents.

Building Climate Resilience Strategies: An EDF Perspective

Jean-Yves Caneill, Head of Climate Policy, Electricité de France, France

- No link to presentation slides available

Electricité de France (EDF) is the largest power producer in France, producing 643 terrawatt hours electric per annum (TWhe/a), at 117 grams of carbon dioxide per kilowatt hours electric (CO_2/kWhe) (2012). About 82% of EDF's electricity is generated from nuclear energy; 19 plants are in operation, of which 14 are located along rivers and 5 are situated along the coast. In total, 58 nuclear reactors are operated with a capacity of 900 to 1,450 megawatts electric (MWe), with both coastal and river plants.

Climate change affects both energy supply and demand. Extreme temperatures result in increased energy demands, grid networks can be affected by snow and ice, and hydropower is dependent on precipitation patterns. The renewable energy sector and the nuclear sector are affected as well.

Climate change needs to be integrated into management forecasting, from the beginning until at least three to five years into the future. Incorporating climate change factors in the design phase becomes important too, especially when designing infrastructure and electric facilities with lifetimes of over 40 years. Key questions that arise relate to the use of the precautionary principle in future investments, use of probability functions based on historical values as opposed to future climate forecasting, and the need for detailed examination of extreme values.

EDF's approach to addressing climate change has evolved over the last few decades. What started off in 1990 as an activity primarily focused on meteorological data has now morphed into working with others internationally on climate modeling and other aspects of climate change. EDF's response to climate change has two major approaches: the climate hazard plan and the climate adaptation plan.

The evolution of EDF's climate response strategies can be tracked through the years in parallel with extreme weather events. The Lothar Storm of 1999 highlighted the need for maps for reinforcements, as well as the probabilistic design of transport lines. The heat wave of 2003 established the need for a permanent climate hazard plan. The climate hazard plan has four aspects: preparation, anticipation, communication, and crises management preparedness. In employing this approach, EDF aimed at ensuring safety of its people and goods, while securing power supply.

EDF's climate adaptation strategy has a four-pronged approach: adapting existing assets to climate change, preparing new assets, emergency preparation, and R&D on climate change impacts. EDF has begun adopting climate response strategies into its operations. These include mainstreaming climate impacts into the design of future infrastructure; enhancing climate resilience to extreme events using the climate hazard plan; and preventing extreme events from having catastrophic impacts.

EDF further builds its adaptation strategy on two concepts: resilience and resistance. Resistance is defined as the capacity of its installations to resist climate hazards, and resilience is defined as the capacity of its operation teams to face extraordinary events to guarantee safety of its equipment and services to its customer. The latter includes returning to normal service in the shortest possible timeframe.

To build resistance, EDF has decided to move its aerial lines to underground lines and to invest in dikes for certain power plants. To build resistance of its operations and assets, EDF is in the process of creating FIRE (intervention force on electricity networks, manpower, and equipment) and FARN (intervention force on nuclear plants) for facing extraordinary events. In all these cases, cooperation from the public authorities is required.

Over the years, a permanent group has been established comprising EDF and administrative authorities to anticipate and address issues related to heat waves, for example, anticipating possible regulation of heat release in rivers. EDF has also been actively contributing to the national adaptation strategy, focused on the importance of adapting existing and future infrastructure to climate change and advising on regulation.

EDF found that, in some hot summers, increased temperatures in France caused the river water temperatures to rise such that compliance with warm water release regulation would necessitate to stop some units. This resulted in the plants situated along the river to be disrupted during a period that plants along the oceans were shut down for regular maintenance. Learning from this experience, EDF has deviated from its prior practice and now keeps its plants along the ocean operational in summer and shuts down the ones located along the river for maintenance at that time of the year.

Through its experiences addressing climate change, EDF has recognized the necessity to further invest and develop R&D in this area. EDF has been developing R&D with the following focus areas: environmentally oriented tools, improving generation system and planning optimization tools, and investigating long-term climate consequences.

EDF's primary challenge related to climate change is the increased demand due to heat waves that results in lower power plant efficiency, creating considerable economic losses. A key objective is to undertake a financial assessment of potential adaptation measures to climate change that will focus on the risk of power plant unavailability, as well as a profitability evaluation of the investment.

Various modeling studies are being developed that will provide better insight into water resource issues, resilient management strategies, quantification of impacts, and performance efficiency of nuclear plants, among others.

Climate change poses new technical challenges, and as a result, more sophisticated meteorological and climate tools need to be developed. Vulnerabilities are not restricted to the traditional energy sectors; effects on renewables—especially the intermittency of production—will need to be examined. Collaboration and partnerships among the public and private sectors will be critical to anticipate impacts, define roles and responsibilities (especially in the case of extreme events), and share knowledge and skills among people and organizations. Policymakers and the private sector will need to grapple with striking the right balance between resilience and resistance, as well as develop appropriate policies and regulations.

The U.S. Gulf Coast: Risk and Adaptation

Brent Dorsey, Director, Corporate Environmental Programs, Entergy, United States of America

- Link to presentation slides: http://www.iea.org/media/workshops/2013/egrdutrecht/8.Dorsey.pdf

Entergy, a power and gas company with an installed capacity of 30 gigawatts electric (GWe) and around 15,000 employees has a majority of its operations in Southern United States, a region that is projected to experience increased flooding and more intense hurricanes due to climate change. Entergy launched a project that aimed at developing a comprehensive, objective, consistent fact base to quantify climate

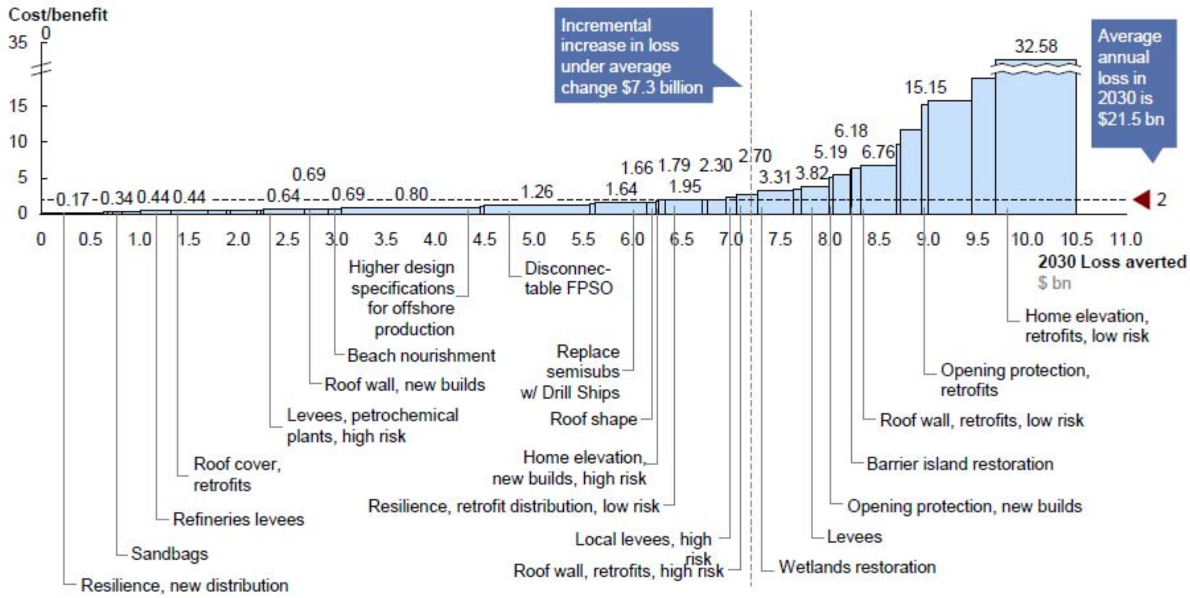

Figure 8. Adaptation Supply Curve indicating the most profitable adaptation measures in coastal areas

risks on the U.S. Gulf Coast and develop economically sensible approaches for addressing this risk. The project had two dimensions: the development of an Entergy adaptation program and the development of a community adaptation program, called Blue Ribbon Resiliency Communities (BRRC). The project was the first comprehensive analysis of climate risks and adaptation economics along the U.S. Gulf Coast.

In the Gulf Coast region, climate change is expected to increase financial loss over time because of increased risk of storm surge (mainly Louisiana) and increased risk of strong winds (Gulf Coast region, including more inland areas).Given the potential scale of loss, Entergy (in cooperation with America's Wetland Foundation) developed measures that would address this loss and minimize the growth of the risk profile of their region. The measures examined are presented in an adaptation supply curve (Figure 8).

