Vulnerability of and adaptation in energy systems to climate change and extreme weather events

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International Atomic Energy Agency

Preamble: IAEA Mandate and Work

"Atoms for Peace" to promote safe, secure and peaceful nuclear technologies:

- Safety and Security: Nuclear installations, standards
- Safeguards and Verification: NPT + Addl. Prot.
- Science and Technology - peaceful applications of N science and technology: Health, agriculture, water, …
- Nuclear Energy: Efficient and Safe Use of Nuclear Power → Planning and Economic Studies

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Preamble: Why on Earth?

IAEA: >150 MSs; ~30 using NE, ~ 60 interested
NE-PESS assistance to MS includes:
- tools & capacity building to explore own SED options
- assess 3E linkages: economy-energy-environment

Related activities:
- develop and disseminate energy planning tools: models
- train analysts in integrated energy planning
- >100 developing country MSs: energy models
- provide tech. guidance: national energy studies

CC & EWE - Energy systems in developing countries:
- most vulnerable under current climate
- bulk of new investments – long lifetimes
- hedging: reduce vulnerability vs retrofit afterwards

3

Overview

1. CC - Weather extremes - energy systems
2. Selected energy sources/technologies
3. Weather extremes in energy supply models
4. Summary and conclusions

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1. CC - Weather extremes - energy systems

Vulnerability of Energy Systems to Climate Change and Extreme Events – less explored

Motivations:

- CC → possible increases in frequency and intensity of extreme weather events
- Energy systems: vulnerable under current climate regime and weather patterns; efforts to reduce vulnerability
- IEA: USD 26 trillion investments to provide demand; +10.5 trillion to reduce GHGs - Clim/weather proofing
- IAEA: account for WEs in energy planning

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1. CC - Weather extremes - energy systems

Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend[b]	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely*[c]	*Likely*[d]	*Virtually certain*[d]
Warmer and more frequent hot days and nights over most land areas	*Very likely*[e]	*Likely (nights)*[d]	*Virtually certain*[d]
Warm spells/heat waves. Frequency increases over most land areas	*Likely*	*More likely than not*[f]	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not*[f]	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not*[f]	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis)[g]	*Likely*	*More likely than not*[f,h]	*Likely*[i]

1. CC - Weather extremes - energy systems

Sector/ Extreme	Tempera -ture	Precipit- ation	Wind	Tropical cyclones	Floods	Droughts	Coastal storms	Forest + wild fire	Landslides
coal fuel cycle									
oil and gas									
thermal power plants									
hydropower									
nuclear power									
solar energy									
wind power									
electric grid									

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2. Selected energy sources/technologies

Coal fuel cycle: from mines to waste disposal / CCS

Mining: vulnerability depends on mining method

e.g., surface: temp, rain, floods (QLD 2010);

deep: water

Processing: coal cleaning: water; droughts

Storage: floods

Transport: usual weather impacts: rail, barges, ports

Back end:

Combustion by-products: fly-ash, bottom ash, boiler slag: wind, precipitation, floods

CCS: water needs: drought

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2. Selected energy sources/technologies

	Without CO_2 Capture	With CO_2 Capture	% change with CO_2 capture
*Water Consumption Factors (gallons per MWh net power)**			
Nuclear[‡]	720	--	
Subcritical PC	520	990	+90%
Supercritical PC	450	840	+90%
IGCC, slurry-fed	310	450	+50%
NGCC	190	340	+80%
Cooling duty factors (MMBtu per MWh net power)			
Subcritical PC	4.7	11	+130%
Supercritical PC	4.1	9.3	+130%
IGCC, slurry-fed	3.0	3.7	+20%
NGCC	2.0	4.2	+110%

2. Selected energy sources/technologies

Thermal power plants – vulnerable to CC & EWEs:

Higher air temp: reduces efficiency of thermal conversion (Carnot) → capacity loss 1-2%/°C T^

A: none (not even Euro), but SC/USC higher efficiency

Higher water temp/lower availability: load reduction, less generation (.1-5.6% across scenarios)

A: using non-traditional water sources (oil/gas fields, mines, treated sewage)

re-use of process water from flue gases (can cover 25-37% of cooling needs)

coal drying, condensers (^ heating value, v water T)

condenser at cooling tower outlet: reduce evaporation loss

alternative techs: dry cooling towers, regenerative cooling

Costs: US$ 250k-500k/MW

2. Selected energy sources/technologies

Thermal power plants – vulnerable to CC & EWEs:

More hot: exacerbates impacts of warmer temps (above) + self-ignition of stockpiles – A: cooling (water!)

