Strengthening Climate Resilience

Climate change, disasters and electricity generation

By Dr. Frauke Urban and Dr. Tom Mitchell

Strengthening Climate Resilience Discussion Paper 8

The Climate Smart Disaster Risk Management Approach

Strengthening Climate Resilience

The questions in the approach are suggestions only and there may well be others

1. Tackle changing disaster risks and uncertainties

1a
Strengthen collaboration and integration between diverse stakeholders working on disasters, climate and development

To what extent are climate change adaptation, disaster risk management and development integrated across sectors and scales? How are organisations working on disasters, climate change and development collaborating?

1b
Periodically assess the effects of climate change on current and future disaster risks and uncertainties

How is knowledge from meteorology, climatology, social science, and communities about hazards, vulnerabilities and uncertainties being collected, integrated and used at different scales?

1c
Integrate knowledge of changing risks and uncertainties into planning, policy and programme design to reduce the vulnerability and exposure of people's lives and livelihoods

How is knowledge about changing disaster risks being incorporated into and acted upon within interventions? How are measures to tackle uncertainty being considered in these processes? How are these processes strengthening partnerships between communities, governments and other stakeholders?

1d
Increase access of all stakeholders to information and support services concerning changing disaster risks, uncertainties and broader climate impacts

How are varied educational approaches, early warning systems, media and community-led public awareness programmes supporting increased access to information and related support services?

2. Enhance adaptive capacity

2a
Strengthen the ability of people, organisations and networks to experiment and innovate

How are the institutions, organisations and communities involved in tackling changing disaster risks and uncertainties creating and strengthening opportunities to innovate and experiment?

2b
Promote regular learning and reflection to improve the implementation of policies and practices

Have disaster risk management policies and practices been changed as a result of reflection and learning-by-doing? Is there a process in place for information and learning to flow from communities to organisations and vice versa?

2c
Ensure policies and practices to tackle changing disaster risk are flexible, integrated across sectors and scale and have regular feedback loops

What are the links between people and organisations working to reduce changing disaster risks and uncertainties at community, sub-national, national and international levels? How flexible, accountable and transparent are these people and organisations?

2d
Use tools and methods to plan for uncertainty and unexpected events

What processes are in place to support governments, communities and other stakeholders to effectively manage the uncertainties related to climate change? How are findings from scenario planning exercises and climate-sensitive vulnerability assessments being integrated into existing strategies?

3. Address poverty & vulnerability and their structural causes

3a
Promote more socially just and equitable economic systems

How are interventions challenging injustice and exclusion and providing equitable access to sustainable livelihood opportunities? Have climate change impacts been considered and integrated into these interventions?

3b
Forge partnerships to ensure the rights and entitlements of people to access basic services, productive assets and common property resources

What networks and alliance are in place to advocate for the rights and entitlements of people to access basic services, productive assets and common property resources?

3c
Empower communities and local authorities to influence the decisions of national governments, NGOs, international and private sector organisations and to promote accountability and transparency

To what extent are decision-making structures de-centralised, participatory and inclusive? How do communities, including women, children and other marginalised groups, influence decisions? How do they hold government and other organisations to account?

3d
Promote environmentally sensitive and climate smart development

How are environmental impact assessments including climate change? How are development interventions, including ecosystem-based approaches, protecting and restoring the environment and addressing poverty and vulnerability? To what extent are the mitigation of greenhouse gases and low emissions strategies being integrated within development plans?

Figure 1: The Climate Smart Disaster Risk Management Approach

Strengthening Climate Resilience (SCR) through Climate Smart Disaster Risk Management, is funded by the UK Department for International Development (DFID) and aims to enhance the ability of developing country governments and civil society organisations to build the resilience of communities to disasters and climate change. It is coordinated by the UK Institute of Development Studies, Plan International and Christian Aid, who are working with a variety of organisations across ten countries (Kenya, Tanzania and Sudan in East Africa; Nepal, India, Bangladesh and Sri Lanka in South Asia and Philippines, Indonesia and Cambodia in South East Asia). SCR has developed the Climate Smart Disaster Risk Management Approach. If you would like to be involved in SCR meetings or work with the programme to trial the Climate Smart Disaster Risk Management Approach with your organisation, please either visit the SCR website www.csdrm.org or email scr@ids.ac.uk.

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Abstract

This paper explores the links between changing disaster risks due to climate change and the impacts on electricity generation.

Electricity generation is important for powering economic growth. Climate change alters disaster risks for electricity generation. These considerations are often overlooked in energy research and policy.

We want to shed light on a new and emerging research agenda.

We assess the vulnerability of various electricity generation options - fossil fuels, nuclear power, hydropower and renewable energy - to changing disaster risks and addresses the implications for energy policy and planning.

Finally, the paper makes suggestions how changing disaster risks could be taken into account in electricity generation. Suggestions include:

1. **assessing disaster risks** in Environmental Impact Assessments, feasibility studies and siting procedures for new power plants

2. **improving the linkages** between energy ministries, climate ministries, and disasters ministries in relation to energy policy

3. **planning and developing** climate change adaptation strategies for electricity generation.

Abbreviations

CBO	Community based organisation
CBDRM	Community Based Disaster Risk Management
CCA	Climate Change Adaptation
CCAI	Climate Change Adaptation Initiative
CCS	Climate Change Secretariat
CSDRM	Climate Smart Disaster Risk Management
DMC	Disaster Management Centre
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
DFID	Department for International Development
FGDs	Focus Group Discussions
GS	Grama Sevaka - village level government officer (also called Grama Niladhari)
HFA	Hyogo Framework for Action
KPIs	Key Person Interviews
IDP	Internally Displaced Person
IDS	Institute of Development Studies
IPCC	Inter-governmental Panel on Climate Change
LTTE	Liberation Tigers of Tamil Eelam
MDG	Millennium Development Goals
MENR	Ministry of Environment and Natural Resources
NACCC	National Advisory Committee on Climate Change
NCDM	National Council for Disaster Management
NGO	Non-government organisation
OfERR	Organisation for Eelam Refugee Rehabilitation
PVCA	Participatory Vulnerability and Capabilities Assessment
SCR	Strengthening Climate Resilience
SRES	Special Report on Emission Scenarios
TAFLOL	Task Force to Logistics and Law and Order
TAFREN	Task Force to Rebuild the Nation
TARFRER	Task Force for Rescue and Relief
UNFCCC	United Nations Framework Convention on Climate Change
UN-ISDR	United Nations International Strategy for Disaster Reduction

Foreword: Climate change, disasters and electricity generation
By Frauke Urban

Electricity generation is important for powering economic growth. However, climate change alters disaster risks for electricity generation and these considerations have often been overlooked in energy research and policy. This paper aims to explore the links between changing disasters risks due to climate change and their impacts on electricity generation.

This paper assesses the vulnerability of various electricity generation options such as fossil fuels, nuclear power, hydropower and renewable energy to changing disaster risks and addresses the implications for energy policy and planning.

Finally, the paper makes suggestions how changing disaster risks could be taken into account in electricity generation.