Figure 9. Climate Resilience Spider Web ***(USAID, How Resilient is your Coastal Community, 2007)***

The second dimension of this project was community involvement. Launched in the Gulf Coast region, the BRRC had resulted in nine Blue Ribbon

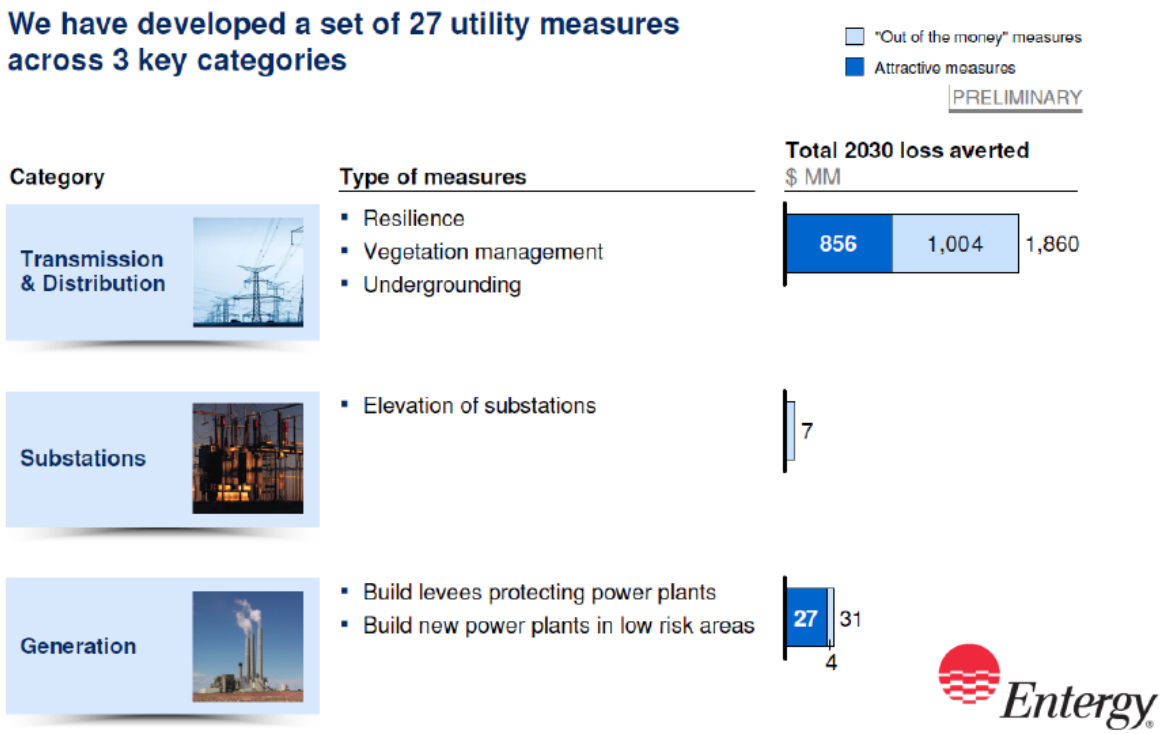

Figure 10. Climate adaptation measures currently under consideration by Entergy

cities by the end of 2012. BRRC adopted the spider web-type modeling and benchmarking approach shown in Figure 9.

Based on the results of this project, Entergy developed its own climate change adaptation program that focuses on the resiliency of its assets and involves mainly generation, transmission and distribution, and vegetation management. Entergy also developed its own adaptation supply curve based on the project. Entergy measures and associated costs averted are shown in Figure 10.

Climate Resilience Strategies in the Energy Distribution and Demand Sectors

The energy distribution and demand sector faces its own set of challenges when dealing with the impacts of climate change. Hydropower generation is of great importance to energy systems, as certain attributes make it very attractive, e.g., quick start capability and back-up reserve. However, changes in precipitation patterns, and changes to the amount of water available and its timing, will have great impacts on this sector. Current R&D activities have focused on modeling scenarios to better understand the vulnerabilities of this sector to climate impacts. Studies are also being conducted to define "smart" adaptation strategies, foster understanding of aspects of climate proofing infrastructure, and conduct cost–benefit analyses of resilient strategies.

Various approaches need to be adopted by this sector to address climate vulnerabilities and build resilience. Technical practitioners must undertake modeling for such sectors on a larger scale, using better information and data, and providing better certainty of results. Advanced technologies being used by other countries—technologies that are more resilient—should be considered. Sharing best practices among countries will help foster a clearer picture of the impacts and vulnerabilities of climate change on the sector. Alternative technological options, like district heating and cogeneration, should be considered in the energy mix, and barriers that deter its development should be addressed.

Energy Production and Climate Resilience Strategies: Hydropower Sector

Hoyt Battey, Water Power Market Acceleration and Deployment Team Lead, U.S. Department of Energy, United States of America

- Link to presentation slides: http://www.iea.org/media/workshops/2013/egrdutrecht/9.Battey.pdf

More than 60 countries use hydropower to meet more than half of their electricity needs. Because of certain attributes such as back-up reserve and quick start capability, hydropower has remained an attractive option in most countries. In 2011, hydropower accounted for 7.8% of U.S. electricity generation, and the industry employs over 300,000 people. Significant economic growth has already taken place in areas where water stressors are high or increasing, and this trend is expected to continue in the future. As a result, hydropower sector climate vulnerabilities need to be examined and addressed.

Climate change can have huge impacts on the hydropower industry because of its reliance on water availability. For example, changes in precipitation can affect the amount of water available, and shifting precipitation patterns can affect the timing of availability. If extreme weather events increase, flood control might become a greater priority than energy generation.

As per Section 9505 of the 2009 Omnibus Public Lands Act, a detailed assessment was conducted on climate change's impact on hydropower production capability at all federal water projects. The main findings of the assessment indicated that, while changes to average annual generation were modest, there will most likely be an increase in dry water years across regions (from an average of two per decade to three), with increases in wet water years in some places. Additionally, significant seasonal impacts will be experienced with some dramatic decreases in summer generation (30% to 40%), often linked to timing of snowmelt. Changes that can occur in the mean annual runoff in the United States due to climate change are shown in Figure 11.

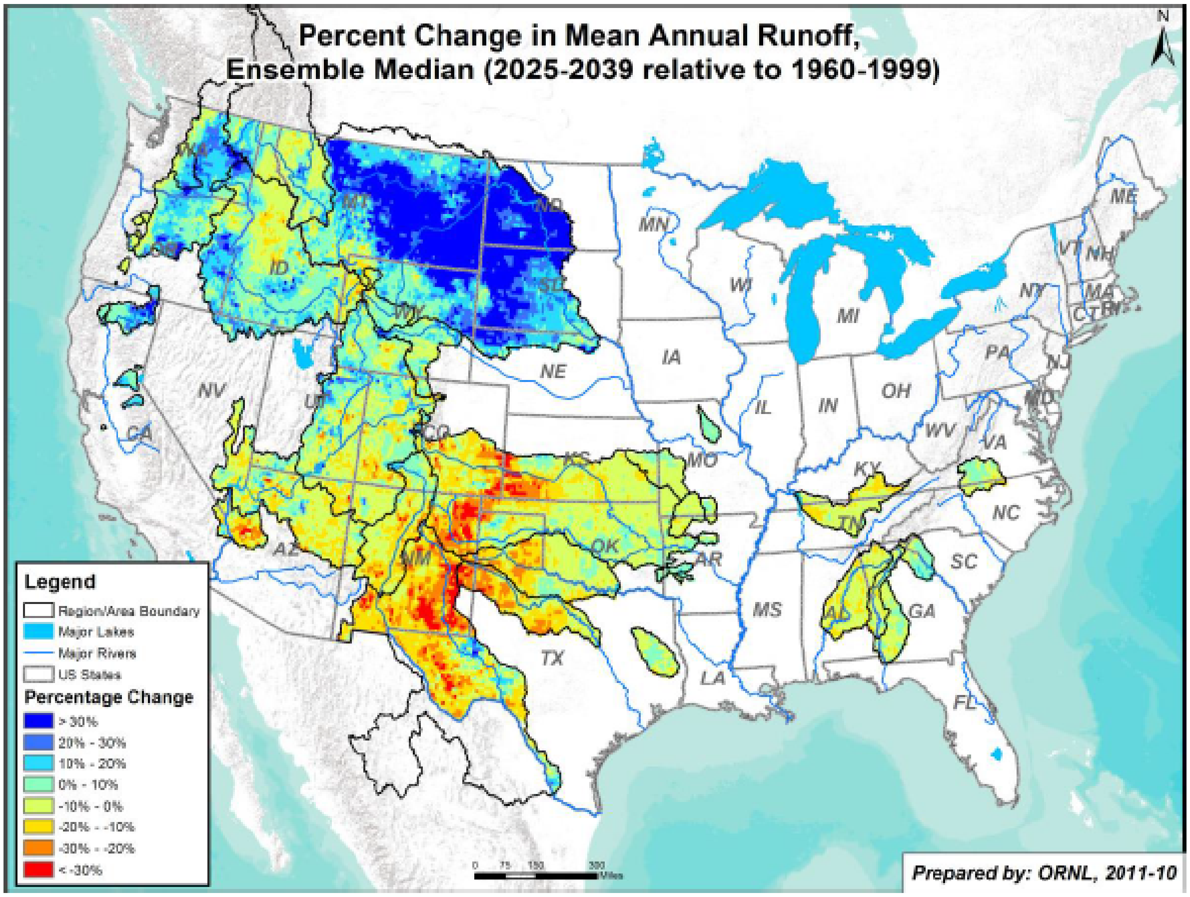

Figure 11. Mean annual runoff is projected to increase in the North of the United States and decrease in the South

The next 9505 assessment is due in 2016 and will build on the current assessment by improving the granularity of data, developing better modeling of water / power systems, better quantifying uncertainty of results, and including an assessment of non-federal hydropower projects.

Some related emerging issues that need to be understood better are GHG emissions from reservoirs and consumptive water risk. Strategies that can be used to address risks associated with hydropower and climate change impacts involve the use of advanced technological systems, such as Alden fish-friendly turbines, advanced pump storage technologies, and better water quality modeling.