Less cold: less corrosion, less freezing of stockpiles

Drought: exacerbates impacts of warmer temps (above)

More heavy precip: damage; coal drenching → reduced boiler efficiency (~1%/10% increase in moisture)

A: change reference climate for drainage design

Extreme wind: damage to building & cooling towers

A: Adjust construction standards

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2. Selected energy sources/technologies

[Sunshine State]

Solar energy: thermal heating-TH, PV, CSP – diverse CC & EWE:

^ mean temp: ^ TH performance; v PV efficiency (0.5%/°C T^); v CSP efficiency; faster aging

Cloudiness: ^ negative, v beneficial for all types; evacuated tube collector for TH can use diffuse insolation; CSP cannot use diffuse light

A: diffuse light: rougher surface for PV; optimize mounting angle; apply tracking system for TH and PV; install/increase storage for CSP

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2. Selected energy sources/technologies

Solar energy: thermal heating-TH, PV, CSP – diverse CC & EWE:

Hot spells: PV-material damage; PV+CSP: reduced output - CSP efficiency v by 3-9% as ambient temp increases from 30 to 50°C

A: cooling PV panels (passive or active)

Cold periods: TH-reduced output (heat loss from unglazed collectors)

A: anti-freeze chemicals in cold regions, but: heat exchanger and secondary cycle are needed

Wind storms: material damage

A: strengthened mounting structure

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2. Selected energy sources/technologies

Solar energy: thermal heating-TH, PV, CSP – diverse CC & EWE:

Wind & sand storms: v power output (sand & dust deposition, made worse by higher humidity)

A: cleaning, tracking system to rotate panels out of wind; elastomeric coating instead of glass

CSP: thermal storage; turning mirrors upside down or out of wind (tower)

Hail: material damage to TH; fracturing glass plate cover; damage to photoactive material

A: use reinforced and thicker glass; increase protection

Lightning: damage to inverter

A: apply lightning protection

Solar evolving: new designs/materials → reduce vulnerability

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2. Selected energy sources/technologies

Electricity grid: overhead lines, underground cables, substations, transformers, control centres

~50% of grid system faults caused by weather effects

Lightning: line, earth wire, transmission tower: flashover

Wind: debris blown against conductors: short circuit;
line conductors swing or oscillate: flashover
trees blown over → damage overhead line
very high winds: mechanical damage

High temperature: overhead line to trees: flashover

Ice: ice build-up on insulators, switchgear: flashover

Ice storms: freezes on overhead lines: collapse

Heavy snow: trees falling over overhead lines

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2. Selected energy sources/technologies

Electricity grid – adaptation options:

Lightning: more earth wires, spark gaps, surge arresters

Protection: safety corridors, vegetation management, physical protection

Network redundancy: alternative supply routes

Future: design changes –
heavier snow and ice loading
higher wind speeds

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3. Weather extremes in energy supply models

IAEA: energy planning tools –

Energy supply model: MESSAGE

Model for Energy Supply System Alternatives and their General Environmental impacts

Software designed for setting up optimization models of *energy supply systems* to assess capacity expansion and energy production policies

A *physical flow model*: for a given vector of demands for energy goods or services, it assures sufficient supplies utilizing available technologies and resources

Based on specified criteria, it *optimizes* the system expansion and operation

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17/32

3. Weather extremes in energy supply models

Criteria and Techniques

Criteria: Cost minimization; Profit maximization
Multi-objective optimization

Mathematical Techniques: Linear programming
Mixed-integer programming; Non-linear programming