Suggestions include assessing disaster risks in Environmental Impact Assessments, improving feasibility studies and siting procedures for new power plants, enhancing the linkages between energy ministries, climate ministries, and disasters ministries in relation to energy policy and planning and developing climate change adaptation strategies for electricity generation.

This approach can enhance the ability of developing country governments, private firms and civil society organisations to build the resilience of communities to disasters and climate change with regard to electricity generation.

This paper aims to explore the links between disaster risk management (DRM) and low carbon development and thereby shed some light on a new and emerging research and development agenda. The most important links between DRM and low carbon development are related to four issues:

1. The carbon and greenhouse gas implications of measures to reduce disaster risk
2. The carbon and greenhouse gas implications of post-disaster and reconstruction interventions;
3. Climate change-related changing disaster risk for low carbon development options and their limits;
4. How low carbon development reduces vulnerability to climate change.

The first two issues have been addressed in the Strengthening Climate Resilience Discussion Paper 3 by Urban, Mitchell and Silva Villanueva (2010). The third issue is being addressed in this paper. The fourth issue deserves future attention as it goes beyond the scope of this paper. This paper was written for the Strengthening Climate Resilience Programme. Strengthening Climate Resilience (SCR) through Climate Smart Disaster Risk

Management is a programme funded by the UK Department for International Development that aims to enhance the ability of developing country governments and civil society organisations to build the resilience of communities to disasters and climate change.

It is coordinated by the Institute of Development Studies (UK), Plan International and Christian Aid, who are working with a variety of organisations across ten countries (Kenya, Tanzania and Sudan in East Africa; Nepal, India, Bangladesh and Sri Lanka in South Asia; and Philippines, Indonesia and Cambodia in Southeast Asia). SCR has developed the Climate Smart Disaster Risk Management (CSDRM) approach.

The CSDRM approach aims to 1. tackle changing disasters risks and uncertainties, 2. enhance adaptive capacity and 3. address poverty and vulnerability and their structural causes.

This paper on climate change, disasters and the electricity sector provides some suggestions for how to tackle changing disasters risks and uncertainties in relation to electricity generation; it explores options for enhancing adaptive capacity in the energy generation sector and it discusses how to address vulnerability and their structural causes related to electricity generation.

If you would like to be involved in SCR meetings or work with the programme to trial the Climate Smart Disaster Risk Management approach with your organisation, please either visit the SCR website: www.csdrm.org or send an email to info@csdrm.org.

1. Introduction

Global energy security is a key challenge today, due to high energy use fuelled by rapid economic and population growth, the depletion of fossil fuel resources and political instability in fossil fuel-rich areas (Kowalski and Vilogorac, 2008). This challenge has been reinforced by the recent conflicts in the Middle East in early 2011. Climate change and its impacts on changing disaster risks pose another major challenge to the energy sector and particularly electricity generation which is important for powering development and economic growth.

The Intergovernmental Panel on Climate Change (IPCC) reports that the global mean surface temperature has risen by 0.74°C ± 0.18°C during the last century. This increase has been particularly significant over the last 50 years (IPCC, 2007a). Climate change can exacerbate existing disaster risks and can increase the frequency and severity of some extreme climate events, such as heat waves, heavy precipitation events and storms (IPCC, 2007a). While the social and economic impacts of climate change on disaster risks have recently received some attention, the international research community knows less about the impacts of climate change on disaster risks in specific sectors. The energy sector and electricity generation is such a case in point.

Energy access and a reliable energy supply are directly linked to economic growth and poverty reduction (IEA, 2002). It is often argued that energy access is a prerequisite to achieve the Millennium Development Goals (MDGs) (DFID, 2002; WHO, 2006). Electricity generation plays an important role in providing energy access. As such it is crucial to reduce the vulnerability of the electricity generation sector to climatic changes and changing disaster risks. Climate change brings new challenges and risks to the energy sector and electricity generation. Increasing disaster risks related to floods, storms and droughts can disrupt electricity generation and can damage infrastructure; which can in turn threaten economic activities. This has impacts on many sectors of the economy and on people as they depend on electricity supply for their daily lives. However, considerations of changing disaster risks for energy infrastructure and electricity generation have often been overlooked in energy research, policy and practice. Most research focuses more broadly on the energy sector, rather than on electricity generation.

While there is a growing literature on the impacts of climate change on the energy sector (e.g. IPCC, 2007a; 2007b; 2007c; Brennan et al., 2008; ESMAP, 2011), the changing disaster risk perspective tends to remain under-explored. This is despite the fact that changing disasters risks might threaten energy security and disrupt energy supply, which could have significant socio-economic and political implications.

This paper therefore aims to explore the links between changing disasters risks due to climate change and their impacts on electricity generation.

Electricity generation is here defined as both small-scale and large-scale modern electricity generation infrastructure, including decentralised and centralised options. We therefore focus explicitly on electricity generation infrastructure for supply and exclude energy demand as well as energy exploration, extraction, transportation, refining, transmission and distribution. The authors acknowledge the high impact disasters such as storms, floods and temperature fluctuations can have on non-electricity generation, energy distribution and transmission systems; however this goes beyond the scope of this paper and needs to be elaborated in more detail in future research and publications.

Earlier research on the impacts of climate change on energy issues has focused on: changes to energy demand; and climate impacts on the energy sector.

1. In terms of changing energy demand, there is comprehensive literature which indicates for example that some of the expected changes are a lower demand for heating, but higher demand for cooling (e.g. Cartalis et al., 2001; Hadley et al.; 2006, Tol, 2002a; Tol, 2002b;).

2. Recent studies such as by ESMAP (2011) and (Brennan et al., 2008) indicate the climatic impact on the energy sector and suggest that adaptation measures are needed.

This paper builds on these earlier findings and assesses them in the light of changing disaster risks. The paper aims to provide some insights of how vulnerable to climate change various electricity generation options are; such as power plants based on fossil fuels, nuclear energy, hydropower, wind energy, solar energy and bioenergy, and how changing disaster risks can be taken into account when it comes to energy policy and planning. The paper thereby addresses issues at the interface of the electricity sector, climate change and disasters and aims to shed some light on a new and emerging research and development agenda.

Section 2 explores the effects of changing climate patterns and changing disaster risks on electricity generation and provides an analysis of what this means for fossil fuel, nuclear and renewable electricity generation. Section 3 explores the impact of changing disasters risks on future energy policy and section 4 concludes the paper.

2. The impacts of changing climate patterns and changing disaster risks on energy options and electricity generation infrastructure

It is understood today that a changing climate can lead to a change in energy consumption patterns. This change in consumption pattern might result in economic and political pressures that require new approaches and new thinking in the energy sector (Dutton in Troccoli, 2010). The request by the UK government in March 2011 to reduce fossil fuel dependency and to invest more substantially in a transition to low carbon energy was a reaction to the rising oil prices linked to the conflict in Libya.

It showed that today (some) policy-makers seem to be willing to adopt new approaches and new thinking for the energy sector when faced by the double challenges of peak oil and climate change.