Climate Change and the Electricity Infrastructure: Exploring Why, Where, How and When to Adapt

Gerard P.J. Dijkema, Faculty of Technology, Policy and Management, Delft University of Technology (TU Delft), Netherlands

- No link to presentation slides available

TU Delft, along with KWR Watercycle Research Institute, Deltares, TNO (Netherlands Organisation for Applied Scientific Research), and Amsterdam University, is participating in the Infrastructure, Climate Change Adaption and Hotspots (INCAH) project. The Dutch project focuses on technology, assets and networks, and economy. Issues being explored by the project include defining smart adaptation strategies, climate proofing the physical infrastructure, developing robust and resilient infrastructure networks, and costs and benefits of adaptation. Climate change impacts need to be factored in, especially when designing infrastructure with long lifespans and those that can be affected by extreme weather.

The project has conducted a detailed study on the impacts of climate change in Netherlands' energy sector. The main takeaway from the study is that climate impacts will be felt at every level, and the sector needs to be prepared for it. A good example is the impacts experienced post-2003 heat wave. These included cooling water restrictions and a reduced reserve capacity in the electricity grid, increased use of air conditioners, and altered investment strategies of the power sector.

Adaptation strategies are required for thermal power plants. Retrofitting cooling systems is a measure that is being considered, but costs related to such technologies need to be investigated. Measures that can be put in place to incentivize operators to encourage adoption of these technologies need to be examined as well.

Additionally, the climate resilience of the electricity network needs to be better understood. Up to 15% (2003 to 2007) of power failures in the Dutch high-voltage grid have been due to weather-related events. In the Netherlands, 10 of the 12 largest power plants (2014) are located at sea level, as is a majority of the national high-voltage grid. To climate-proof physical infrastructures, several aspects need to be examined in detail, including climate impacts on the performance of the electricity network as a whole, and needed changes to the existing infrastructure to prepare for the future.

One of the critical research questions that the project addresses was how to support the evolution of climate-resilient infrastructure in the Netherlands. Agent-based modeling is one of the approaches that can be adopted to help address this question. This modeling enables one to capture an electricity network's development as a consequence of the repeated interactions and decisions of a set of software agents, representing real-world actors associated with the electricity infrastructure. The assumption made by this modeling technique is that long-term development of electricity transmission infrastructure can be conceptualized to occur as a result of repeated decisions of two types of actors (agents).

The outcomes of such research projects must be translated into robust and sound policies that hedge against the worst possible consequences. It is also important to identify sufficient solutions and understand key complex system dynamics.

Near Future Challenges for R&D in the District Heating and Cooling Sector

Ingo Weidlich, Project Coordinator, Research and Development, AGFW, Germany

- Link to presentation slides: http://www.iea.org/media/workshops/2013/egrdutrecht/12.Weidlich.pdf

District heating and cogeneration (DHC) helps increase energy system efficiency, thus indirectly reducing GHG emissions. Through combined heat and power (CHP), DHC is connected to the electricity system, creating a mutual dependency that exists between the electricity and heat markets.

The European Union (EU) Energy Efficiency Directive (October 2012) requires annual energy savings of 1.5% of the total distributed energy until 2020. District heating is expected to be one of the measures to help realize this target. In Germany, for example, to achieve 80% reduction in GHG emissions by 2050 from 1990 levels, Germany will need to increase its share of renewable electricity by 80%. For Germany to achieve its 2050 goals, district heating will need to be a major player in the energy turnaround.

Increased use of district heating is reliant on subsequent expansion of the electricity grid. However, the German electricity grid's expansion continues to face challenges, including balancing power from 35+ GWe to -24 GWe, managing peak loads, storage, customer behavior, and renewable electricity imports. Grid expansion is necessary for transmission and distribution; cost estimates are in the neighborhood of € 20 billion for expansion and € 27 to € 42 billion for the distribution grid in Germany. A smart market and a smart grid—allowing storage capacity and demand and supply flexibility—will need to be established.

Several barriers deter DHC and CHP development. First, the market for CHP installations and its base load is deteriorating. Installations are reaching lower full load hours, and as a result, higher flexibility (at higher costs) becomes essential. In the short term, the power merit order in Germany will push CHP infrastructure out of the power market in favor of renewable energy, nuclear power, and brown coal. The power market acts as an (inter)national copper plate, with the heat market serving the local needs of a city or a region. Supply within the (district) heating network is in balance with the demand. The critical challenge remains connecting the district heating network to the power market in an even more flexible way by adding electric boilers.

A German case study examined DHC and CHP's potential. Findings indicated that the load and production management potential of CHP with thermal storage is very high, and with auxiliary electric heating systems, an additional potential of 11.7 GWe renewable energy can be realized.
The costs for such heat storage facilities can range from € 1.4 to 2.2 billion, and significant advantages exist for use of such thermal energy storage systems. Additionally, DHC offers the opportunity to integrate renewable heat sources, such as biomass-fired CHP geothermal heat and solar thermal heat.

R&D Activities Underway and Priority Gaps and Opportunities for Climate Resilience and Preparedness

Natural systems and socially developed systems (e.g., energy production) are interconnected. As energy demand escalates, GHG emissions increase further exacerbating climate change. Increasing temperatures, sea level rise, and extreme weather events are posing greater risks to the energy sector. Water usage is also increasingly an issue for the power sector. Demand for energy and demand for freshwater are interrelated and rising quickly. Many regions are vulnerable to water shortages from climate change.

Addressing the effects of climate change involves a two-pronged approach: climate mitigation and climate adaptation. Climate adaptation involves, among other actions, building resilient infrastructure. A comprehensive risk-informed system would aim at hardening, recovery, and survivability of the energy system. Eliminating all risks is not a realistic option. It is important to strike the right balance between prevention, anticipation and being prepared for recovery.

Building infrastructure entails making assumptions about earth's resources the effects of climate. Risks related to invalid assumptions are high, both for the natural systems and for the stakeholders involved in infrastructure development. Therefore, plans for infrastructure investment should be flexible to optimize value. Systems should be adaptable, and contingency measures should be in place. As assumptions are risky, improved information, such as real-time environmental data, is needed to support design decisions. Fully understanding the interaction between natural and social systems requires information sharing.

Currently, actions and solutions are mostly sector-specific. This leads to a risk of overlooking aspects from a comprehensive electricity system resilience perspective. A range of stakeholders should be consulted while planning and implementing resilience measures. A resilient energy system must be holistic, considering multiple sectors, generation modes, consumers, and the grid. By working across sectors and sharing scenarios, integrated models can be developed that further our understanding of how long-term physical conditions will affect infrastructure design. Along with climate change, technological, energy market, and social trends, should be taken into consideration. Robust integrated plans should include staged risk-optimal measures for different stakeholders in the energy market(s).

One priority in planning is relevant RD&D for power plants and electricity transmission, and some progress has been made in this area. Technologies, tools, and techniques are being developed and implemented to address resilience challenges, such as smart grid technologies, vegetation management to prevent power outages from fallen trees, and onsite physical security (e.g., at utilities and substations). Advanced cooling systems are being developed to address water usage issues; as a result, industry is using once-through cooling less and cooling towers more, and large power plants are starting to use air-cooled condensers (ACCs). Modelling tools are being developed to help predict water availability. Such tools can be used for local, regional, and national assessment of consumptive and withdrawal demands. Results of the tool could help with risk evaluation and future planning. In the nuclear industry, an ad hoc expert group on climate change is assessing the vulnerability of nuclear power plants and the cost of adaptation. Participants are investigating the energy–water nexus, security of energy supply, regulations and policies, and a cost assessment methodology to examine both direct and indirect costs of inaction versus costs of adaptation.

Risks and Opportunities in Addressing Climate Change and Building Climate Resilience: A Netherlands–Deltares Perspective

Ipo Ritsema, Director, Deltares, Netherlands

- Link to presentation slides: http://www.iea.org/media/workshops/2013/egrdutrecht/13.Ritsema.pdf

Deltares is a Dutch foundation dedicated to top-level development and practical application of expertise in water, subsurface, and infrastructure for people, environment, and society. The organization supports infrastructure R&D related to the areas of flood defense, water and energy, transport and building, and the ecosystem. The goal is to optimize opportunities and reduce risks.

The relationships between natural systems and socially developed systems (e.g., energy production) are interconnected and somewhat cyclical. Earth provides resources that we use to make energy, a process that affects earth's resources. Physical conditions change—climate patterns, water regimes, ground motions and subsidence—influencing energy demand and availability, increasing the need for generation, storage, and supply.

Energy systems must be designed and adapted to consider both sides of the equation. When infrastructure is built, assumptions are made about earth's resources—and about impacts of climate. Risks related to invalid assumptions are high, both for the natural systems and for the stakeholders involved in infrastructure development. Plans for infrastructure investment should be flexible to optimize value.

Certain questions about the interfaces between energy sources and systems must be posed, e.g., the likelihood of renewables to make systems more vulnerable and the possibility that addressing climate change will affect generation capacity.

Current Deltares projects include hydropower dam design and reservoir management to reduce environmental risks. The multifaceted projects involve reliable reservoir inflow predictions and water quality studies. One key goal is a water prediction tool that minimizes generation-marketing risks. A reliable predictive model would integrate the meteorological uncertainty of wind power, water flow, and load demand, supporting predictive power on grid imbalance for electricity generation and storage. Deltares is also looking into capitalizing on water's potential as an energy source, such as tidal energy and "blue" energy (salt–fresh water mixing), while examining environmental impacts. There are numerous collaborative projects examining offshore wind, hydrocarbon, thermal energy underground storage.

