Climate change vulnerability and adaptation in the energy sector, focus on the nuclear power sector

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OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA)
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Gradual change: *Changes in mean and variability over decades*
- Temperature
- Precipitation
- Wind patterns
- Insolation
- Sea level rise

Extreme events: *Occurrence above or below threshold, near to boundaries of observed values*
- Heat waves, heavy precipitation, drought, high winds/storms, etc...
- Increasing frequency and intensity, affecting larger areas, prevailing longer

Source: Derived from IPCC
Mitigation and adaptation

Much research has been done on how to mitigate climate change (CC) through changes in the energy system.

- Few studies have evaluated the reverse: the impact of CC and extreme weather (EW) on energy infrastructure.
- Expectations are that regardless of mitigation action now, there will be a certain level of CC (IPCC AR5 WGI).

⇒ identify the impacts of CC and EW and adapt to lessen those impacts.
Impacts on energy infrastructure

Extraction/Resource → Transport → Conversion → Transmission & Distribution
IAEA activities

IAEA workshop organised in 2010
⇒ Raised interest in Member States
⇒ Results published in *Climatic Change*

Ongoing study: *Adaptation of nuclear and non-nuclear energy infrastructure*

- Techno-economic evaluation
- Long-term climate change / Extreme weather
- Country case studies: Argentina, Cuba, China, Egypt, Ghana, Pakistan, Slovenia
CRP Case study: Argentina

- Observed climate trends and regional projections for CC → main vulnerabilities presenting potential hazards for the electricity system.

Major vulnerability
⇒ Decrease in rainfall / streamflow of the rivers in the regions of Cuyo and Comahue
⇒ Home to ~ 52% of the country’s hydropower plants (HPPs) capacity (> 18% of the country’s installed capacity)

Quantification and adaptation
⇒ Model-based, reference vs risk-based scenarios
⇒ Decline in HPPs generation to be compensated by up to 4% of country’s installed capacity by 2040

- Vulnerability analysis indicates no threat to NPPs

⇒ Methodology for siting of nuclear power plants, incl. possible flooding (eg. 23 m above the level of Parama river for Atucha I and II) and water availability for cooling

Source: Derived from CNEA
Desinventar database: key vulnerability in the electricity sector to EW events

Special focus: heat waves / cold waves and power outages

Vulnerability

⇒ increased vulnerability of the electricity system, in particular its distribution component;

⇒ Distribution system more vulnerable to heat waves than cold waves, more vulnerable in megacity than smaller cities suffering equivalent heat waves conditions

Source: Derived from CNEA
CRP Case study: Slovenia

- GIS supported vulnerability evaluation
- Risks to power grids due to ice storms
  - Siting of transmission line
  - Siting of windfarms

Spatial Attractiveness

Environmental Vulnerability

Risk-assessed spatial suitability for windfarms

Risk-assessed siting for two alternative power lines

Windfarms

⇒ Very suitable area: 31 km²
⇒ Potential capacity: 930 MW
⇒ Potential annual energy production: 1.68 TWh

Source: Derived from “Jožef Stefan” Institute
Different analytical frameworks – identify, assess, adapt
Cumulative investment over 2014-2040: US $25 trillion in oil and gas supply; US $20 trillion in power supply
Sectors with large inertia – long lived assets
Design and build with CC in mind: climate-safe

Source: Derived from IEA
Examples of CC impacts on NPP

- Floods
- Storms
- Frazil ice
- Drought / heat wave
- Forest fires
- Ice storms
How can CC events affect a NPP?

Containment: ultimate barrier between reactor and environment

Grid: take power from NPP and supply NPP with power

Storms (wind, debris), ice storms, forest fires, heat wave

Storms (debris), heavy rain, floods, frazil ice, heat wave, drought, algae, ...

Auxiliary blds: emergency power gen. & other equip.

