ENERGY AND CLIMATE CHANGE: IMPACTS AND ADAPTATION

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- 70% of GHGs come from electricity generation, from industry, buildings and transport.
- If we continue as we are today, economic and population growth will imply tripling of emissions.
- But climate is changing anyway and we have to take measures to adapt to it.
- The energy sector is very vulnerable to this change.

Most Discussion on Energy and CC has Focussed on Mitigation

Impacts on the Energy Sector

- General impacts on different parts of the energy sector
- Impacts by source with respect to resource endowment
- Impacts by source with respect to energy supply
- Impacts on demand
- Cross sectoral impacts

Impacts on Energy	Temperature Increase	Other Climate Variables Floods, droughts, EEs, rainfall, cloud cover
Thermal Power	No impact on supply but reduced efficiency due to higher temp. of cooling water.	Decrease in fuel availability from floods, storms.
Hydro Power	Increased evaporation reduces generating capacity.	Reductions in generating capacity via floods (more storage), droughts (less runoff)
Biomass	Effects on NPP could be +ve or −ve.	Most impacts would reduce NPP (EEs, droughts, floods)
Wind	Output decreased due to decrease in air density	Most impacts would reduce generating capacity
Solar	Efficiency decreases	Most impacts reduce generating capacity except droughts.
Transmission/ Distribution	Changes in capacity utilization	Reductions in system reliability
Energy Demand	Heating demand down Cooling demand up	Power outages to end users

- Hurricane Sandy generated an estimated loss of $5 billion for business interruption (Kinetic Analysis Corp). Significant damage to business was due to lack of power, especially for small business (CNN Money, 30/10/2012).
- As a consequence of Fukushima accident Japan faces a severe electricity shortfall. (National Geographic Daily news, 8/3/2012). "The cost to purchase an additional 20 million tons of LNG due to make up for the loss of the nuclear power plant outages will be $44 billion (3.4 trillion yen)".

Extreme events affect business due to loss of energy even in developed countries

- Hydropower: Resource Endowment .
  - Reduced production impacts already being observed in some regions (Andes cordillera, Zambezi Basin, Rio Lempa basin and the Simú-Caribbean basin of Central America)
  - Stability of stream flows is predicted to be impacted. Studies for some rivers in South America confirm this but actual effects are very basin specific.
  - An important factor is the competing demand for water especially agriculture, which will alter availability for hydropower.

Climate Impacts on Energy Systems

- Hydropower: Energy Supply.
  - Climate change adds a significant amount of uncertainty to the already uncertain design and operation of hydropower systems.
  - Modeling by the Norwegian University of Science and Technology examined climate impacts on river flows and hydropower generation to 2050. Systems at highest risk had both a high dependence on hydropower generation for electricity and a declining trend in runoff. South Africa is quoted as one example with a potential reduction of 70 gWh per year in generation by 2050. Afghanistan, Tajikistan, Venezuela, and parts of Brazil face similar challenges.
  - Variations in runoff can be accommodated through increased storage capacity but obviously at an increased cost.

Climate Impacts on Energy Systems

Impacts on supply of hydropower

- Wind: Resource Endowment
  - Expected higher temperatures and low humidity in southeastern Europe are expected to be accompanied by shifts in the northern extent of wind fields in the Mediterranean that affect the endowment of wind energy
  - Soil instability in permafrost areas affected by warming may compromise construction of wind farms that involve installation of large towers subjected to forces from the rotating turbine.
  - Climate variables can also affect vertical wind speed profile; such effects are very site specific.