Fully understanding the interaction between all natural and social systems requires information sharing, specifically models of physical conditions. By working across sectors and sharing scenarios, integrated models from global to regional can be developed, as well as a better understanding of how long-term physical conditions will affect infrastructure design. The full range of issues—water and groundwater, land motion, flooding, water quality—must be considered.

Addressing the inevitable effects of infrastructure buildout involves a two-pronged approach: climate mitigation and climate adaptation. A key aspect of climate mitigation is increasing the use of renewable energy sources. However, renewable energy systems currently have multiple design constraints, such as system inefficiencies, the potential for interference between energy systems, and the limited capacity of water bodies for thermal storage. However, R&D advances suggest opportunities, such as through multi-functional spatial planning, use of real-time weather and water data for energy system operations, and optimization of generation and storage operations.

The second prong, climate adaptation, involves building a resilient infrastructure. As noted above, building in flexibility—and enhancing flexibility of at-risk existing assets—is key. Systems should be adaptable, and contingency measures should be put in place. Again, real-time environmental data will support design decisions, as would fragility curves for new long-term climate and water scenarios, and risks. Other considerations include costs (Figure 12), timing of adaptation measures, and possible interference between energy systems.

Over time, the Dutch have grown to accept sea level rise as inevitable and, thus, have implemented a risk-based approach to water control and identified safety levels that depend on population density and land use. Spending on infrastructure has decreased yet Dutch water control infrastructure continues to become more robust. The key is to treat water and land use as multi-sectoral—an energy–food-water nexus.

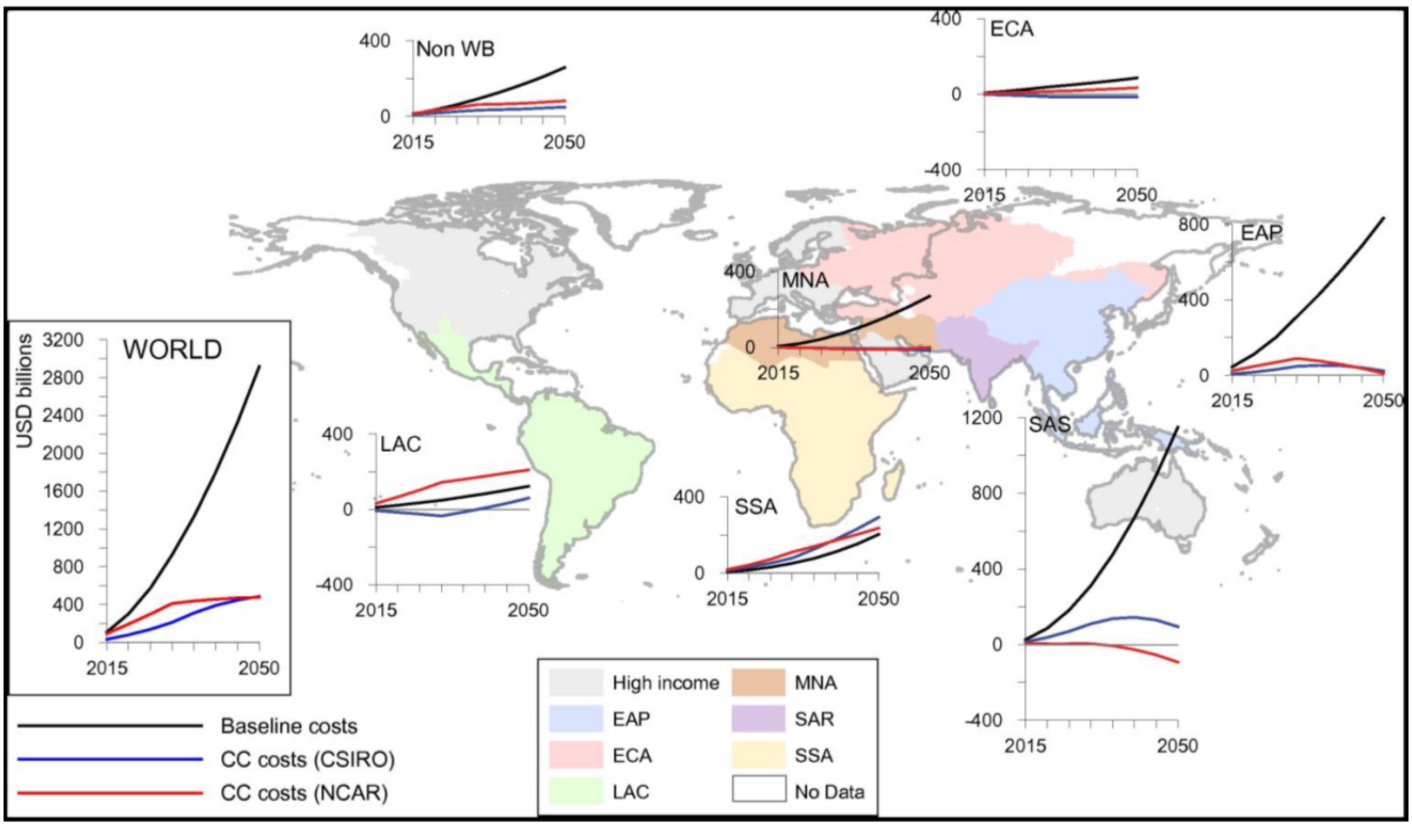

Figure 32. Estimated global and regional adaptation costs

Source: Philip J Ward, Kenneth M Strzepek, W Pieter Pauw, Luke M Brander, Gordon A Hughes3 and Jeroen C J H Aerts, "Partial costs of global climate change adaptation for the supply of raw industrial and municipal water: a methodology and application," *Environ. Res. Lett. 5* (October-December 2010) 044011, doi:10.1088/1748-9326/5/4/044011.

Perspectives from the IEA Electricity Security Action Plan

Christelle Verstraeten, Analyst, International Energy Agency

- Link to presentation slides: http://www.iea.org/media/workshops/2013/egrdutrecht/14VerstraetenIEA.pdf

The International Energy Agency (IEA) was formed in the wake of the 1973 oil embargo with a mission to promote member country energy security. Since that time, energy demand has increased significantly—roughly in parallel with GDP, with emerging countries' energy use escalating rapidly to catch up with developed markets. Barring unforeseen circumstances, future growth will follow the same near-exponential trend. Figure 13 shows the relevant drivers for electricity supply.

Simultaneous with increasing energy demand is the growing impact on climate. Events such as floods, storms, and extremes of temperature have risen markedly over the past two decades. In the last 12 years, natural disasters have cost mankind $1.3 million (USD)—and 1.1 million lives. The changing climate and natural disasters, in turn, have an impact on electricity networks. Demand increases in parallel with both population growth and extremes of temperature, while natural disasters threaten infrastructure. Eliminating all risks upfront is not a realistic option. There needs to be a balance between prevention / anticipation and recovery, and emergency plans must be in place. Being prepared for recovery is as important as prevention and anticipation.

Climate resilience is a dimension that affects all aspects of electricity systems security. There are three pillars of the challenge of power security: the need for power to be affordable, secure, and from low carbon source. Dispatchable solutions include carbon capture and nuclear, and onshore and offshore renewables are considered variable solutions. When considering resilience of an energy system, one must consider the integration of renewables into the fuel mix, market design and the interconnectivity of the transmission network. Key issues that will need to be addressed include the increased climate

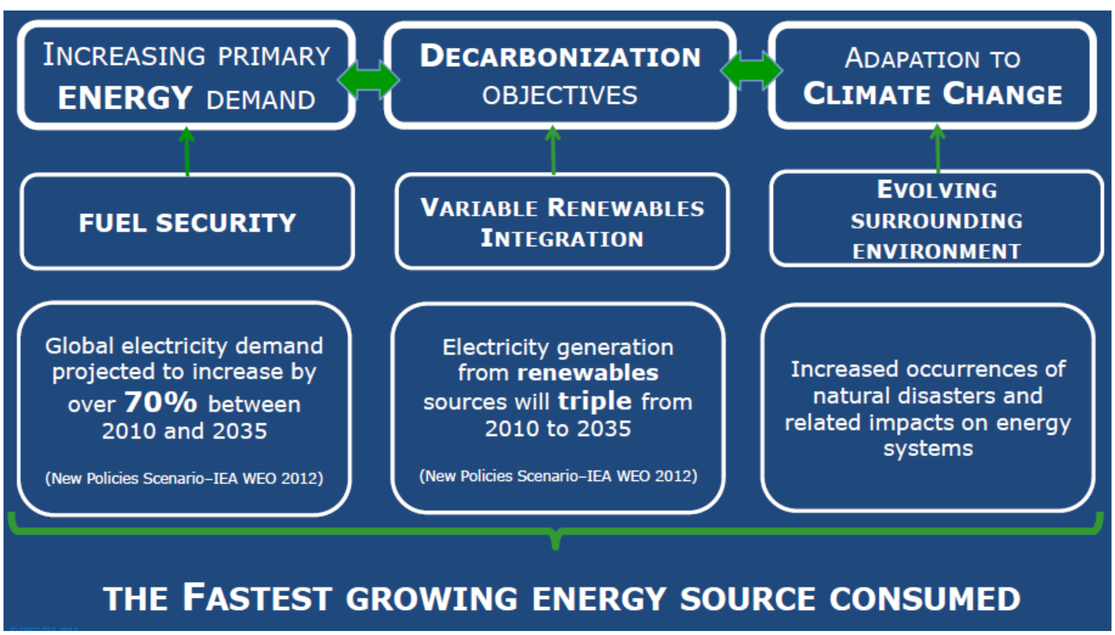

Figure 13. Drivers of electricity supply

vulnerability of an energy system due to its connectivity with traditional energy systems, effects on generation capacity due to climate adaptation measures, vulnerability of power networks, and the predictability scenarios being used to make decisions.