The IPCC reports 'climate change could affect energy production and supply; (a) if extreme weather events become more intense, (b) where regions dependent on water supplies for hydropower and/or thermal power plant cooling face reductions in water supplies, (c) where changed conditions affect facility siting decisions, and (d) where conditions change (positively or negatively) for biomass, wind power or solar energy production' (IPCC, 2007b:367). The United Nations Framework Convention on Climate Change (UNFCCC) suggests that a diversification of energy and electricity generation options is needed as an adaptation strategy to climate change. It advocates for increasing the share of solar, wind and hydropower for electricity generation[1] . The UNFCCC further recommends to invest in technological change and to expand the energy supply links to other regions to increase energy security (UNFCCC, 2010).
Following on from the energy security concerns of the UNFCCC, Kowalski and Vilogorac (2008) define energy security as the availability of energy supply at cost-effective prices at adequate times and in adequate quantities to such an extent that the economic and social development of a country can be ensured. The authors therefore refer to energy security in relation to both technical security of supply and quality of supply.

Regarding the climate change debate, it has to be acknowledged that climate impacts tend to be localised and can sometimes be difficult to predict. However there is increasing evidence that the Global South and people in developing countries are already faced with severe climatic changes today, whereas the impacts of climate change are being felt to a lesser extent in the Global North (IPCC, 2007a).

The following section will explore how changing climate patterns and disaster risks affect electricity generation from fossil fuel energy, nuclear energy, hydropower, wind energy, solar energy and bioenergy, and how this poses serious challenges to energy security.

2.1 The relationship between climate change and disaster risks

About 75% of emissions leading to climate change have historically been emitted from developed countries according to the World Resources Institute (WRI, 2005), while the 50 least developed countries caused historically only 1% of the emissions leading to climate change (Global Humanitarian Forum, 2009). Poor people and poor countries are nevertheless the most affected by climate change as they lack the financial, technical, infrastructural and institutional resources to adapt.

The IPCC suggests that climate change can exacerbate disaster risks such as risks associated with droughts, the frequency and severity of tropical cyclones and flooding (IPCC, 2007a).The United Nation's International Strategy for Disaster Reduction ISDR establishes a link between climate-related hazards and disasters. It reports that between 1988 and 2007 about two - thirds of all disaster events were of climatological nature. These

1 However the UNFCCC also acknowledges the vulnerability of hydropower to climate changes such as decreased precipitation.

climatological disaster events accounted 'for approximately 45% of the deaths and 80% of the economic losses caused by natural hazards' (ISDR, 2008a:2). ISDR reports changes in long-term observed precipitation trends during 1990-2005 with more dry spells in the Sahel and the Southern African region, throughout the Mediterranean and parts of South Asia, increases in heat waves in many world regions and increases in heavy precipitation events. ISDR also reports an observed increase in the frequency and severity of droughts over wide regions since the 1970s, especially in the tropics and subtropics.

It has also observed an increase in tropical cyclones, particularly over the North Atlantic, and coastal erosion due to intensified storms (UNISDR, 2008b). Van Aalst assessed the relationship between climate change and extreme weather events and argues that potential increases in extreme events due to climate change are often exacerbated by increased socio-economic vulnerability, thereby making the impacts even worse (Van Aalst, 2006). Both climate change and changing disasters risks have an impact on electricity generation, such as on power plants and fuel availability. The following sections will discuss the impact of climate change and changing disasters risks on electricity generation from fossil fuels, nuclear power, hydropower, wind energy, solar energy and biomass.

2.2 The impact of changing climate patterns and changing disaster risks on electricity generation from fossil fuels

Currently more than 80% of the global primary energy supply comes from fossil fuels, mainly from oil and coal (IEA, 2010). In some countries such as China and India, the electricity sectors account for more than 40% of national greenhouse gas emissions (IEA, 2007). In addition to the electricity sector, energy is used for industries, transport, services, agriculture, households and similar which is also mainly fossil fuel based and contributes to greenhouse gas emissions.

Due to its heavy reliance on fossil fuels, electricity provision is a major contributor to global climate change (IPCC, 2007c). However, fossil fuel-based electricity provision from oil, coal and natural gas does not only significantly contribute to climate change, but there is evidence it might also be vulnerable to the impacts of climate change and changing disaster risks.

Despite evidence of extreme weather events and the link between climate change and disasters, the impacts on electricity generation from oil, natural gas and coal is currently under-researched, particularly in developing countries.

There are four major ways in which climate change and intensified disaster risks can affect the fossil fuel based electricity sector:

First, fossil fuel based power plants are likely to be impacted by changing disaster risks. This can include the increased intensity and frequency of storms, floods, heavy precipitation events and sea-level rise which could damage the fossil fuel power plant infrastructure. Siting has to be carefully conducted to avoid building new power plants in areas which are prone to storm surges, storms, waves and long-term sea-level rise.

This is particularly important for countries with coastal locations and island states.

Second, one of the main risks with climate change is that increased temperatures, lower precipitation levels and an increase in the frequency and severity of droughts is likely to lead to water stress. This affects the output of power plants which need fresh water for cooling purposes. The lack of water is a risk which can potentially lead to a decrease in electric output and can pose a threat to the economy (ESMAP, 2011). This is a generic problem for all thermal power plants dependent on water cooling.

Third, high temperatures reduce the thermal generation efficiency, which in return can decrease the power output (ESMAP, 2011). This is also a generic problem for all thermal power plants.

Fourth, climate change and intensified disaster risks pose a threat to resource availability. Oil and gas exploration are often conducted offshore. Tropical storms, hurricanes, cyclones and floods can pose a series danger. This point will be elaborated in more detail below by using the example of Hurricane Katrina.

Whereas limited research has been done on the impacts of climate change on the fossil fuel power plants and fossil fuel resource availability, one case is relatively well researched, namely the impacts of Hurricane Katrina on US oil rigs in the Gulf of Mexico. It has to be noted here that most of the oil from the Gulf of Mexico is used for petrol production for transport purposes; however a smaller share of the oil is used for electricity generation. About 20 large oil power plants are located in the vicinity of the Gulf of Mexico (EIA, 2010).

Increases in sea level, ocean wave heights and most importantly tropical cyclones can hamper the exploration and extraction process of fossil fuels like oil and gas. The most dramatic impact of a tropical cyclone on fossil fuel infrastructure was Hurricane Katrina which hit the US coast in 2005. According to Demirbilek, it battered 93,000 square miles across 138 parishes and counties and destroyed large parts of the energy infrastructure in the Gulf of Mexico (Demirbilek, 2010). Kaiser et al. (2010) report that the hurricane season 2004-2005 with Hurricanes Ivan, Katrina and Rita led to the highest number of damaged and destroyed fossil fuel structures in the history of Gulf operations. It is estimated that 126 oil and gas platforms were completely destroyed while another 183 were damaged (Kaiser et al., 2010:1). The authors estimate a total loss of about US$1.3 and US$4.5 billion due to the damage of the hurricanes. Kaiser (2008) reports that when a hurricane enters the Gulf of Mexico,crews and supply vessels are evacuated, oil production stops and drilling rigs move out of the projected path of the storm. Ports along the coast and rivers are also shut down (Kaiser, 2008).

The Gulf of Mexico alone supplies 25% of the US’s domestic oil and gas needs. However the region is very vulnerable to disasters due to its location in the Hurricane Belt (Kaiser, 2008).