Floods, heat wave, snow storms

Cooling water: cool condenser & remove decay heat
Cooling for thermo-electric power plants

Normal Operation

Fossil
- Boiler (furnace)
- Steam
- Condenser Cooling Water
- Generator

Nuclear
- Containment Structure
- Steam Generator
- Condenser Cooling Water

Same issues:
- Rankine cycle
- Different cooling options (once-through, closed, hybrid...), same environmental regulations (intake, thermal releases), etc

Accidental Conditions

Shut down → no fuel → no residual heat

Circulating Water System (CWS)

Essential Service Water System (ESWS) to remove residual (decay) heat: “Ultimate Heat Sink”
Cooling for thermo-electric power plants

Thermal Efficiency decreases with increasing cooling temperature
(thermodynamics AND environmental regulations)

Increased ambient temperatures
→ reduced efficiency & environmental compliance
→ reduced electric output (revenue stream)
What data do we have?

- IAEA Outage data (loss of kWh production) according to several classifications
What data do we have?

### Outages per cause from 2004 to 2011

<table>
<thead>
<tr>
<th>Cause</th>
<th>Duration (1000 h)</th>
<th>Energy Loss (TWh)</th>
<th>No. of events</th>
</tr>
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<td>A</td>
<td>2 728</td>
<td>648</td>
<td>12 039</td>
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<td>B</td>
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<td>561</td>
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<td>746</td>
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<td><strong>Total</strong></td>
<td><strong>15 665</strong></td>
<td><strong>5 054</strong></td>
<td><strong>35 076</strong></td>
</tr>
</tbody>
</table>

IAEA PRIS database

**Awareness of issues but limited economic impact so far**

Outages caused by environmental conditions

- 17.7% duration
- 2.2% Energy Loss
- 9.2% Events
What data do we have?

- IAEA/NEA incident database, data from national reports, nuclear regulators and operators. Examples of shutdowns due to external events:
  - Loss of “ultimate heat sink”, Cruas NPP, France, December 2009 (due to blockage of ESWS intake by massive quantity of algae)
  - CWS water intake blockage, Olkiluoto NPP, Finland, January 2008 (due to frazil ice)
  - CWS water intake blockage, Osarshamn NPP, Sweden, September 2013 (due to jelly fish)
  - Loss of off-site power, Dungeness B NPP, UK, October 2013 (caused by debris landing on power lines during storm)

- Other data provided in the course of the NEA study in the form of “case studies”

- Data about incidents themselves, but often information about measures required by the regulators to reduce the risks of similar events.
Adaptation Measures in Finnish NPPs

- **Olkiluoto NPP:**
  - Measures to prevent blockage (by snow) of air intakes of heating, ventilation and emergency diesel generators
  - OL3: heating of air intakes
  - Pumping “warm water” upstream of cooling water intake to prevent frazil ice formation

- **Loviisa NPP:**
  - Construction of air cooling system (tower) to supplement sea cooling in case of frazil ice or other pbs with sea water
  - Heating water intake grids to prevent frazil or pumping warm water upstream
  - Study on building deep water intake in case of high sea temperatures (possibly economical in the future)
Adaptation Measures in French NPPs

- **Le Blayais flooding (Dec. 1999)**
  - High tide + storm surge + waves generated by high wind in the estuary (not linked to CC) → exceeded the worst-case “design scenario”
  - Water went over the dikes – flooding of NPP site and in units 1 & 2
  - INES level 2

- **Review of flood risks / adaptation**
  - Re-assessment of flood risks for all 19 NPPs
  - Improvements where necessary (elevated dikes, water tight doors, plugging, etc) & specific flood procedures
  - Upgraded protection of most NPP against floods – for a cost of 110 M€

EDF presentation, RIC 2010, External flood and extreme precipitation hazard analysis
The cost of ‘inaction’

- **Direct impact:**
  - Loss of production due to partial/full outage because of:
    - compliance to environmental regulations (e.g. thermal releases) or safety regulations (max. temp. cooling water for safety-related cooling systems) or
    - Event affecting operation of NPP (e.g. the cooling system) or
    - Event affecting the transmission grid.
  - Loss of efficiency due to higher cooling water temperature (data not publically available)
  - Cost of repairs, refurbishment, safety upgrades

- **Indirect impact:**
  - Purchase by utility of power on “spot market” to compensate for loss of production
  - Compensation of customers (energy-intensive industry) required to reduce their electricity consumption (load management/shedding)

- **Who pays what?** Insurers, operators, tax payers?
Dealing with CC in the nuclear sector

- Guidelines (e.g. siting), safety standards, safety assessments and regulations

- Design (e.g. taking into account CC risks)

- Technology (e.g. cooling technologies, reactor design, on-site water production)

- Planning and plant management (e.g. based on demand forecast, outage planning)

- Demand-side management
Technical solutions

Containment: ultimate barrier between reactor and environment

- Flood dikes
- Water-tight doors
- AC

Floods, heat wave, snow storms

Storms (wind, debris), ice storms, forest fires, heat wave

- Anti-collapsing towers
- Under-ground lines

Auxiliary blds: emergency power gen. & other equip.