Climate Impacts on Energy Systems

- Wind:Energy Supply
  - The energy contained in wind is proportional to the cube of the wind speed, which means that alterations in the latter can have significant impacts on the former.
  - Hence any analysis of climate impacts on wind energy supplies should include the frequency distribution of wind speeds as well as the average value.
  - Although wind power production is likely to be potentially more vulnerable to the negative impacts of climate change than hydropower generation, wind power systems have smaller life spans, making them more adaptable in the longer term.
  - In this context, climate impact studies on wind power systems should focus on the total exploitable wind resource, indicating the future availability of power generation and identifying/prioritizing areas for site-specific viability assessments

Climate Impacts on Energy Systems

- Solar Power: Resource Endowment
  - Climate change can affect the solar energy resource by changing atmospheric water vapor content, cloudiness, and even cloud characteristics that affect atmospheric transmissivity.
- Solar Power:Energy Supply
  - A reduction in solar radiation reduces efficiency. For example, a 2% decrease in global solar radiation will decrease solar cell output by 6%.
  - Efficiency of CSP would be reduced by higher mean temperatures and could also be impacted by available water

Climate Impacts on Energy Systems

- Wave & Tidal Energy: Resource Endowment
  - A 20% decrease in mean wind speed lowers available wave power levels by 67%, while an equivalent increase raises them by 133%. Changes in wave formation in the future are difficult to predict. Impacts on tidal energy unknown.
- Liquid Biofuels: Resource Endowment
  - Complex impacts on NPP, depending on temperature, rainfall and carbon fertilization effects.
- Liquid Biofuels:Energy Supply
  - Studies for Brazil indicate higher potential yields with climate change but likely to require irrigation during dry periods.

Climate Impacts on Energy Systems

- Thermal & Nuclear Power: Energy Supply
  - Coal-fired & nuclear power plants both operate under a Rankine cycle. Increased temperature raises the specific volume of air and energy consumption in the compressor and reduces the amount of net energy generation.
  - Same applies to natural gas. A 33ºC increase in ambient temperature (common in deserts on a daily basis) could cause an 8.4% reduction in the heat rate and a 24% reduction in the power output of a single-cycle gas turbine.
  - In addition, the significant amounts of water needed to cool thermal power facilities make them vulnerable to fluctuations in water supplies.
  - With climate change, coal-based generation will increasingly be linked with carbon capture and storage (CCS) technology that will increase the demand for water to cool amine-based wet scrubbing processes and for CO2compression. This could as much as double the amount of water used per kW of electricity delivered.

Climate Impacts on Energy Systems

- <u>Oil & Gas Resources: Resource Endowment</u>
  - Climate change may force the shutting down of oil- and gas-producing areas (for example, those lying on melting permafrost in Alaska).
  - But it could also increase the feasibility of exploration in areas of the Arctic through the reduction in ice cover.
  - In Siberia, for instance, the actual exploration challenge is the time required to access, delineate, produce, and deliver oil under extreme environmental conditions, where temperatures in January range from −20°C to –35°C. Warming may ease extreme environmental conditions, expanding the production frontier.

Climate Impacts on Energy Systems

- <u>Oil & Gas Resources:Energy Supply</u>
  - Oil and gas production from offshore facilities, as well those in low-lying coastal areas, are disrupted by extreme events, such as hurricanes, that can lead to shutdowns.
  - Hurricanes in the Gulf of Mexico in 2004 and 2005 resulted in a large number of destroyed and damaged offshore oil and gas structures: more than 124 platforms were destroyed and over 660 structures were extensively damaged.
  - Production is also affected by structural damages caused by other extreme events, such as flooding due to sea level rise and storm surges that may cause erosion and other damage.

Climate Impacts on Energy Systems

- Oil & Gas Resources:Energy Supply
  - At high latitudes (for example, near the Arctic), rising temperatures and permafrost melt can compromise the structural integrity of the energy transfer and production infrastructure built upon it.
  - Oil refining is a large water consumer and is thus affected by lower water availability. Total water consumption in an average U.S. refinery is estimated at 65 to 90 gallons of water per barrel of crude oil. Some refineries already face water resource competition issues without considering climate change (for example, REPLAN, the largest refinery in Brazil). Water demand in oil refineries can also rise as a result of higher temperatures and its use in cooling units (around 50%).

Climate Impacts on Energy Systems

- Adaptation is also important for a country such as Spain due to its great dependency on energy imports and expected water shortages.