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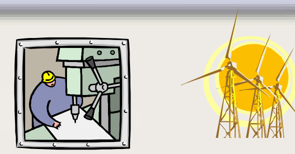
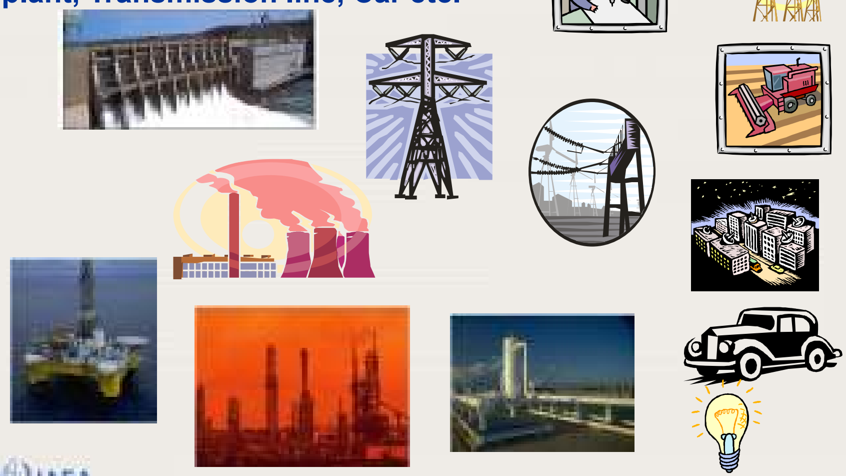
3. Weather extremes in energy supply models

Elements of Energy Supply System:

Oil extraction facility, Hydro power plant, Transmission line, Car etc.





3. Weather extremes in energy supply models

Technologies in MESSAGE:

A *technology* represents a process that

- *Converts* one energy form into another energy form or into energy service
  - e.g. conversion of crude oil to oil products, oil products to electricity, electricity to light
- *Transfers/transmits/distributes* an energy form
- *Supplies/produces* an energy form (e.g. hydro power, oil import)

3. Weather extremes in energy supply models

Technologies in MESSAGE

Characteristics of a conversion technology that can be built into the model may include:

- Multiple inputs and outputs
- Seasonal variation in capacity
- Efficiency varying with time
- Costs varying with time
- Limits on production
- Capacity build-up constraints
- Market penetration
- Emission control

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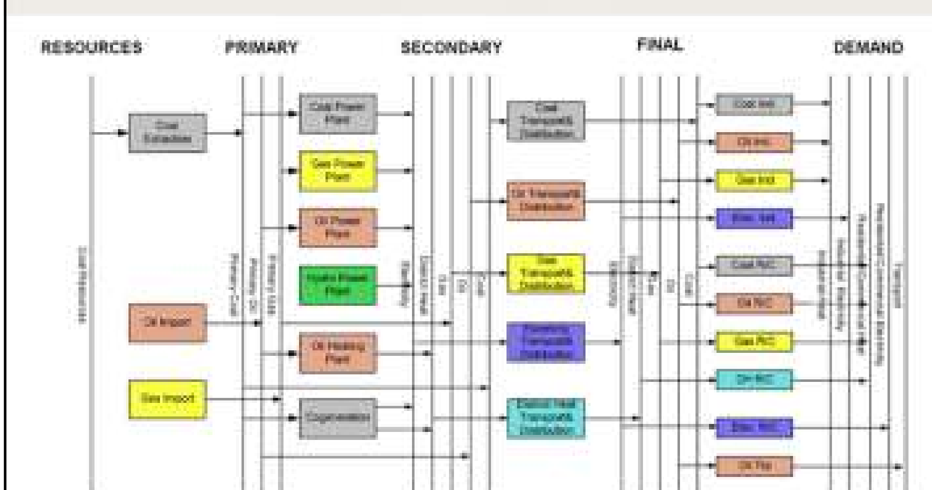
3. Weather extremes in energy supply models

Energy chain in MESSAGE



3. Weather extremes in energy supply models

MESSAGE: powerful, flexible; Many options to include:
- *impacts* of extreme weather events: supply chains, technology availability factors, technological specifications
- *hedging* against impacts: supply reliability requirements, reserve margins, technology options (e.g., dry cooling)

➔ optimal (least cost) energy portfolio w/extremes

Renewables and storage: already included

Intermittency: simplified representation

Development need:

Better representation of extreme weather impacts – Integrate risk analysis methods

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4. Summary and conclusions

CC and EWEs → energy systems: need to prepare

Options for managing weather impacts:

adaptation: technological, operational adjustments

vulnerability reduction: existing: structural changes

new build: design and construction innovation

Energy planning - capacity expansions:

account for impacts on supply chains

seek optimal supply portfolio w/ hedging

Tool: energy supply model w/ risk analysis features

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