- Filtering systems
- Deep intake
- Heated water intake
- Recirculating release
- Alternative cooling sources

IAEA
International Atomic Energy Agency

NEA
NUCLEAR ENERGY AGENCY

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R&D needs

- **Technology:** (objectives: reduced usage of water / reduced impact / reduced costs)

  - Cooling technologies:
    - Closed cooling systems, hybrid systems
    - “low” profile cooling towers (public acceptance)
    - Dry cooling (e.g. Bilibino NPP, Russia)
    - More efficient Heat Exchanger equipment (e.g. Condensers)

  - Modelling of cooling water intakes & thermal releases to reduce environmental impact and/or improve efficiency (*)

  - non-traditional water resources (e.g. Treated waste water) (e.g. Palo Verde, AZ, USA)

  - On-site production of “fresh” water (desalination)

  - Innovative reactor designs (e.g. Gen IV, higher operating temperatures/efficiency) - Advanced power conversion technologies (e.g. SCO2)
Weather forecast: (objectives: improved management of supply [e.g. Outages] and demand)

Planning based on better assessment of demand.
- "air temperature" is most important parameter driving electricity demand.
  (e.g. In France, in winter, -1°C ~ 2300 MW electricity production)
- predicting consumption with 1 to 2 weeks lead-time can help optimise selection of generating units to meet demand.

Planning outages:
- planning refuelling and maintenance outages during peak heat periods (provided outages can be balanced by increased production at other sites or imports) for most vulnerable units (located on rivers)
- After 2003 heat wave, EDF reviewed its maintenance planning to ensure operation of all coastal units during summer

R&D to improve forecasting tools:
- to select, size and engineer future plants, test robustness against CC / extreme weather events.
- Multi-scale approaches to combine long-term forecasts (several decades, time scale of investment / construction / operation) with short term projections (for operational purposes, fleet management)
Conclusions

- **New plants:** (typically 60 year lifetime → operation until ~2080)
  - Design, siting – take into account CC risks. (max. sea level rise, max. temp., max. wind speed, etc...).

- **Existing plants:**
  - Siting and safety case take into account (known) extreme weather events
  - Safety requirements are always a driver for change (often, safety upgrades improve CC resilience too). For non-safety issues: (e.g. thermal efficiency, outages due to environmental reasons), “economic decision”

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<table>
<thead>
<tr>
<th>INACTION</th>
<th>ADAPTATION</th>
</tr>
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<tbody>
<tr>
<td>o cost of adaptation vs. electricity market ‘economics’ (wholesale price, overcapacity)</td>
<td>o safety requirements</td>
</tr>
<tr>
<td>o adaptation can lead to reduced power output (e.g. closed cycle vs. direct cooling)</td>
<td>o fleet operator</td>
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<tr>
<td>o single plant operator</td>
<td>o remaining lifetime (~ 20-30y)</td>
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<td>o remaining lifetime (~ 10y)</td>
<td>o “high” number of events</td>
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<tr>
<td>o “low” number of events</td>
<td>o security of energy supply</td>
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</tbody>
</table>

Need to make the economic case for resilience
Conclusions

- Importance of addressing (generation + grid + consumers) together to design resilient energy systems

- (Short term) economics not enough to drive changes (viewed as costs):
  - Role of governments to put in place investment framework for long term
  - Role of regulations to drive technological changes.

- In terms of R&D needs / activities with respect to nuclear power & CC:
  - Cooling & other technologies to reduce water dependence
  - Forecasting methods to improve plant/fleet management & balance supply & demand
  - Safety assessment methods to address future CC events in design & safety cases
  - Economic assessment methodology to make a better case for adaptation.

- Nuclear power technology is adapting to CC to make it safer & more resilient against Climate Change: a robust low C generating solution for the future!