Possible Impacts on Spain

- Spain imports energy to a value of 4.5% of GDP. Climate vulnerability could affect some of these energy imports.
- 82.7% of the primary energy consumed was imported in Spain in 2010 (Observatorio de Energía y Sostenibilidad en España 2011, Cátedra BP de Energía y Sostenibilidad, Universidad Pontificia Comillas). This has declined a bit in 2011 thanks to renewables.
- Significant water shortages are predicted for Spain (IPCC, 2007). 2011 hydro production was lower that the historic average (IDAE, Balance energético 2011).

Possible Impacts in Spain

- Rübbelke and Vögele (2010) analyse how water scarcity for cooling purposes may affect electricity supply in EU.
- They show under several scenarios that:
  - Less power plant capacity will be available in France and thus it will export less electricity.
  - Nuclear plants in Germany and Switzerland will also face cooling problems. As they rely on imports from France they will also reduce exports.
- Adaptation in nuclear sector requires it to focus upstream on water supply management and downstream on electricity generation in power plants.

Possible Impacts on Nuclear Power in Europe

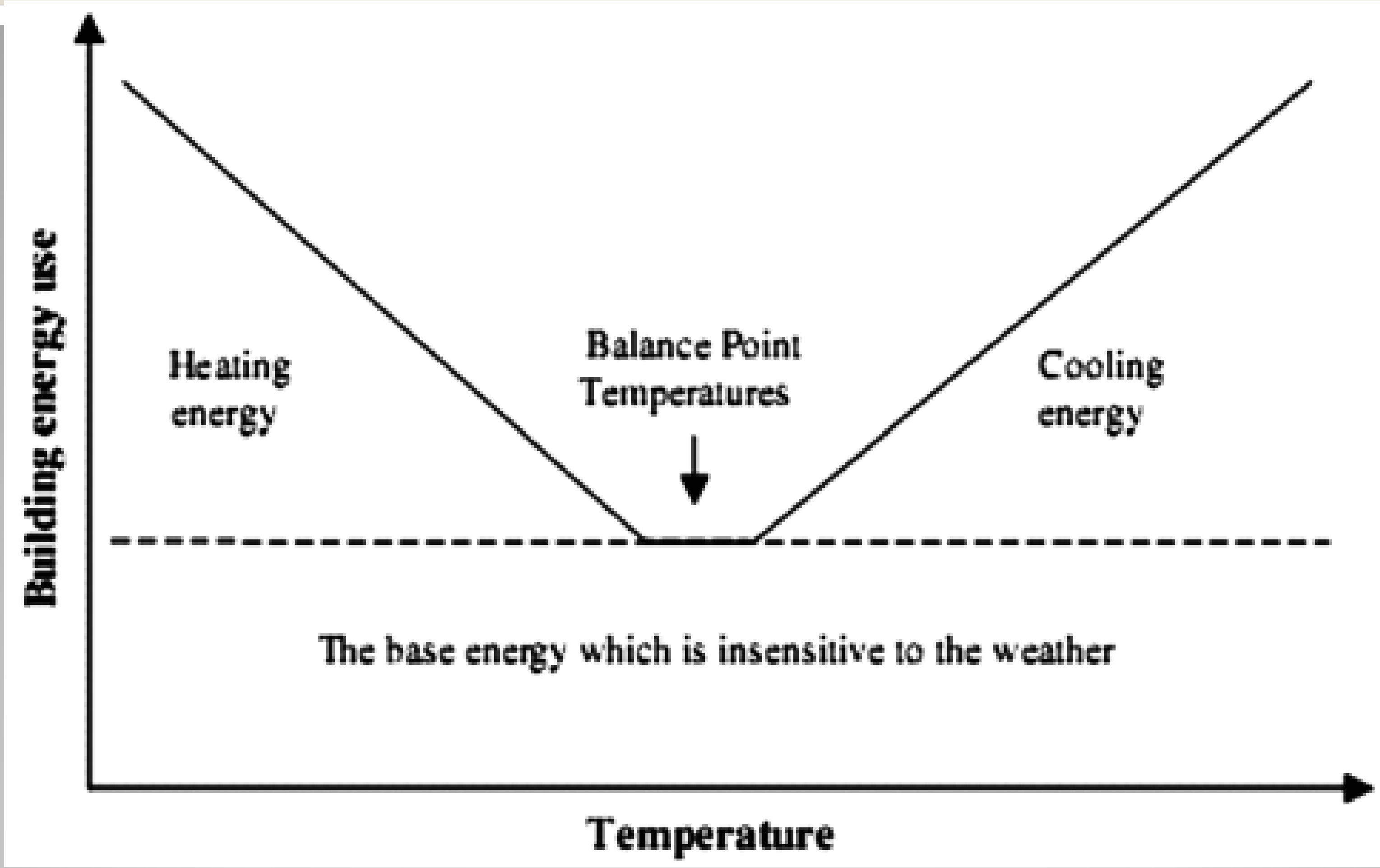
- Extreme winds and ice loads, combined wind-on-ice loads, lightning strikes, conductor vibrations, and avalanches, landslides, and flooding, can cause power transmission and distribution lines to fail.
- Oil and gas pipelines can be impacted by a range of weather and climate factors. Climate change increases the probability, recurrence, and distribution of natural disasters (heavy precipitation, high temperatures, strong winds, and floods).
- For example, two colder-than-normal winters in Russia in 2005−2006 and 2009−2010 led to severe disruptions in natural gas supply to Europe. Electric power transformers failed in the 2006 summer heat wave, impacting several areas of the United States
- On the other hand transport by sea faces some opportunities. E.g. as Arctic sea ice melts at unprecedented rates, new shipping routes will open up.