Intensified disaster risks might therefore become a challenge to reliable oil based electricity production.

Table 1 indicates the effects of climate change and changing disaster risks on fossil fuel based electricity generation.

Change in meteorological variable	Impact on fossil fuel plant	Impact on electricity generation
Temperature increase	Potential impact on water availability for cooling purposes.	Potentially decreased electricity generation due to limited water availability. Increased temperatures decrease the thermal generation efficiency of power plants.
Increase in average precipitation	None, unless flooding occurs. If flooding occurs risk of damage to power plant equipment.	None if no flooding occurs. If flooding occurs decreased electricity generation.
Decrease in average precipitation	Decreased availability of water for cooling purposes.	Decreased electricity generation.
Droughts	Decreased availability of water for cooling purposes.	Decreased electricity generation.
Glacier melting	None, unless flooding occurs. If flooding occurs risk of damage to power plant equipment.	None if no flooding occurs. If flooding occurs decreased electricity generation.
Floods	Risk to power plant equipment and offshore equipment.	Decreased electricity generation if power plant or offshore equipment is flooded, destroyed or damaged.
Increased frequency and/or strength of storms/cyclones	Risk to power plant equipment and offshore equipment.	Decreased electricity generation if power plant or offshore equipment is destroyed or damaged.

Table 1: The effects of climate change and changing disaster risks on fossil fuel electricity generation.

2.3 The impact of changing climate patterns and changing disaster risks on electricity generation from nuclear power

Currently nuclear energy accounts for about 6% of global energy generation. Trends indicate that nuclear energy generation is increasing with more installed capacities and more countries building nuclear power plants (IEA, 2010).

There are two major ways in which climate change and intensified disaster risks can affect the nuclear power sector:

First, nuclear power plants are likely to be impacted by changing disaster risks. The World Energy Council WEC argues changing disaster risks can pose a serious threat to nuclear energy provision. This could be the case for cyclones, hurricanes, typhoons, flooding. This is particularly concerning considering the impacts such extreme weather events could have by damaging nuclear power plants and the risks this poses in relation to nuclear accidents and health and safety (WEC, 2007).

Second, one of the main risks with climate change is that increased temperatures, lower precipitation levels and an increase in the frequency and severity of droughts is likely to lead to water stress. This affects the output of power plants which need fresh water for cooling purposes, as sea water is corrosive. The lack of fresh water is a risk which can potentially lead to a decrease in electric output and can pose a threat to the economy (ESMAP, 2011). This is a generic problem for all thermal power plants dependent on water cooling; however a lack of cooling water can lead to serious consequences in the nuclear power plant and may in extreme cases even risk a nuclear meltdown, as the March 2011 case from Japan has shown.

We will discuss the disaster risk and the cooling issue in more detail below.

First, disasters such as earthquakes, cyclones, hurricanes, typhoons, flooding can have devastating impacts on nuclear power plants. The most striking example is the earthquake scale 9 in Japan in March 2011, which was followed by a large tsunami which flooded parts of the country. Several nuclear power plants were affected by the earthquake and the flooding.
As a consequence these nuclear power plants had to be closed down. Six reactors at the Fukushima power plant triggered an atomic alert due to a break down in cooling operations of the reactor, followed by an explosion in three of the reactors and a partial nuclear meltdown. (BBC, 2011a).
The nuclear meltdown has devastating health and safety implications, both from a national and global perspective. Thousands of people have been evacuated from the area around the power plant. There are concerns about increases in thyroid cancer, leukaemia and high levels of nuclear radiation found in drinking water, food and sea water.
In April 2011, the Japanese authorities have raised the severity level of the nuclear accident to level 7, which is the same level as the nuclear catastrophe in Chernobyl in 1986(BBC, 2011b).
While this accident was due to an earthquake and a tsunami, climatological disasters such as floods, cyclones, other storms and sea-level rise can also

pose a serious danger to nuclear power plants. It is therefore advisable that siting procedures for nuclear power plants take into account disaster risks and that nuclear power plants are primarily built in areas with low disaster risks. It is also advisable that nuclear power plants are built more robustly to be able to withstand disasters. Older power plants should be shut down and replaced with newer, more modern and more robust plants.
Finally, events such as in Japan need to lead to a rethinking of the social and environmental sustainability of nuclear power plants and whether the associated health and safety risks are worth being taken.

Second, weather extremes such as heat waves, reduced precipitation levels and droughts can have high impacts on nuclear energy infrastructure. This has impacts on electricity output as reactors need to be shut down, but more importantly it poses risks to health and safety. This has been observed during the 2003 and 2006 heat waves in France. 77% of France's electricity comes from nuclear power. The nuclear power supply was severely impacted by low river flow rates and droughts, which severely reduced electricity generation from nuclear plants as the rivers had reached the maximum temperatures for cooling reactors (Salagnac, 2007). During the heat waves, 17 reactors had to limit output or shut down. A similar situation was encountered in 2009, when the French government was forced to import electricity from neighbouring countries, with a shortfall of about 8 GW of nuclear power (Forster and Lilliestam, 2009).
Other cases have been reported from Germany which between 1979 and 2007 had to reduce production of nuclear power during 9 summers due to soaring temperatures of water and/or low water flows (Müller et al. 2007). The Unterweser nuclear power plant, which was affected by high temperatures for four consecutive months between June and September 2003, had to reduce its power output by 90%. The Isar nuclear power plant cut production by 60% for 14 days due to excess river temperatures and low stream flow in the river Isar in 2006 (Forster and Lilliestam, 2009). Similar events happened in the Netherlands and other European countries in the same hot summer, which threatened the stability of the national and regional electricity supply.

Lack of availability of freshwater for power generation can in such cases become an issue of national and regional energy security concern with increased adverse effects of climate change. Nuclear and many other thermal power plants are highly dependent on water for cooling. While most of the water is not used by the power plant, the withdrawn water is discharged at higher temperatures into a water body which may already have increased temperature due to climate change. This puts additional pressure on the aquatic environment such as on fish and on those people dependent on fish for their livelihoods, particularly poor people in developing countries.

There is very little research about similar climatic impacts and changing disaster risks on nuclear power plants in developing countries. However the issue is of growing importance. Many middle income countries such as China, India, South Africa, Mexico, Brazil, Korea and Taiwan depend increasingly on nuclear power supply (IEA, 2010).

The World Nuclear Association (2008) reports that China currently has 11 nuclear reactors in commercial operation, 6 under construction and there are plans for a six-fold increase of nuclear capacity by 2020. By 2020 a total nuclear capacity of 50 GWe is planned to be achieved followed by another three- to four-fold increase to 120-160 GWe by 2030.
In 2008, nuclear power made up 2% of China's total electricity. Although this does not seem much, the country has seen a significant increase in nuclear power expansion since the 1990s and the yearly nuclear output in 2008 was 6,8394 GWh (IEA, 2010).