Resiliency and the Energy–Water Nexus

David Hunter, Manager, Federal and Industry Affairs, Electric Power Research Institute, United States of America

- Link to presentation slides: http://www.iea.org/media/workshops/2013/egrdutrecht/15.Hunter.pdf

The Electric Power Research Institute (EPRI) is an independent, non-profit center for public interest energy and environmental research. Founded in 1972, EPRI members generate or distribute approximately 90% of the electricity in the United States, and the organization has 450+ participants in more than 30 countries.

EPRI's approach to resilience is a comprehensive risk-informed system aiming at hardening, recovery, and survivability of the energy system. Resiliency includes improving the recovery time of power supply in case of failure. Since 1992, the number of power service interruptions has increased significantly, and roughly two thirds are weather related. A secondary challenge is vegetation, i.e., trees interfering with power lines. Customer expectations are moving upward in parallel; the inherent assumption is that the lights will stay on.

Technologies, tools, and techniques are being developed and implemented to address resiliency challenges. Many smart grid technologies are focused on resiliency, such as distribution automation, automated service restoration, robust communications systems, and advanced metering infrastructure (AMI) integrated with outage management systems (OMSs) and geographic information systems (GISs). Research is being conducted on unmanned aerial vehicles (UAVs) for damage assessment after storms. Vegetation management (tree trimming) helps with prevention, and EPRI is conducting R&D to examine other means of addressing this challenge, such as selective undergrounding. Onsite physical security (e.g., at utilities and substations) is also a consideration. In addition, EPRI stresses the health, safety, and skills of the workforce; quick responses depend on the staff's health and level of training.

Water is becoming more of an issue for the power sector. Demand for energy and demand for fresh water are inter-related—and with population growth, both are rising. Many regions are already showing vulnerabilities to water shortages, and further impacts of climate variability are unknown. Water resource management requires a broad stakeholder consensus. Developing more efficient cooling techniques and technologies for power plants is an R&D priority (Figure 14). The industry is adapting, including using once-through cooling less and cooling towers more, and some large (>1,000 MWe) power plants are using air-cooled condensers (ACCs), although dry cooling presents several challenges (cost, size, wind effects, and penalties in hot weather).

EPRI is involved in several joint projects investigating other developments in this area, such as:

- Waste heat and solar-driven green adsorption chillers for steam condensation
- Thermosyphon cooler technology
- Advanced M-cycle dew point cooling tower fill
- Heat absorption nanoparticles in coolant

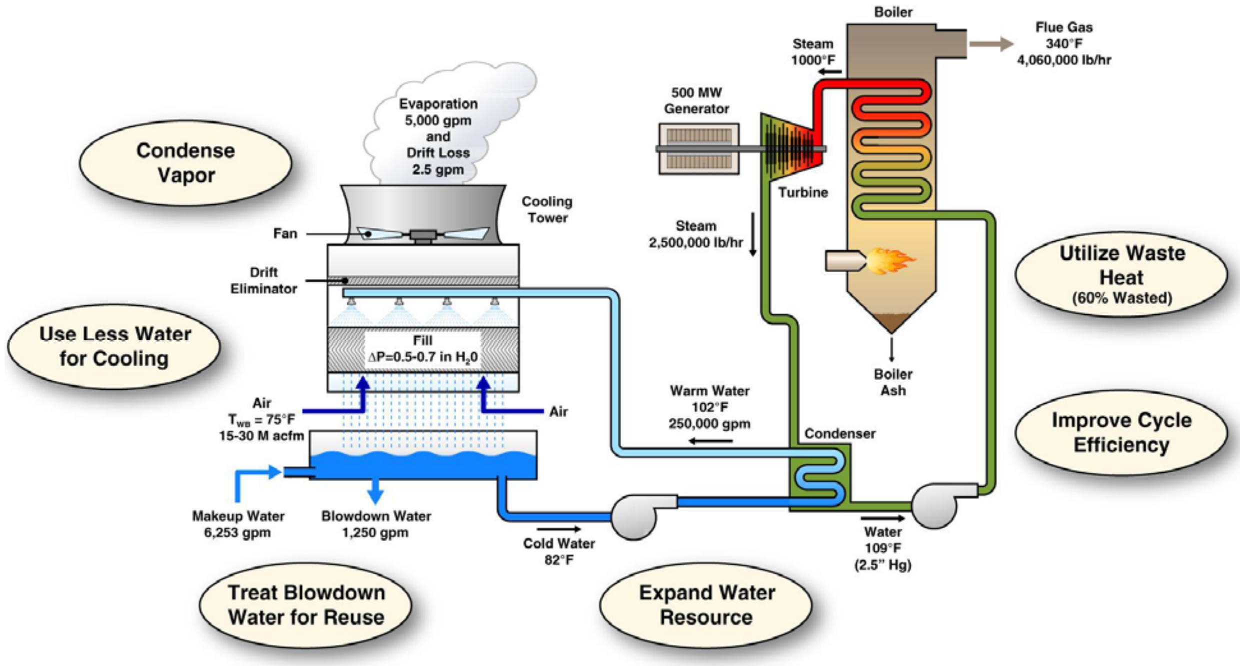

Figure 14. Advancing cooling technologies, novel water treatment, and waste heat recovery concepts to improve efficiency and water use

- Hybrid dry/wet cooling to enhance ACCs

EPRI has also developed a modeling tool to help predict water availability. The "Water Prism" is a watershed-scale decision support system that computes system water balance on a regional scale, projecting both consumptive and withdrawal demands for up to a 40- to 50-year timeframe. The model can be used to explore water-saving strategies through scenarios. The tool also helps power plant owners decide when a structural change in water use is needed. EPRI used Muskingum Basin as a test case; the Water Prism showed generally low water risk with isolated higher-risk areas (e.g., near a large plant that uses once-through cooling). Nationwide assessment could help with risk evaluation and future planning.

Renewable Energy and Electric Grids: A Holistic Perspective on Climate Resilience RD&D Strategies

Peter Vaessen, Principal Consultant, DNV GL Group, Norway

- Link to presentation slides: http://www.iea.org/media/workshops/2013/egrdutrecht/16.Vaessen.pdf

DNV GL is a global organization with expertise in energy markets and policies, electrical transmission and distribution infrastructure, and renewable and conventional energy generation.

There is a need to look at climate resilience from a new perspective. A range of factors play into resilience of an energy system: technological advancements, and increasing societal dependence on power, ageing population, centralization and decentralization, and additionally the impact of climate change. Currently, actions and solutions seem sector-specific, examining the "now situation" in the context of those sectors' geographic markets and systems, e.g., transmission companies look at only how to make transmission systems more resilient as opposed to taking a more holistic approach. There is limited interaction between generation, transmission and distribution, energy users, governmental entities, and the financial sector. By taking on a comprehensive view to electricity system resilience one reduces the risk of overlooking various aspects related to the interconnectivity of systems, as well as minimizes the complexities of timing with multiple sectors and stakeholders involved. Anticipating resilience measures over time can become extremely challenging.

The primary challenge for energy companies in the future will be to get adequate amounts of energy to the right place at the right time, while simultaneously dealing with the impacts of climate change.

Solutions to this challenge must consider a range of stakeholders while planning and implementing resilience measures. Context should include not only climate change but also technological, energy market, and social trends. Robust integrated plans would include staged risk-optimal measures for different stakeholders in the energy market(s). If not assessed holistically, investments in resilience innovations could evolve into stranded assets. Risk-optimal cost–benefit decisions must be sound and must consider effectiveness, efficiency, and implementation lead times.

First steps in resilience planning would be creating and assessing various multi-factor scenarios and deriving risk-optimal RD&D options. For example, large increases in wind and solar due to the phase-out of thermal generation could correspond with link centralization (super grid) and decentralization (smart grid) initiatives. Planners would also have to consider the pace of developments, power flows, power balance, and their interconnections.

Stakeholders would benefit from building timing-related investment models / decision and information support models. Ultimately, though, the keys are leadership, communication, and co-ordination.

Nuclear Power: OECD NEA Perspective – R&D Activities Underway and Priority Gaps and Opportunities for Climate Resilience and Preparedness

Henri Paillere, Nuclear Energy Analyst, Organisation for Economic Co-operation and Development, Nuclear Energy Agency

- Link to presentation slides: http://www.iea.org/media/workshops/2013/egrdutrecht/17.Paillere.pdf

As a low-carbon energy source, with only indirect emissions, nuclear energy plays a role primarily in climate mitigation. However, adaptation is also critical to nuclear, as it is for all energy infrastructures, since it is vulnerable to extreme climate events such as drought, flood, gales, and snow and ice storms. For example, just as for fossil fuel power plant, a nuclear power plant is cooled with a circulating water cycle, such as once-through cycle or recirculating cycle with cooling towers. When the cooling water is no longer available, the plant has to shut down. However, unlike conventional thermo-electric power plants, cooling is still needed to remove the reactor's residual heat. This adds additional constraints on the availability of cooling water for nuclear power plants. .

There is recorded data on nuclear power plant outages due to extreme weather events and other environmental conditions. From 2004 to 2011, 9.2% of outages and 17.7% of outage duration were caused by environmental conditions. Adaptation measures can help to reduce these losses. Having precise data is useful to determine which adaptation measures can be developed to improve the resilience of nuclear power plants.