Climate Impacts on Transmission & Distribution

Extreme Ice & Snow Loads near Munster, Germany

- Households use about 1/3rd of all end use energy and demand is increasing fast (19% between 1990 and 2005).
- In temperate countries about ½ is for heating but cooling demand is growing there as well as in emerging economies in non-temperate zones.
- Various empirical studies have found that total energy demand depends on outdoor temperature in a U-shaped fashion: low temperatures correspond to relatively high energy demand (higher energy demand for heating), intermediate temperatures correspond to lower energy demand, and high temperatures correspond to higher energy demand again (higher energy demand for cooling). This implies CC may have ambiguous effects, depending on region and season. Some studies do however predict increased overall demand. (7-10% in S. Europe by 2050)

Climate Impacts on EnergyDemand



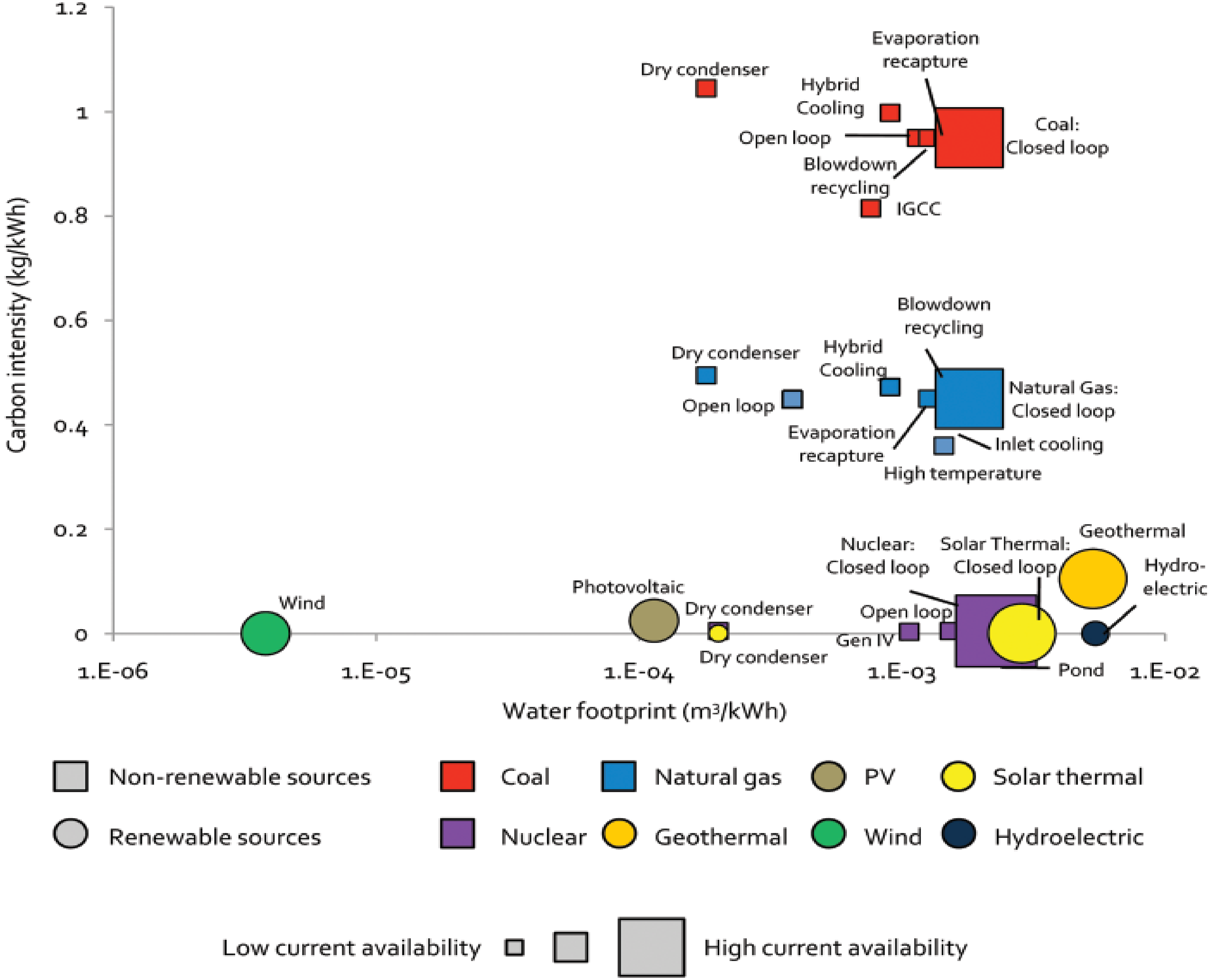
Relation Between Building Energy and Outside Temperature

- Energy Demand: Non-Household
  - Cooling processes are sensitive to outside temperatures and could increased demand.
  - In the agricultural sector a warmer climate will lead to a rising demand for water and irrigation, and therefore increase the use of energy (either natural gas or electricity) for pumping.
  - The demand for cooling of livestock and poultry facilities is similarly expected to increase in a warmer climate, and heating needs in cattle barns and chicken houses would likely fall.
  - But no quantitative estimates available for these.

Climate Impacts on Energy Demand