The situation is similar in India, South Africa, Mexico and Brazil which have increased their nuclear power capacity from 0% among the total electricity generation in 1980 to 2% in India, 3% in Brazil, 4% in Mexico and 5% in South Africa in 2008. In comparison, in Korea and Taiwan electricity comes to 34% and 17% from nuclear power, respectively. In both countries

Table 2 indicates the effects of climate change and changing disaster risks on nuclear electricity generation.

Change in meteorological variable	Impact on nuclear plant	Impact on electricity generation
Temperature increase	Potential impact on water availability for cooling purposes.	Potentially decreased electricity generation due to limited water availability.
Increase in average precipitation	None, unless flooding occurs. If flooding occurs risk of damage to power plant equipment, potential health and safety implications.	None if no flooding occurs. If flooding occurs decreased electricity generation.
Decrease in average precipitation	Decreased availability of water for cooling purposes.	Decreased electricity generation.
Droughts	Decreased availability of water for cooling purposes.	Decreased electricity generation.
Glacier melting	None, unless flooding occurs. If flooding occurs risk of damage to power plant equipment, potential serious health and safety implications.	None if no flooding occurs. If flooding occurs decreased electricity generation.
Floods	Risk to power plant equipment, potential health and safety implications.	Decreased electricity generation if power plant is flooded, destroyed or damaged.
Increased frequency and/or strength of storms/cyclones	Risk to power plant equipment, potential health and safety implications.	Decreased electricity generation if power plant is destroyed or damaged.

Table 2: The effects of climate change and changing disaster risks on fossil fuel electricity generation.

in 1980 less than 10% of the electricity came from nuclear power (IEA, 2010). Increasing temperatures, heat waves, droughts, low river levels and water scarcity can have a high impact on these countries and can threaten energy security and a stable energy supply in case of heavy dependency on nuclear power and other thermal power plants.

2.4 The impact of changing climate patterns and changing disaster risks on electricity generation from renewable energy

2.4.1 Hydropower

Hydropower is the most commonly used renewable energy source today (IEA, 2010). The World Energy Council estimates that there is a global potential of more than 41,202 TWh/year (4,703 GW) of hydropower with a technically exploitable potential of more than 16,494 TWh/year (1,883 GW) (WEC, 2007). At the end of 2005, globally 778 GW were installed and another 124 GW were under construction (WEC, 2007).
Both large hydropower and small hydropower play a role in the energy provision of many developing countries and some developed countries (e.g. Norway, Sweden). Large hydropower plants usually have a capacity of more than 10MW and are linked to dams and reservoirs whereas small hydropower plants have lower capacities and are built around river run-offs with low environmental impact. China, India and Brazil have all major dam developments. Chinese dam builders are also actively engaged in large dam-building in Southeast Asia, Africa and Latin America as developers, contractors and investors (Bosshard, 2010). In China, wide-spread rural electrification has been achieved due to the expansion of hydropower as a means of boosting agricultural productivity and providing electricity.

There are two major ways in which climate change and intensified disaster risks can affect the hydropower sector:

First, hydropower plants are highly vulnerable to water stress, drought, decreased precipitation and higher temperatures. This can lead to water discharge, which results in reduced electricity production.

Second, hydropower plants could be impacted by changing disaster risks. This can include the increased intensity and frequency of storms, floods and heavy precipitation events.

Both points are elaborated in more detail below.

Hydropower is highly vulnerable to climate change and changing disaster risks. Changes in river flow, evaporation and dam safety are the main drivers through which climate change impacts hydrological processes (Mideksa and Kallbekken, 2010). The potential to generate electricity correlates strongly with the changes in water discharge. Although increased precipitation and river flow eventually boosts energy production, excess flow may impact negatively. Under normal circumstances in dam operation, the opening of flood-gates and turbine shut-down help fend off negative impacts of flooding.

Due to their robust structures, large hydropower plants are less prone to flood impacts or strong storm surges and cyclones (Michaelowa et al. in Troccoli, 2010).

Yet, the future impacts of climate change, like lowering of reservoir capacity associated with lower snow melt and lower river flow have not been considered while designing most hydropower plants.

Studies from the Colorado River in the US suggest that modest climatic changes, such as an increase in temperature in 2 degree Celsius and a 10% decline in precipitation, might reduce river run-off by up to 40%. This in turn might have impacts for hydroelectric generation (Kiparsky and Gleick, 2003).

For Europe, the regions most prone to a decrease in developed hydropower potential are Portugal and Spain in southwest Europe, and Ukraine, Bulgaria and Turkey in the southeast, with potential decreases of 20–50% and more. This is likely to impact negatively on overall electricity production in these countries (Lehner et al., 2005). In addition, it is currently not well explored what happens to large hydropower plants in extreme weather events such as cyclones.

Small hydropower might be even more significantly impacted by climate change and changing disaster risks due to their dependency on small rivers which are prone to seasonality and can dry up quickly with higher temperatures, increased droughts and decreased water flows. Cyclones, storms, floods and landslides can also seriously damage small hydropower equipment. This can have a high impact on electricity provision, primarily for the rural areas, and agricultural productivity. People in rural areas are the most vulnerable to the impacts of these climatic changes on the energy sector. This is particularly the case for several developing countries, like Ghana, Ethiopia and Brazil, which depend on more than 75% of hydropower for their electricity provision (IEA, 2010).

A recent study from Brazil shows the country's hydropower sector is vulnerable to climate change impacts. 83% of Brazil's electricity comes from hydropower. Due to increasing temperatures, lower water flow and alterations in the rainfall regime, total energy production in Brazil could be reduced by 7% annually by the end of the century (Pereira de Lucena et al., 2009). This could have an effect on the capacity of Brazil to generate electricity and to power economic processes, particularly during peak times. Another example indicates that the Ethiopian capital Addis Ababa was reported to have been without any power for months in 2009 due to water shortages at the country's large hydropower dams.
In Ghana, droughts pose a serious risk to energy provision as not enough water is available to generate electricity from hydropower. This makes the power sector very unreliable as concerns are raised that 'climate change threatens Ghana's economic future' (Annansi Chronicles 2007:1). Interestingly many Ghanaians seem to prefer solar power over grid-based power as it is more reliable and cheaper (Ashden Awards, 2007).

Table 3 shows the effects of climate change and changing disaster risks on hydropower generation.

Change in meteorological variable	**Impact on hydropower plant/ resources**	**Impact on electricity generation**
Temperature increase	Increased evaporation, reduced river run-off and lower water levels.	Decreased electricity generation.
Increase in average precipitation	Increased river run-off and higher water levels.	Increased electricity generation.
Decrease in average precipitation	Reduced river run-off and lower water levels.	Decreased electricity generation.
Droughts	Reduced river run-off and lower water levels.	Decreased electricity generation.
Glacier melting	Increased river run-off and higher water levels.	Increased electricity generation
Floods	Increased river run-off and higher water levels. Flood gates are opened.	Increased electricity generation.
Increased frequency and/or strength of storms/cyclones	Risk to power plant equipment, reservoir and dam.	Decreased electricity generation if power plant, reservoir or dam is de-stroyed or damaged.

Table 3: The effects of climate change and changing disaster risks on hydropower generation.