The NEA has set up an ad hoc expert group on climate change to assess the vulnerability of nuclear power plants and the cost of adaptation. Participants in the expert group represent nine member countries of the Nuclear Energy Agency, as well as four multinational organisations. The group includes experts from research and academic institutions, technical safety organizations, and industry; the expertise in nuclear safety and risk assessment, meteorology, climate change, sustainable energy systems, nuclear technology and economics. The study is addressing the energy–water nexus, security of energy supply aspects, environmental and safety regulations and policies. The study will also assess the cost implications of climate change on the operation of nuclear power, to examine direct and indirect costs of inaction versus the costs of adaptation. Direct costs of inaction include loss of electricity production due to partial/full outages, loss of efficiency due to higher cooling water temperatures, and costs of repairs, refurbishment, and safety upgrades. Indirect impacts include steps taken by utilities and consumers to compensate for production losses.

In addition, member countries are sharing case studies on the impact of extreme weather on nuclear power plant operations and safety. For example, in January 2008, a sudden drop in temperature near the Olkiluoto power plant in Finland caused the formation of frazil ice, resulting in a circulating water cycle intake blockage. Measures were subsequently taken to reduce the risks of events occurring again. For instance, pumping warm water upstream of the intake to prevent frazil ice formation when temperatures drop below a certain threshold.

Besides engineering solutions to improve resilience, RD&D is needed to develop longer term solutions. For instance, advanced cooling technologies which could equip future nuclear reactors, improved weather forecasting tools and associated planning to adapt to and prepare for extreme weather, and safety assessments that account for increasing probability and amplitude of extreme weather events. A resilient energy system must be holistic, considering generation, consumers, and the grid.

Because nuclear power generation can be affected by climate change and because of the long operating lifetimes of nuclear power plants (typically 60 years for new designs), climate is already taken into account in design and siting of any new plants. As noted above, there are safety and non-safety drivers to change existing plants as well. However, it is sometimes difficult to make the case for investing in adaptation measures for plants that have only a limited lifetime left; governments can play a role through investment incentives and regulation. The Nuclear Energy Agency study on nuclear power adaptation to climate change with recommendations to policy makers will be published in the second half of 2014.

Framework for Accelerating R&D Investment in Climate-Resilient Energy Technologies

There is a clear need for a more climate-resilient energy infrastructure, one with the capability to anticipate and prepare for extreme weather and natural disasters on one hand and respond and recover to climate impacts on the other hand. Resilience efforts are under way, including RD&D to develop advanced technologies, tools, and techniques; conducting vulnerability assessments; and taking steps towards developing an enabling policy framework.

Yet far more work is required, and there are multiple barriers to advancing a climate-resilient infrastructure and economy. Technologies are in early stages, information needed to determine next steps is lacking, stakeholders have competing incentives, and supporting environmental, energy, and climate policies are not yet in place. Critical to moving forward is improving the investment environment, which is currently poor, not only as a result of the information shortage and weak policies but also because of a lack of suitable financial vehicles.

Governments should take steps to improve the investment environment, accelerating relevant RD&D and unlocking the potential of energy efficiency. There is a need for a long-term robust adaptation strategy that supports energy-related R&D. This strategy should be developed with input from a range of stakeholders and be expanded into regular information exchange and dialogue between sectors and governments. New enabling policy and institutional frameworks must be established to encourage innovation and accelerate design and implementation of energy infrastructure that increases climate resilience. Governments should establish supporting financial vehicles and incentives, such as carbon prices, loan guarantees, credit enhancements, and R&D subsidies. In addition, public awareness campaigns and education would help to promote green business and consumer behavior.

Barriers and Incentives for Future Investment – IEA Perspective

Takashi Hattori, Unit Head, Environment and Climate Change Unit, International Energy Agency

- Link to presentation slides: http://www.iea.org/media/workshops/2013/egrdutrecht/19.Hattori.pdf

IEA and OECD have three overarching recommendations to governments to address climate change:

- Create an investment environment that will build confidence in clean energy
- Unlock the incredible potential of energy efficiency – "the hidden" fuel of the future
- Accelerate innovation and public RD&D

Both organizations are promoting measures to enhance the investment environment. IEA regularly publishes *Energy Technology Perspectives* (ETP), and OECD has established a Green Investment Policy Framework (Figure 15). ETP recently reported that clean energy investment pays off: every dollar invested in clean energy can generate three dollars in return. Governments should create an environment in which clean energy innovation can thrive and within which policies are regularly evaluated to ensure that they are effective and efficient (Figure 16).

Carbon price, energy efficiency policy, and technology support are the backbone of a least-cost package to achieve the 2°C Scenario (2DS). Reaching this goal will require a portfolio of technologies: power generation efficiency and fuel switching, end-use fuel switching, end-use fuel and electricity efficiency, nuclear, renewables, and carbon capture and sequestration.

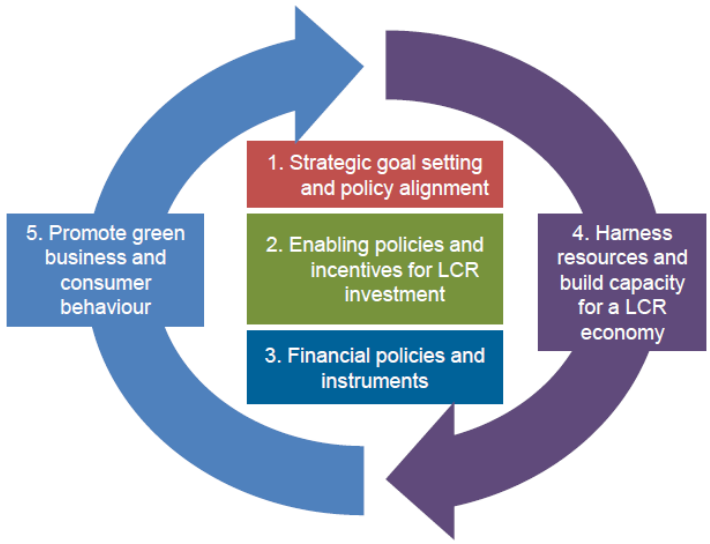

Figure 15. The OECD green investment policy framework

Unfortunately, energy-related RD&D in IEA member countries has slipped in priority; from 1980 to 2011, energy's share in total RD&D dropped from above 10% to around 4%. The financing sources for investments in green infrastructure are about one-third public sector and two-thirds private sector; the latter is subdivided into corporate sources and the financial sector; the financial sector, in turn, is subdivided into bank asset financing and other non-bank sources, including institutional investors and pension funds. In 2012, institutional investors in OECD countries managed $83 trillion in pension assets; about 1% was invested directly in infrastructure, and an even smaller portion was invested directly in green infrastructure. This indicates the issue is not money but rather an unattractive investment climate. The barriers to investment in green infrastructure are:

- Weak, uncertain, or counterproductive environmental, energy, and climate policies
- Regulatory policies with unintended consequences
- A lack of suitable financial vehicles with attributes sought by institutional investors
- A shortage of objective information and data to assess transactions and underlying risks

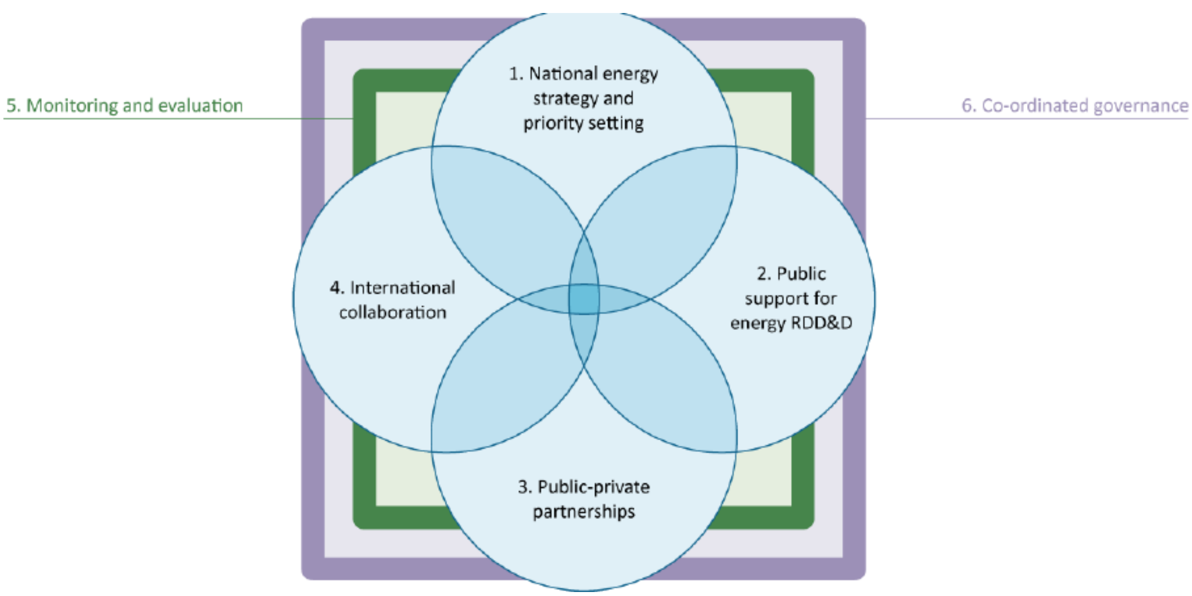

Figure 46. The energy innovation policy framework (ETP, 2012)

The following are suggested actions that governments can take to address these investment barriers:

- Ensure a stable and integrated policy environment
- Address market failures (including a lack of carbon pricing)
- Provide a national infrastructure roadmap
- Facilitate the development of appropriate financing vehicles or de-risking instruments
- Reduce the transaction costs of green investment
- Promote public–private dialogue about green investment
- Promote market transparency and improve data on infrastructure investment

Governments must begin using some of the tools available to further climate resilience. Leaders should set strategic goals, such as long-term infrastructure planning. Stakeholders could be incentivized to achieve those goals through enabling policies such as establishing carbon prices and eliminating fossil fuel subsidies. Supporting financial policies and instruments, such as loan guarantees and credit enhancements, should be put in place, while R&D subsidies would also provide necessary resources for a low-carbon, climate-resilient economy. In addition, public awareness campaigns and education would help to promote green business and consumer behavior.