- Competition for water resources (for example, for electricity generation) is a key cross-sector impact.
- Impacts on energy systems have impacts on other sectors and vice versa.
- Many studies look at water availability but few examine scope for reduction of water demand. Next slide shows water and carbon intensity of different energy sources.

Cross Sector Considerations



Carbon intensity (kg/kWh)
1.2
1
0.8
0.6
0.4
0.2
0
1.E-06
1.E-05
1.E-04
1.E-03
1.E-02
Water footprint (m3/kWh)
Dry condenser
Hybrid Cooling
Evaporation recapture
Coal: Closed loop
Open loop
Blowdown recycling
IGCC
Blowdown recycling
Dry condenser
Hybrid Cooling
Open loop
Natural Gas: Closed loop
Evaporation recapture
Inlet cooling
High temperature
Nuclear: Closed loop
Solar Thermal: Closed loop
Geothermal
Hydro-electric
Wind
Photovoltaic
Dry condenser
Open loop
Gen IV
Dry condenser
Pond
Non-renewable sources
Coal
Natural gas
PV
Solar thermal
Renewable sources
Nuclear
Geothermal
Wind
Hydroelectric
Low current availability
High current availability

- Increase in uncertainty about availability of energy from most sources.
- Decrease in generating capacity for many hydropower plants but some possible increases as well.
- Potential decrease in generating capacity for wind and solar (but high uncertainty)
- Complex impacts on liquid biofuels, (possible increases)
- Potential increase in endowment of oil and gas but major increases in risk of disruption to supply
- Increased risk of disruption to transmission and distribution of electricity, oil and gas.
- Changes in pattern of demand with possible overall increases.
- Increase in water demand for energy and major conflicts with water use for other purposes.