2.4.2 Wind Energy

Wind energy is the second most commonly used source of renewable energy, after hydropower according to the IEA (IEA, 2010). Micro-wind systems are sometimes the only cost-effective and technically-feasible opportunity to bring electricity to poor communities that live far away from the central grid. Many Non-Governmental Organisations (NGOs) like Practical Action, Oxfam and Renewable World support small-scale wind energy projects in developing countries. Many of these projects are community-based, which can enable a sharing of the benefits among the community and can increase the ownership of and responsibility for local energy provision (Urban et al., 2010; Urban and Sumner, 2009).

There are two major ways in which climate change and intensified disaster risks can affect the wind power sector:

First, wind power generation depends on wind availability. Climatic changes which affect wind speeds and other factors such as air density can have either positive or negative effects on wind power generation.

Second, wind turbines plants could be impacted by changing disaster risks such as storms, floods, sea level rise (particularly offshore turbines).

Both points are elaborated in more detail below.

Wind energy systems are susceptible to climatic variations. The level of electricity generation depends on wind speeds. Changes in wind pattern due to climate change are very regional and differ significantly from one region to another. Studies suggest changes in global wind speeds could affect Europe and North America minimally, however it could significantly affect South America as wind speeds may increase by up to 15% by 2100. This could result in a new potential for power generation in South America (Pryor, and Barthelmie, 2010; Segal et al., 2001).

A significant increase in wind speeds can have both positive (1) and negative (2) effects: (1a) with increasing wind speeds areas which had low wind speeds before can be utilised for generating low carbon electricity from wind turbines, (1b) higher wind speeds will increase the electric outputs of the wind turbines, (2) too high wind speeds can lead to the shutdown of wind turbines or even their destruction. Most wind turbines shut down at about 70-90 km/hour. However a study from Brazil suggests the wind power sector might not be negatively impacted by climate change, but could in contrary benefit from it due to higher wind speeds. The authors suggest diversifying the energy mix by investing increasingly into wind energy as a pathway towards a low carbon economy (Pereira de Lucena et al, 2010).

Pryor and Barthelmie (2010) summarise a range of climatic changes that can affect wind energy generation such as changes in air density, land cover / sea ice cover changes, icing, changes in sea levels, sea salinity content and wave heights. Many wind turbines are found in coastal regions and increasingly offshore. Altering sea-levels and salinity content may have implications on offshore and near-shore wind turbines, with flooding or corrosion of turbines becoming frequent.

Another aspect of importance to the foundation of offshore wind turbines is the wave heights, which is significantly dependent on wind speeds. According to a study of the northeast Atlantic, an increase of 5 to 8% of wave height is projected by the end of the 21st century, which raises questions about the appropriateness of certain offshore energy sites, in the light of current climatic changes (Pryor and Barthelmie, 2010).
Changing disaster risks such as the exposure to more frequent and more severe storms and flooding can pose a serious challenge to offshore and near-shore wind turbines. Concerns about wave changes, salinity changes and sea level changes are also important for wave power generation[2] . Harrison and Wallace (2005) indicate how the impacts of climate change can change disaster risks for offshore wind energy: changes in the climatic conditions for wind and waves affect offshore wind and wave power, leading to reduced power generation with lower wind speeds and less waves, while risking damages to equipment with higher wind speeds and more waves. (Harrison and Wallace, 2005). Taking the case of the North-East Atlantic, climatic variations since the 1980s have led to an increase in wave heights (Bacon and Carter, 1993). In Europe offshore wind speeds have increased by 15-20% over the past 40 years. Higher winds and higher wave heights may threaten device survival for offshore wind technology (and marine energy technology such as wave and tidal).

2 Wave power generation is not discussed in detail here as it goes beyond the scope of the paper. Only commercially available renewable energy technologies have not been assessed in this paper.

Additionally, a projected increase in sea-levels, estimated to be about 36 cm by 2080 in Europe, might have adverse consequences on deep waters devices (Harrison and Wallace, 2005).

Quantification of changes projected due to climate change, particularly wind speeds, could better inform plans to develop wind power sources globally. To adapt to changing wind speeds and changing disaster risks, turbines that are able to operate at and can physically withstand high wind speeds and storms are advisable. Long-term insurance schemes for power yields and damage from storms should be promoted (Breslow and Sailor, 2002).

Table 4 shows the effects of climate change and changing disaster risks on wind energy generation.

Change in meteorological variable	**Impact on wind energy plant/ resources**	**Impact on electricity generation**
Temperature increase	Indirect impact on air density and wind patterns	Either increased or decreased electricity generation possible
Increase in average precipitation	None	None
Decrease in average precipitation	None	None
Droughts	None	None
Glacier melting	None, unless flooding occurs. If flooding occurs risk of damage to equipment	None if no flooding occurs. If flooding occurs decreased electricity generation
Floods	None, unless flooding occurs. If flooding occurs risk of damage to equipment.	None if no flooding occurs. If flooding occurs decreased electricity generation.
Increased frequency and/or strength of storms/cyclones	Risk to equipment.	Decreased electricity generation if wind turbine is destroyed or damaged.
Increased wind speeds	Better wind conditions.	Increased electricity generations, unless a storm occurs (see above)
Decreased wind speeds	Worse wind conditions.	Decreased electricity generation.
Changes in wind patterns	Changes in air density, wind directions, wind variability.	Either increased or decreased electricity generation possible

Table 4: The effects of climate change and changing disaster risks on wind energy generation.

2.4.3 Bioenergy

Bioenergy is an important source of energy, which can be used for electricity generation, transport, cooking and heating. Bioenergy also plays a large role in many countries in Sub-Saharan Africa, as well as in Asia and Latin America, particularly in the rural areas (IEA, 2010).
For this paper we focus solely on bioenergy for electricity generation. Globally bioenergy for electricity generation has reached an installed capacity of 35GW. The US alone has 500 biomass-powered power plants with an installed capacity of 7GW (IEA, 2010).

Electricity generation from bioenergy draws on a large variety of different sources, including forest by-products such as wood residues, which are the most common source of biomass based electricity in the US; agricultural residues such as sugar cane waste in Mauritius and rice husks in Southeast Asia; and animal husbandry residues such as poultry litter in the UK. One of the main advantages of biomass based electricity is that the fuel is often a residue, by-product or waste product of other processes such as forestry, agriculture or animal farming. This has the benefit that it does not create a competition between land for food and land for fuel. Nevertheless this cannot always be
guaranteed.

Climate change and changing disaster risks are likely to affect biomass-based electricity generation in four main ways.

First, climatic changes can affect the cultivation regimes for biomass. Higher temperatures and higher CO2 levels can affect crop yields both positively and negatively. Climatic changes can increase the prevalence of and the variety of pests, they can increase the pressure on water demand, the risk of fires, and could lead to changes in biodiversity and agro-ecological zones (ESMAP, 2011). Some studies highlight the potentially negative impact of climate change on bioenergy-producing areas which are already vulnerable from a socio-economic perspective, such as in Brazil. Poor biomass-growing farmers might be most affected by climatic changes (Pereira de Lucena et al., 2009). Nevertheless, the results of many bioenergy studies are highly regional, highly variable depending on crop varieties and there is uncertainty in the climate projections (e.g. Pereira de Lucena et al., 2009; IPCC, 2007a). These climatic changes are likely to affect biomass sources from the agricultural and forestry sector, not from waste or animal farming.