Barriers and Opportunities for Future Investment – U.S. Perspective

Craig Zamuda, Senior Advisor, Office of Climate Change Policy and Technology, U.S. Department of Energy, United States of America

- Link to presentation slides: http://www.iea.org/media/workshops/2013/egrdutrecht/20.Zamuda.pdf

A vision of what constitutes climate-resilient energy infrastructure is needed before it can be achieved. Such an infrastructure would have the capability to anticipate and prepare for climate change on one hand and respond and recover from climate impacts on the other. Table 3 lists the features that would define climate-resilient energy infrastructure.

Table 3. Features of a climate-resilient energy infrastructure

Anticipate and prepare	Respond and recover
Vulnerability assessments conducted with adaptation options identified	Power plants able to meet demand given constraints on water availability
Methodologies in place for prioritizing adaptation measures	Electric grid able to withstand increases in storm intensity and wildfires
Climate preparedness incorporated into company risk management frameworks	Coastal energy infrastructure able to withstand sea level rise (SLR)-enhanced storm surge

Resilience efforts are already underway in the United States. Investigators are working toward improved technologies and techniques for generation, water capture, and storm hardening for infrastructure; and tools are being developed to characterize vulnerability. Federal vulnerability assessments provide necessary information to determine next steps. The government is also working towards establishing an enabling policy framework to enhance pace, scale, and scope of these efforts.

Yet climate resilience continues to face challenges. Technologies are in early stages, there are risks in their adoption, and the workforce is not trained for their implementation. There is insufficient information to identify vulnerabilities and make informed decisions about adaptation. Supporting policies are not yet in place, existing policies compete with each other, and there is no guarantee that future policies will not negate present ones that support adaptation measures. Stakeholders, too, often have competing incentives, and information sharing across competitors—and sectors—is the exception rather than the rule. Skepticism about climate change is an underlying factor that counters forward movement.

Despite the bleak picture painted above, there are both near- and long-term opportunities to address these barriers. Near-term actions include the following:

- Assess vulnerabilities and implement win–win “no regrets” measures
- Enable deployment of commercially available technologies and adaptation practices
- Facilitate information exchange through stakeholder engagement and knowledge sharing

Over the long term, stakeholders should develop a robust adaptation strategy with more transformative and innovative solutions. The strategy would involve enhanced basic and applied energy-related R&D. Improved communications should expand into regular dialogue and exchange between governments and institutions that are active in research, energy system planning, siting, and resilience, as well as among local officials and private sector owners and operators of energy assets. New enabling policy and institutional frameworks must be established:

- Innovation policies to broaden the suite of advanced technologies
- Enabling policies and incentives to accelerate deployment and encourage design, operation, and siting of energy infrastructure in a manner that increases climate resilience
- Measures that promote integration of energy sector climate risks into different levels of development planning
- Integrated resilience policies among countries with key energy trade relationships

Discussion and Conclusion

Reliable energy supply at a reasonable cost is a key driver for improvements in social well-being and economic prosperity. As climate change continues to impact our daily lives, we need to be better prepared for its impacts and build increased resilience into our energy systems. Current energy systems need to be strengthened to be able to withstand climate impacts, and future energy systems need to be designed and built to incorporate projected climate conditions.

Vulnerabilities to the Energy Sector

All energy systems, ranging from traditional fossil fuels to renewable energy systems, exhibit vulnerabilities to climate change and extreme weather. Increasing temperatures, decreasing water availability, extreme weather events, and sea level rise will, individually and in combination, exert impacts on the entire energy sector. Projected impacts could include damage to critical infrastructures, decreased power production and generation capacity, increased electricity demand, decreased efficiency in transportation of critical goods, and other disruptions. Some of these impacts will be localized, while other impacts are projected across broad geographic areas. Due to the interconnectivity of our energy systems, repercussions of local impacts on an energy system will be felt on a larger scale.

Major Barriers Inhibiting Greater Resilience

While a significant amount of work is being done in understanding the impacts of climate on energy systems, gaps still exist. Modelling scenarios and risk analyses are being undertaken by governments and the private sector to better inform climate resilient strategies. However, the pace, scale, and scope of the work is insufficient, given the widespread and pervasive nature of the challenge. Research is needed to better understand the interactions between climate change and energy systems. Better information, data, and modelling are required to improve the design and planning processes of energy systems. Climate change poses risks and opportunities that are unique to every individual country and region, and a better understanding of these impacts is required.

Energy RD&D planners need to build climate considerations into their priority setting processes. Current energy systems are based on certain assumptions drawn from historical events. However, climate change has produced fundamental shifts, and previous assumptions need revalidation. Newer climate models and scenarios need to take climate forecasts into consideration and help build resilience into current and future systems. Climate forecasting and its communication require strengthening so that the uncertainties and probabilities of extreme weather events can be better understood and incorporated into decision making processes. Better information and data will allow energy practitioners to better anticipate climate impacts and, as a result, be better prepared.

Strategies to deal with climate vulnerabilities need to be developed at every scale, starting at the whole energy systems level and continuing down to the last asset that might be impacted. This comprehensive approach requires an understanding of climate impacts and buy-in at all levels, from top management down to the facility operator. It is important to strike the right balance between prevention and anticipation of a climate-related event and to be prepared for recovery.

Climate impacts need to be taken into account during the project design, planning, and management phase, and climate proofing needs to be mainstreamed. Implementing programs and incentives for integrating climate risks at all levels of the planning process will help address this need. Enabling government policies and private sector engagement can accelerate deployment and encourage design, operation, and siting of energy infrastructure to build resilience. While a significant amount of work is being undertaken to strengthen energy sector resilience to climate impacts, concerted action is needed to meet the challenges of anticipated climate change.

Response Approaches

Climate change will have wide and varied impacts on the energy sector, and approaches to address these challenges and build resiliency in energy systems will need to take that full range into consideration. Some of the response approaches identified by the workshop include:

- Undertake a flexible and risk-informed approach that can adapt to new information; stakeholders need to be able to anticipate the changes and plan accordingly.
- Energy sector vulnerabilities are unique to every country and locality; as a result, implementation of climate preparedness measures will be best undertaken at the local or regional level.
- Prioritization of needs and actions is critical, because adaptation and resilience will be a challenge for decades, if not centuries.
- Increased resilience is not an “either/or” approach but a two-pronged strategy that involves undertaking both short-term and long-term resilience efforts simultaneously.
- The importance of climate resilience and its urgency need to be conveyed both to the public and the private sector.
- Company efforts to understand and address climate vulnerabilities can be technically challenging, time-consuming, and detail-intensive: companies need resources and expertise to identify the vulnerability of their assets and thoroughly assess appropriate actions.

RD&D Needs

RD&D needs for building climate change resilience and preparedness will vary for different countries, regions, technologies, and energy systems. The workshop identified some overarching needs for technology development and for building enabling frameworks for climate resilience and preparedness.

Technology

While RD&D needs differ for various energy technologies, the focus is on developing energy technologies that are more resilient to droughts, wildfires, storms, floods, and sea level rise. This includes “hardening” existing energy infrastructure (e.g., transmission and distribution lines, power plants, oil and gas refineries and offshore and onshore oil and gas platforms). Specific technology needs identified include the following:

- For thermoelectric power plant cooling systems (coal, natural gas, nuclear, geothermal, concentrated solar) and oil and gas production, improvements in cost-effective and more energy- and water-efficient technologies are needed, including enhanced water capture/reuse and use of non-traditional waters.
- With an increase in intermittent renewable energy (solar, wind), developing resilient smart grid technologies is becoming increasingly critical. Smart grid technology needs include distribution automation, automated service restoration, robust communications systems, and advanced metering infrastructure (AMI) integrated with outage management systems (OMSs).
- Technologies for farming climate-robust crops that can increase biofuel production is another area that requires further investigation.
- Technologies that help to prevent damage from an extreme weather event or assist in damage assessment need to be developed as well. These include unmanned aerial vehicles (UAVs), selective undergrounding of transmission and distribution lines, and vegetation management.

Enabling Frameworks

Successful development and deployment of advanced technologies in this area require supportive and enabling frameworks that can assist in ensuring that the technologies are effective, affordable, and accessible to the energy sector. Specific needs identified in this area include:

- Holistic approaches to explore and address needs for technology solutions and related RD&D, made available to and adapted to support all stakeholders (government, private, and financial sectors).
- Models that illuminate impacts and vulnerabilities and provide meaningful specificity at the regional and local levels across a range of varied energy systems.
- Risk assessments that cover entire energy systems and take into account the interconnected nature of current energy systems with other sectors.
- Metrics to assess progress and common definitions for such terms as *climate preparedness* and *climate resilience* are needed to drive improvements in the climate resilience of energy systems.
- Cost-benefit analyses to evaluate climate resiliency measures in existing and new systems (e.g., retrofits in power plants) will point to the most effective risk reduction investments.
- New tools will assist in incorporating climate impacts and vulnerabilities into the design, planning, and management procedures of vulnerable energy system components.