Summary on Impacts of CC on Energy Systems

Adaptation Measures

- Type of Adaptation Responses
- Building adaptive capacity
- Delivering Adaptation Actions
- Increasing Climate Resilience

- Typology based on:
  - Timing (proactive or reactive). Proactive aims to reduce exposure to risks, reactive aims to alleviate impacts once they occur.
  - Temporal scope (short term versus long term).
  - Costs and benefits (no-regrets, low-regrets or win-win options). Examples of no-regrets options include monitoring climate and modelling climate impact assessments.
  - Local or systemic. Local measures could be adjustment to SLR or infrastructure in coastal areas. Systemic measures could be to address impacts on resource endowments.
  - Nature of agents involved (public or private; or "market driven" versus "policy-driven").

Types of Adaptation

- Improving knowledge
  - Provide higher-resolution models for local and small-regional impact evaluation where most energy facility decisions operate.
  - Research the technologies and practices to save cooling energy and reduce electrical peak load demand.
    - Space cooling efficiency potential
    - Interaction between water demand and use
    - Role of regional interconnections to improve resilience of supply systems
    - Understand impact of severe weather events on sub-sea pipeline systems.
  - Research how the changing regional patterns of energy use impact regional energy supply, institutions, and consumers.

Building Adaptive Capacity

- Data availability on impacts: (PRECIS, PESETA, ENSEMBLES Etc. for Europe).
- Risk management often ignores climate factors
  - Severe drought in Venezuela forced rationing of electricity but under investment to cope with such events was as much to blame.
  - In Iran in 2009 electric power stations had to be shut down because of a lack of water. Lack of electricity resulted in people chopping firewood, which eroded the landscape further, causing more drought.

Building Adaptive Capacity

- Businesses have tended to ignore risks of physical impacts of climate change.
  - Recent survey revealed that 80% of 500 corporations were more concerned about risks from climate change via regulations and higher energy prices than from physical impacts of CC
  - Cooperation between regulators and government agencies on one side and energy companies is essential in designing measures to address SLR, weather extremes etc., which need both public and private action. The two are strongly complementary

Building Adaptive Capacity

- Actions can be categorized as technological, behavioural and structural.
- Technological actions include:
  - Physical protection such as targeted retrofitting of existing infrastructure to address increased in exposure
  - Better design of assets in planning stage through improved design standards (e.g. structural footings for new pipeline systems in areas where permafrost can no longer be considered permanent).
  - Increased efficiency in use of water. E.g. Amoco reduced its freshwater consumption by 14% and effluent flow by 24% by optimizing techniques.
  - New technologies (e.g. Smart grids to accommodate renewable sources with intermittent generation into existing grids).

Delivering Adaptive Actions

- <u>Behavioural actions </u>include:
  - Reconsider location and design of investments. Substantial investments in new infrastructure are likely to take place in next decades as a result of scheduled decommissioning, new development, etc. These should take account of CC impacts, based on improved forecasting tools with positive impacts.
  - E.g. Quebec hydropower undertook extensive assessment of likely changes and found that output could fall by 14% with no action, but could increase by 15% with appropriate adaptation actions.
- These measures require climate risks to be mainstreamed into decision-making processes.

Delivering Adaptive Actions

- Structural actions include all actions requiring sector-wide changes. These could be physical regulations as well as economic or fiscal incentives.
- An important example of the latter are tools to hedge costs of protecting energy infrastructure in a disaster does strike.
- Some energy firms are already a major user of weather derivatives for high probability events and insurance against catastrophic events. E.g. Weather derivatives can hedge exposure to colder than expected winter, reducing impacts on consumer bills. Used to stabilize revenues, control costs and manage cash reserves.
- Use is mainly in developed world, especially N. America and Australia but now also in India.