Second, the changing disaster risk associated with climate change poses challenges to the bioenergy sector. Changes in the intensity and frequency are likely to increase the risk of tropical storms, cyclones, floods and other extreme weather events (IPCC, 2007a). This can harm biomass-based electricity generation and poses a danger to power plant equipment and electricity generation.

Third, cooling water operations for biomass-based power plants are likely to be affected by increased temperatures. Water stress and droughts might intensify these problems (ESMAP, 2011). This is a generic problem for all thermal power plants depending on water cooling.

Fourth, it has been suggested that high temperatures reduce the thermal generation efficiency, which in return can decrease the power output (ESMAP, 2011). This is a generic problem for all thermal power plants.

Table 5 indicates the effects of climate change and changing disaster risks on biomass-based electricity generation.

Change in meteorological variable	**Impact on biomass-based power plant / resource**	**Impact on electricity generation**
Temperature increase	Potential impact on water availability for cooling purposes. Lower availability of biomass if plants reach threshold of biological heat tolerance or if sea level rise reduces the area where plants grow, otherwise there is an increase in biomass availability, increased fire risk.	Increased temperatures decrease the thermal generation efficiency of power plants. Either increased or decreased biomass availability on crop variety. Increased fire risk may jeopardise crop harvest.
Increase in average precipitation	Higher biomass availability if the precipation increase occurs during the growing season.	Increased electricity generation.
Decrease in average precipitation	Lower biomass availability unless precipitation decrease occurs outside the growing season. Increased fire risk.	Decreased electricity generation, increased fire risk may jeopardise harvest.
Droughts	Lower biomass availability. Increased fire risk.	Decreased electricity generation, increased fire risk may jeopardise harvest.
Glacier melting	If under-irrigation of biomass resources: short to medium increase but long - term decrease depending on the situation of glaciers with regards to the current and future snow lines. Otherwise no changes.	As per availability.
Floods	Decreased availability of biomass resources if floods affect area where biomass is sourced.	Decreased electricity generation if power plant is flooded, destroyed or biomass availability is reduced.
Increased frequency and/or strength of storms/cyclones	Decreased availability of biomass resources if storms affect area where biomass is sourced.	Decreased electricity generation if power plant is flooded, destroyed or biomass availability is reduced.

Table 5: The effects of climate change and changing disaster risks on biomass electricity production, partly based on and amended from Michaelowa et al., 2010.

2.4.4. Solar energy

The World Energy Council WEC suggests 'the total annual solar radiation falling on the earth is more than 7 500 times the world's total annual primary energy consumption of 450 EJ' (WEC, 2007:381). The potential of what is feasible due to technical, economic and spatial limitations is however significantly lower, though difficult to quantify. The WEC argues for a transition from fossil and nuclear power, which is prone to the impacts of climate change and changing disasters risks, to renewable energy, mainly solar energy (WEC, 2007).

There is a range of solar energy applications installed world-wide for electricity production. The WEC highlights the role of photovoltaic (PV) panels and solar thermal power plants such as concentrated solar power (CSP) for the global electricity supply. It indicates the most promising areas for CSP are the Southwest of the US, Central and South America, Africa, the Middle East, the Mediterranean countries of Europe, South Asia, certain countries of the Former Soviet Union, China and Australia. However there are major barriers which still need to be overcome before solar energy can compete with fossil fuel energy.

These barriers are higher production costs, a lack of adequate Research and Development (R&D) and a lack of favourable policies (WEC, 2007). Nevertheless costs for solar power could be more competitive in many places if fossil fuel subsidies would be reduced. In addition, generation costs for solar energy are significantly below the generation costs for fossil fuels as energy from the sun is for free and no fuel has to be purchased. However the up-front costs for solar energy are high and are a prohibitive factor for individual consumers as well as for investors.

There are two major ways in which climate change and intensified disaster risks can affect the solar power sector. First, solar power generation depends on the availability of solar radiation. Climatic changes which affect cloud cover and solar radiation can have negative effects on solar power generation.

Second, solar equipment could be impacted by changing disaster risks such as storms, floods, heavy precipitation events and other extreme weather events. Both points are elaborated in more detail below.

Michaelowa et al. (2010) argue a changing climate might affect solar energy production due to changing cloud covers and increasing temperatures which might reduce the electric output. PV cells can operate even on cloudy days, however mirror-based solar thermal applications such as CSP need direct sunlight (Fidje and Martinsen in Mideksa and Kallbekken, 2010).

However the key issue here is the impact of climate change on disaster risks. An increase in the frequency and severity of cyclones and storms could increase the risk of destruction of solar energy infrastructure (Michaelowa et al., 2010).

Sea-level rise and flooding could also impact solar energy equipment. Nevertheless, there are many uncertainties and more research is needed into the changing disaster risks for solar energy.
Michaelowa et al. (2010) suggest some adaptation strategies as a response to changing disaster risk due to climate change, such as:

- Design more robust CSP plants which are resistant to cyclones, storms and other extreme weather events.

- Use mobile repair teams for repairing distributed systems after their damage by extreme weather events.

Table 6 indicates the effects of climate change and changing disaster risks on solar based electricity generation.

Change in meteorological variable	**Impact on solar power plant / resources**	**Impact on electricity generation**
Temperature increase	Better conditions if accompanied by increased solar radiation, lower cloud cover, worse conditions if accompanied with decreased solar radiation and higher cloud cover, otherwise unchanged.	Either increased, decreased or unchanged electricity generation possible. Increased temperatures decrease the thermal generation efficiency of power plants.
Increase in average precipitation	Worse conditions if accompanied with decreased solar radiation and higher cloud cover, otherwise unchanged.	Either decreased or unchanged electricity generation possible.
Decrease in average precipitation	Improved solar radiation and cloud cover.	Increased electricity generation.
Droughts	Higher solar radiation and lower cloud cover.	Decreased electricity generation.
Glacier melting	None, unless flooding occurs. If flooding occurs risk of damage to equipment.	None if no flooding occurs. If flooding occurs decreased electricity generation.
Floods	None, unless flooding occurs. If flooding occurs risk of damage to equipment.	None if no flooding occurs. If flooding occurs decreased electricity generation.
Increased frequency and/or strength of storms/cyclones	Risk to power plant equipment.	Decreased electricity generation if power plant is destroyed or damaged.
Increased solar radiation	Better solar conditions	Increased energy generation.

Decreased solar radiation	Worse solar conditions	Decreased energy generation
Changes in cloud cover	Better conditions if less cloud cover, worse conditions if more cloud cover.	Either increased or decreased energy generation possible.

Table 6: The effects of climate change and changing disaster risks on solar based electricity generation.

3. Climate change and changing disaster risks: implications for energy policy and planning

'Energy exploration, extraction, transportation, refining, generation, transmission and demand are all critically exposed to weather and climate events in one way or another' (Dutton in Troccoli, 2010:22). According to the Stern Review on the Economics of Climate Change and DFID's Disaster Risk Reduction (DRR) Policy, about two thirds of disasters are estimated to be caused by climate hazards, which are increasing in number and severity due to climate change (Mitchell and Aalst, 2008:3).