Roles of the Different Actors

Addressing energy sector climate vulnerabilities and developing effective response strategies will require action in both the near and long term by all stakeholders, including government, the private sector, academia, and others. Private sector activities focus on conducting vulnerability assessments and implementing win–win, “no regrets” measures. Such measures need to occur at a broader scale and at an accelerated pace. Government and the private sector could expedite RD&D activities by identifying the top priorities for climate resilient investments, developing enabling policies and incentives, and developing better analytical and technical information. Government could support such activities by developing and disseminating tools and information.

Path Forward

The workshop identified critical RD&D needs related to the climate vulnerabilities of energy systems, advanced technologies, and climate response strategies. Workshop presentations and results will be made broadly available, and key findings will be communicated to CERT and the IEA Technology Network to help inform and influence the development of national RD&D agendas on this topic.

To make energy systems better climate prepared and resilient, greater focus needs to be placed on basic and applied energy-related R&D. This focus will ensure that relevant technologies and climate response strategies are developed. Stakeholder involvement is critical as well. Regular dialogues or convening sessions that engage governments, the private sector, and academia will encourage exchange of best practices and lessons learned. Establishing new policy and institutional frameworks will incentivize the development of effective solutions and broaden the suite of advanced technologies. Further, such frameworks will allow for "hardening" of energy systems by encouraging appropriate design, siting, and operation of energy infrastructure. Incorporating climate risks into all levels of system planning is critical.

The workshop concluded by noting that relevant RD&D activities need sharper focus and a concerted push from the international community. Raising awareness and mobilizing the needed resources will require establishing partnerships among governments, the private sector, and academia as well as organized knowledge sharing to ensure that information is publicly accessible. A strong and meaningful RD&D agenda will promote solutions that help to avoid the most severe consequences and reduce costs in the long term, while assuring a safe, affordable, sustainable, and secure energy system for the future.

Appendix A: Acronyms

ACC	Air-Cooled Condenser
AMI	Advanced Metering Infrastructure
AR5	Fifth Assessment Report
BRRC	Blue Ribbon Resiliency Communities
CERT	Committee on Energy Research and Technology
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
DHC	District Heating and Cogeneration
DOE	U.S. Department of Energy
DTU	Technical University of Denmark
EDF	Electricité de France
EGRD	Experts' Group on R&D Priority Setting and Evaluation
EPRI	Electric Power Research Institute
EU	European Union
FARN	Nuclear Rapid Response Force
FIRE	Intervention Force on Electricity Networks
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
Gwe	Gigawatts Electric
IEA	International Energy Agency
INCAH	Infrastructure, Climate Change Adaption and Hotspots
IPCC	Intergovernmental Panel on Climate Change
kWhe	Kilowatt Hour Electric
Mwe	Megawatts Electric
NEA	Nuclear Energy Agency
OECD	Organisation for Economic Co-operation and Development
OMS	Outage Management System
PV	Photovoltaic

RAF	Risk Assessment Framework
R&D	Research and Development
RD&D	Research, Development and Demonstration
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (Netherlands Organisation for Applied Scientific Research)
TU Delft	Delft University of Technology
TWhe/a	Terrawatt Hours Electric per Annum
UAV	Unmanned Aerial Vehicle
U.S.	United States
USD	United States Dollars

Appendix B: Speakers

Name	Position & Affiliation
Battey, Hoyt	Water Power Market Acceleration and Deployment Team Lead, U.S. Department of Energy
Boot, Pieter	Head of Department, Netherlands Environmental Assessment Agency
Caneill, Jean-Yves	Head of Climate Policy, Electricité de France
Dell, Jan	Supply Chain Sustainability, ConocoPhillips, United States
Dijkema, Gerard P.J.	Faculty of Technology, Policy and Management, Delft University of Technology, the Netherlands
Dorsey, Brent	Director, Corporate Environmental Programs, Entergy, United States
Halsnaes, Kirsten	Professor, Technical University of Denmark (DTU), Management Engineering
Hattori, Takashi	Unit Head, Environment and Climate Change Unit, International Energy Agency
Hunter, David	Manager, Federal and Industry Affairs, Electric Power Research Institute, United States
Kool, Rob	Chair EGRD, Manager, NL Agency, the Netherlands
Marlay, Robert	Vice-Chair EGRD, U.S. Department of Energy
Paillere, Henri	Nuclear Energy Analyst, Organisation for Economic Co-operation and Development, Nuclear Energy Agency
Ritsema, Ipo	Director, Deltares, The Netherlands
Snorrason, Arni	Director-General, Icelandic Meteorological Office
Vaessen, Peter	Principal Consultant, DNV GL Group, Norway
Verstraeten, Christelle	Analyst, International Energy Agency
Weidlich, Ingo	Project Coordinator, Research and Development, AFGW, Germany
Zamuda, Craig	Senior Advisor, Office of Climate Change Policy and Technology, U.S. Department of Energy

Appendix C: Agenda

Day 1

9:00		Welcome	*Bert Stuij, Manager Energy Strategy and Transition, Nl Agency*
9:10		Introductions & Meeting Objectives	*Rob Kool, Manager, Chair EGRD, NL Agency*
9:30		Opening Remarks	*Robert Marlay, Vice Chair EGRD, US*
OVERVIEW OF ENERGY SECTOR VULNERABILITIES TO CLIMATE CHANGE			
Moderator: Craig Zamuda			
10:00	1	IEA Energy Security Nexus Forum Initiative	*Takashi Hattori, IEA/SPT/EED*
10:30		Break	
11:00	2	Energy Preparedness and Resilience: A Netherlands Perspective	*Pieter Boot, Netherlands Environmental Assessment Agency (PBL)*
11:30	3	U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather	*Craig Zamuda, Senior Advisor, Climate Change Policy and Technology, U.S. Department of Energy*
12:00	4	Climate Impacts on Renewable Resources in the Nordic Countries	*Árni Snorrason, Director-General at Icelandic Meteorological Office*
12:30		Discussion	
13:00		Lunch	
ENERGY PRODUCTION AND CLIMATE RESILIENCE STRATEGIES			
Moderator: Birte Holst Jørgensen			
14:00	5	Integrating Climate Resilience in Renewable Energy Investments in The North Sea Area	*Professor Kirsten Halsnaes, DTU Management Engineering, Technical University of Denmark*
14:30	6	Oil and Gas Production	*Jan Dell, Supply Chain Sustainability ConocoPhillips, U.S.*
15:00	7	RD&D activities, gaps and opportunities: Électricité de France Perspective	*Dr. Jean-Yves Caneill, Head of Climate Policy,Électricité de France*
15:30	8	Thermoelectric Power Plants	*Brent Dorsey, Entergy, U.S. (via webinar)*

16:00		Break	
ENERGY DISTRIBUTION /DEMAND AND CLIMATE RESILIENCE STRATEGIES			
Moderator: Birte Holst Jørgensen			
16:30	9	Hydropower	*Hoyt Battey, U.S. Department of Energy*
17:00	10	Climate change and the electricity infrastructure - exploring why, where, how and when to adapt.	*dr.ir. Gerard P.J. Dijkema, Faculty of Technology, Policy and Management, TU Delft, The Netherlands*
17:30	12	Near future challenges for R&D in the District heating and Cooling sector	*i. A. Dr.-Ing. Ingo Weidlich Forschung und Entwicklung*
18:00		Discussion	
18:30		Close Day 1	
		Dinner	

AGENDA
Day 2

RD&D ACTIVITIES UNDERWAY AND PRIORITY GAPS AND OPPORTUNTIIES FOR CLIMATE RESILIENCE AND PREPAREDNESS			
Moderator: Rob Kool			
9:00	13	RD&D activities, gaps and opportunities: Water and energy	*Ipo Ritsema, Director, Deltares*
9:30	14	RD&D activities, gaps and opportunities: IEA Perspective	*Christelle Verstraeten, IEA*
10:00	15	RD&D activities, gaps and opportunities: Energy & Water Nexus - U.S. perspective	*David Hunter, Electric Power Research Institute , U.S.*
10:30	16	RD&D activities, gaps and opportunities: wind and electric grids	*Peter Vaessen, Principal Consultant, DNV GL Group*
11:00	17	RD&D activities, gaps and opportunities: Nuclear Power: OECD NEA Perspective	*Dr Henri Paillere OECD Nuclear Energy Agency*
12:00		Discussion	

12:30		Lunch	
FRAMEWORK FOR ACCELERATING RD&D INVESMENT IN CLIMATE RESILIENT ENERGY TECHNOLOGIES			
Moderator: Herbert Greisberger			
14:00	19	Barriers and Incentives for Future Investment – IEA Perspective	*Takashi Hattori, IEA/SPT/EED*
14:30	20	Barriers and Incentives for Future Investment – U.S. Perspective	*Craig Zamuda, Senior Advisor, Office of Climate Change Policy and Technology, U.S. Department of Energy*
15:00		Discussion	
SYNTHESIS AND CONCLUSIONS			
Moderator: Robert Marlay			
15:30		Discussion and key recommendations	
16:30		Workshop conclusions	
17.00		End of workshop	

Appendix D: Useful References

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