Delivering Adaptive Actions

- Other structural actions include:
  - *Diversifying energy systems*. The level of diversification has a profound influence on its resilience to climate impacts. High dependence on hydropower has been identified as a cause of problems of supply in Northern Andes, Albania, and East Africa.
  - *Exploiting Opportunities.* There are a number of win-win options, such as energy/water saving and demand side management, which reduce stress on energy systems. An example is the Malta smart grid solution. Another is increased energy efficiency in Tanzania (next slide).

Delivering Adaptive Actions

- <u>Win-Win Options</u> - <u>some examples:</u>
- In Malta a smart grid is being implemented that governs both water and electricity. The grid quickly pinpoints theft, leakage and defective meters thus promoting efficient use of energy.
- In Tanzania, hydropower provides 80% of electricity but Central Tanzania faces falls in reserve margins to zero under a high climate change scenario. This could cause a 1.7% decrease in GDP. But current reserve margins could be restored with simple low cost energy efficiency measures.

Delivering Adaptive Actions

- Other structural actions include:
  - *Decentralizing energy systems, based on locally available renewable sources at secure locations*. This would reduce the probability of large scale outages.
  - *Urban design and land use planning.* Through building design, codes and standards and changes in consumption patterns.
  - *Integrated Planning*. This includes planning for energy sector with others such as water. An example of its application is for Brazil’s power system, which evaluated the least cost options power expansion under climate scenarios. It concluded that increased capacity needed by 2035 to compensate or lack of hydro reliability was made up of gas, higher efficiency sugarcane-bagasse, wind and nuclear or coal.

Delivering Adaptive Actions

- Increasing resilience is key to adaptation in all sectors but specially in the energy sector.
- Main actions that increase resilience are:
  - Source diversification
  - Measures that postpone high cost energy investments where knowledge on impacts is poor. (e.g. Non-regret options of early warning systems, energy efficiency, demand side management)
  - Use of fiscal instruments, which can be changed at low cost as new knowledge becomes available.

Increasing Climate Resilience

- Shale gas might significantly change energy systems worldwide. By 2011 25% of natural gas supply was Shale. It is forecast that this might double by 2030.(Wall Street Journal, 8/4/2012).
- For countries that produce it, there is an energy security benefit (witness fall in US imports of oil)
- In terms of net emissions of GHGs emissions are lower than oil so net impact is not clear.