Fundamentally, there is a growing need for information and research at the local, national, regional and international level, to further assess the link between energy infrastructure, climatic changes and extreme weather events. To reduce global vulnerability to climate change and changing disaster risks, the UNFCCC Bali Action Plan stressed the importance of adaptation to climate change and the need to incorporate adaptation in legally binding climate agreements.

However, adaptation to climate change and changing disaster risks are issues which have not been witnessed in the energy sector so far. The focus has been much more on mitigation by reducing emissions from the energy sector, than finding solutions for adapting to climatic changes and extreme weather events. ISDR argues 'the most likely impacts on the energy sector arise from the economic and political forces as governments and customers seek to mitigate and adapt to climate change'. It suggests climate change adaptation and Disaster Risk Management measures need to be included in electricity and energy policies (ISDR, 2009:19).

There is a need to monitor, analyse and address adverse effects of climate change and disaster risks in a systematic and integrated manner to be able to respond to changing risks in electricity and energy policy-making and planning. Currently many energy and environment ministries do not adequately take climate and disaster risks into account for energy and electricity planning and policies. This will have to change in the future as planning and policy-making authorities need to work more closely together to minimise the risks of climate change on the electricity sector.

Assessing future potentials, risks and costs of different electricity options could be better addressed by mainstreaming climate change into electricity and energy planning.

Also, ‘bottom-up’ integrated assessment models which quantify and simulate energy-economy-climate links may help assessing spatial and sectoral implications along with damage estimates (Mendelsohn et al., 2000:554).

This can help energy and environment ministries and local and national authorities to make more informed decisions about the energy mix for ensuring future energy security, and minimising damage due to extreme weather events and climatic changes.

Electricity generation options should be made more resilient to climate change by carefully assessing siting procedures, feasibility studies and Environmental Impact Assessments for new power plants, which need to take into account existing disaster risks and adaptation strategies to climate change. There is therefore a need to design more robust infrastructure and to establish disaster risk systems. Procedures should be in place for early warning systems to enable evacuation of staff and to secure electricity infrastructure where possible before the extreme weather event hits.

Other Disaster Risk Management and adaptation strategies in the electricity generation sector could be for example using more drought-resistant bioenergy crops, using mobile repair units for rapid response for solar and wind plants, building more robust power plants and dams, having separate non-river-based cooled water reservoirs, using water saving measures for thermal power plants and situating power plants and equipment in areas which are less prone to flood and areas of projected sea-level rise.

Policies such as carbon pricing, subsidies for renewable energy, feed-in-tariffs, tax on fossil fuel energy and incentives for R&D for low carbon energy could boost investments in low carbon energy options and thereby reduce the dependency on fossil fuels (Fischer and Newell, 2004).

Given the high vulnerability of fossil fuel, nuclear and hydropower infrastructure to extreme weather events such as drought, cyclones, storms, flooding and sea-level rise, it is advisable to diversify the energy portfolio and to increase the share of energy options which are less vulnerable to climate change. Nevertheless this paper has shown that all energy options are to some extent affected by climate change and changing disasters risks.

4. Conclusion

This paper elaborates the impacts of projected climate change and changing disaster risks for a range of electricity generation infrastructure. It also assesses how resilient various electricity generation infrastructures are to climate change and found there is significant room for improvement. Section 2 indicates how all electricity options are to some extent vulnerable to climatic changes and extreme weather events.

Oil and natural gas
Oil and natural gas infrastructure are vulnerable to storms, cyclones, flooding and long-term sea-level rise as has been dramatically revealed by Hurricane Katrina. This is expected to increase as oil and gas sources are increasingly likely to come from off-shore, deep water and Arctic fields. Apart from the need to reduce the use of such fossil fuels for urgent mitigation, climate change itself is likely to expose infrastructure to greater risks.

In this respect depending on fossil fuels, like oil and natural gas, has three disadvantages: 1. peak oil (Almeida and Silva, 2009) and depletion of finite fossil fuel resources, 2. climate change and 3. high vulnerability to extreme weather events. There are hence good reasons for diversifying the energy mix and investing into more sustainable energy options for a low carbon future. Nuclear power is vulnerable to droughts which can decrease electricity production, but much more importantly it can cause health and safety issues due to extreme weather events such as storms, flooding and sea-level rise which could damage nuclear power plants.

Hydropower
Hydropower is highly vulnerable to droughts which can decrease electricity production. Wind energy might be impacted positively by climate change to some extent as increasing wind speeds lead to higher outputs and being able to generate wind energy in areas which were previously not suitable. However too strong winds can damage equipment.

Bioenergy
Bioenergy is affected very variably and the climatic effects may be negative for some crops and positive for others. Solar energy might be affected by extreme weather events through storms, flooding and sea-level rise, whereas observed impacts seem to be minimal to date. Reducing the vulnerability of the electricity sector by assessing existing and future disaster risks and actively minimising them is key to ensuring energy security in a changing climate.

Using data more effectively
Global, regional, national and local data on climate impacts from the IPCC, meteorological institutions and research institutions are crucial for being able to incorporate the available knowledge on current and future climatic changes into energy and electricity policy and planning and for reducing the vulnerability of the electricity sector to climate change.

Recommendations: minimising disaster risk in the electricity sector

- Energy and electricity policy and planning needs to assess disaster risks such as storms, floods, droughts and sea-level rise at the national and local level
- Feasibility studies and siting procedures for power plants should include an evaluation of future disasters risks to determine whether a site is adequate or not for a new power plant
- Environmental Impact Assessments should consider the dynamic nature of disaster risks in a changing climate and should include an assessment of future disaster risks for new power plants
- Existing power plants and electricity infrastructure are suggested to be assessed in terms of their vulnerability to extreme weather events and adaptation strategies need to be considered
- Improved linkages are recommended between energy ministries, climate ministries, and disasters ministries in relation to energy and electricity policy and planning
- Energy and electricity policies need to respond to a changing climate and changing disaster risks by proposing adaptation strategies for the electricity sector
- Mainstreaming climate change into energy policies and planning
- Improved collaboration between national and local planning authorities, energy experts and climate / disaster experts

Overall this paper indicates that impacts of climate change and changing disaster risks can be regionally specific and localised. Hence, more research is needed into the impacts of climate change and disasters on the electricity sector from a regional, national and local perspective, particularly for developing countries.

Shifting focus to include Global South
Much of the available literature is currently limited to the Global North. Also, most existing studies refer to large-scale electricity infrastructure only. There is little evidence about how climate change and disasters affect small-scale electricity generation, particularly off-grid and in the Global South. This question is especially relevant as poor countries and poor people have a lower adaptive capacity due to limited access to financial, material and infrastructural resources.

Include adaptation strategies
Finally, the emphasis on mitigation in the electricity sector should be broadened by including adaptation strategies to respond to climatic changes and extreme weather events. By doing so, the electricity sector could increase its resilience to climate change, increase energy security and contribute to 'low carbon climate resilient development'.

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