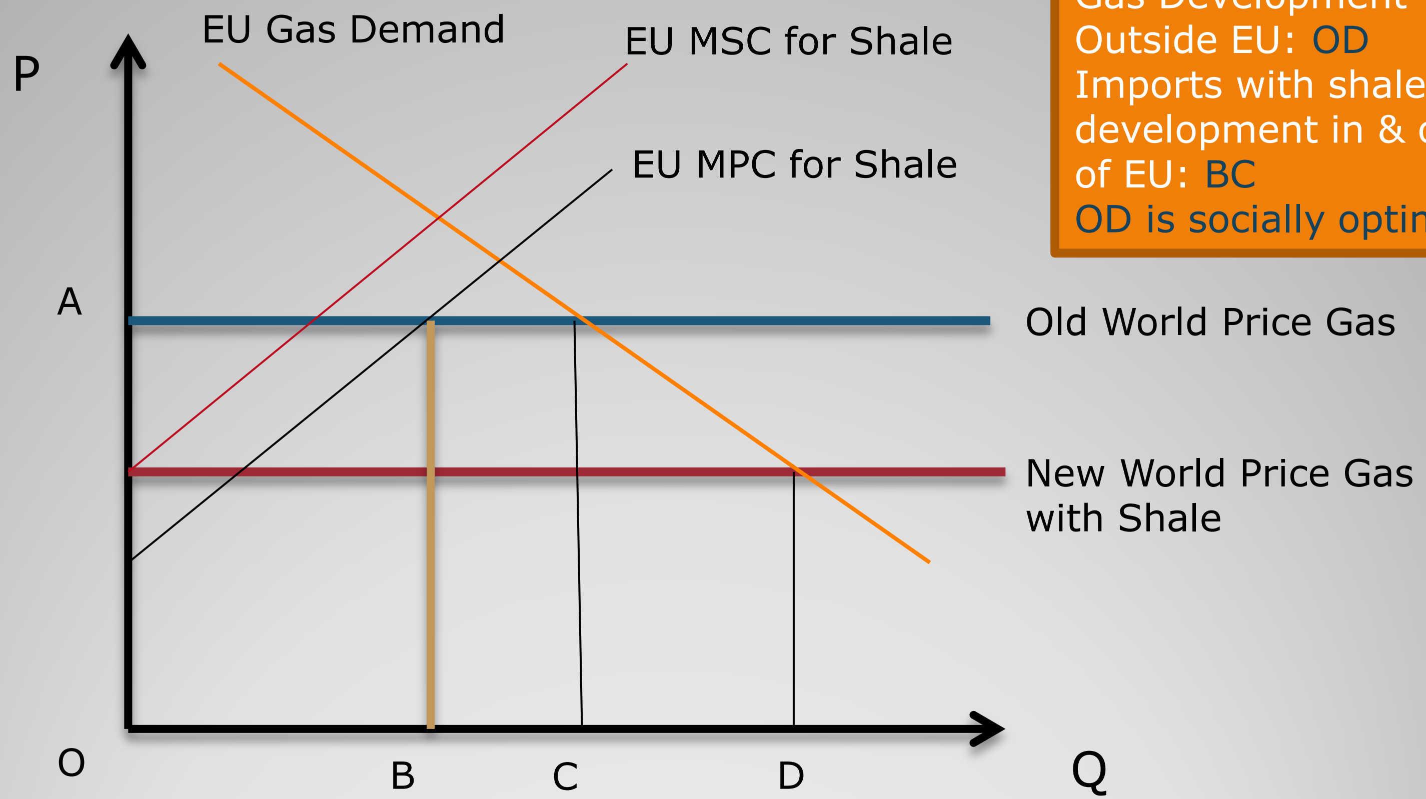
Energy Security and Climate: The Case of Shale Gas

- But there is a major environmental cost.
- Huge reserves in USA, Canada, Mexico, Argentina and Algeria. Similar quantities might be available in Europe.
- Should Europe therefore exploit the source now? Or should it wait?
- If exploit now, we reduce dependency but bear high costs.
- If we delay exploiting we benefit from lower prices from US exploitation and shift dependency from Russia to US (?). We also may benefit from lower environmental costs in the future.

Energy Security and Climate: The Case of Shale Gas

Impacts/ Action	Exploit Now	Do Not Exploit Now
Price of Gas	Price slightly lower than if EU does not exploit	Price not as low as if EU exploits now but difference is small
Imports of Fossil Fuels and ES	Reduced oil imports	Reduced oil imports but more gas imports from new gas producers
Environmental Cost	High	Lower and could also benefit from technology
Carbon Impact	Uncertain	Uncertain
Energy Security	Reduced most	Also lowered if new producer is US (?) but not as much

Energy Security and Climate Change: The Case of Shale Gas



Current Imports: OC
Imports with Shale Gas Development Outside EU: OD
Imports with shale gas development in & out of EU: BC
OD is socially optimal!

Analysis of Shale Gas

- The energy sector faces major impacts from climate change; indeed we are already seeing evidence of these.
- There are strong reasons to believe that we face greater variability in parameters that determine energy supply from different sources.
- This means it is critical that we increase diversification.
- We also need to increase our knowledge base on impacts and responses of supply and demand to different measures

Some Conclusions

- We need to take measures that are technological, behavioural and structural.
- But within these there is a strong preference for those that involve behavioural changes based on fiscal and other instruments. These allow for a flexible response and one that can be modified as more information becomes available.
- At the same time there are opportunities as well as challenges. Let us not forget the former!

Some Conclusions