SYNERGIES: INTERACTIONS BETWEEN CLIMATE CHANGE ADAPTATION AND MITIGATION IN CANADA'S ENERGY SUPPLY SECTOR

Final report

March 2016

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GLOSSARY

Adaptation: Changes to decisions, activities and/or processes due to observed or expected changes in climate and associated impacts.

CAPP: Canadian Association of Petroleum Producers

CCGT: Combined cycle gas turbine, a type of gas turbine where waste heat from the gas turbine is used to produce steam and power a secondary turbine.

CCS: Carbon capture and storage

CSP: Concentrated solar power

DE: District Energy

Embedded energy: The total primary energy required to extract, transport and process the raw materials, manufacture and transport the component and dispose of it at the end of its lifetime.

EOR: Enhanced Oil Recovery.

EPBT: Energy payback time, the time a plant must operate until the energy gain compensates the energy expenditure to build the plant.

EROI: Energy return on investment, the ratio of usable energy delivered from a particular energy source to the energy used to obtain that resource.

FIT: Feed-In tariff, prices guaranteed to producers to deliver power to the grid from a particular technology.

GHG: Greenhouse gases, gases that modify the radiative balance of the atmosphere.

GS: Generating station

GWP: Global Warming Potential, measure of the efficiency in blocking infrared radiation compared to carbon dioxide.

IGCC: Integrated gasification combined cycle

IPCC: Intergovernmental Panel on Climate Change

LCA: Life cycle analysis

Lifecycle emissions: Total GHG emitted over the lifetime of an asset, including construction, operation, maintenance and decommissioning.

LCOE: Levelized cost of electricity.

Mitigation: The reduction of greenhouse gas emissions.

MMBtu: One million British Thermal Unit, corresponding to 28.3 m^3 of natural gas.

NEB: National Energy Board

Net metering: A system by which individual can deliver surplus power to the grid, for example from solar panels, to offset their electricity consumption.

PC: Pulverised coal

PV: Photovoltaic, describing the production of electricity from a light source.

Radiative forcing: A measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism (IPCC AR5). Radiative forcing is usually expressed in units of Watts per square meter (W/m^2).

RE: Renewable energy

Technical potential: The achievable energy generation of a particular technology given system performance and practical constraints.

1. INTRODUCTION

Climate change caused by increasing concentrations of various greenhouse gases in the atmosphere raises two challenges. One is adapting infrastructures and activities to a climate moving out of the range modern society was built upon. The other is to reduce emissions rapidly enough to avoid changes that would be beyond the ability of ecosystems and societies to adjust to climate change. Given limited resources and competing priorities, trade-offs will have to be made between emissions reduction and adaptation efforts. Two questions are whether upcoming mitigation investments could reduce our adaptive capacity, and if investments required in adaptation will contribute significantly to future emissions.

Energy accounts for 37% of total Canadian emissions (25% for oil and gas and 12% for electricity generation).[1] The large potential for emissions reductions in the energy sector and its pivotal socio-economic role designate it as a prime candidate for an assessment of potential interactions between mitigation and adaptation. Between 2005 and 2013, emissions from the electricity sector decreased by 29%, in part due to switching from coal and oil to renewables.[2] Increasing reliance on weather-dependent energy sources raises the specter of an energy system that ironically, might be more vulnerable to climate change.

Energy infrastructure is potentially exposed to weather-related disruptions or efficiency losses due to changing climatic conditions. Reductions in water availability, extreme weather, heatwaves, flooding, landslides and permafrost melting can affect the generation, transportation and distribution of energy. Adaptation measures are thus meant to increase our resilience to climate variability. More precisely, adaptation is defined as “adjusting decisions, activities, and thinking because of observed or expected changes in climate in order to moderate harm or take advantage of new opportunities”.[3]

While the success of mitigation efforts can be tracked using measures such as the global warming potential or carbon equivalent, there is no such clear metric for adaptation. Moreover, being adapted to climate change implies being also adapted to other stressors, complicating the evaluation of adaptation strategies. What is often proposed is mainstreaming climate change concerns, that is, integrating climate risks and resilience into development planning and implementation.

From a policy perspective, there are potential benefits to formally integrating both mitigation and adaptation and leveraging the interactions that advance both aspects, or that at least avoid maladaptation.[4] That being said, information on this topic is scattered and not always relevant to the Canadian context. This document provides a very brief literature survey of interactions between mitigation and adaptation for ten measures intended to reduce energy-related emissions and/or adapt to climate change. It does not provide a complete overview of all existing strategies.

Each measure has been analyzed according to its impact on energy reliability, accessibility, carbon neutrality, and security, and is described in individual factsheets. These factsheets describe possible interactions, if any, between mitigation and adaptation and point to areas where our knowledge and understanding of these issues is lacking. This document’s objective is not to argue for any one measure or technology, but to report on what is known about their potential to reduce emissions as well as the potential pitfalls related to wide-scale implementation. This report is mostly based on the literature as well as comments from experts consulted throughout the project.

2. WIND ELECTRICITY GENERATION

DESCRIPTION

Wind-generated electricity is a renewable source of energy in expansion with 1700 MW of new capacity added in 2014 in Canada.[1] Wind turbines have an average operating lifetime of over 20 years.[2] Operational processes including power generation and plant maintenance generate low GHG emissions and involve little consumption of water.[3,4]

INTERACTIONS BETWEEN ADAPTATION AND MITIGATION

Power produced from wind turbines vary with the wind speed cubed. Wind resources would thus be affected by large-scale shifts in wind speeds and geographic distribution as a result of climate change. Observations indicate a declining trend in mean surface wind speeds over the contiguous U.S. and southern Canada,[5] but these results do not necessarily apply at the height at which wind turbines operate. These trends are possibly due both to changes in the general wind circulation and to changes in the surface roughness[1] due to denser vegetation.[6] According to TechnoCentre éolien, a change in landscape roughness determined by the vegetation type is projected and will negatively affect the generation of power at medium latitudes. Although surface winds are notoriously difficult to model accurately with global climate models (GCMs) and even regional climate models (RCMs), projected future winds lie within the inter-annual variability (±15%) for most of North America.[7] Studies over Canada report an increase in the frequency of localized convective windstorms[8] and stronger wind speeds, particularly in the boreal regions of Canada. In the Whitehorse area, analysis at different altitudes shown that climate change has already modified the wind regime with an increase of 1m/s over the 50-year analysis period.[9]

Operating conditions might also be affected by climate change, either through icing events, temperature increases, lightning, change in the vegetation types, or melting of permafrost. Icing, even in small quantity, reduces significantly the production of energy.[10] No information was found for icing risks in Canada, however they are expected to decrease over the USA.[11] There are already some existing strategies to mitigate such issues, like hydrophobic coating, manual removal of ice or heating blades [Manitoba Hydro]. More generally, the projected increase in air temperature and humidity would both reduce air density and slightly decrease production [Manitoba Hydro].[11] In high latitudes, permafrost instability will have to be taken into account when building foundations for turbine towers, as well as an increasingly limited road access due to shorter ice road seasons. These concerns and their associated costs are however site-specific and suggest adopting a risk-informed site selection process that takes into account future wind potential and climate-related vulnerabilities. Overall, wind electricity generation is considered as more vulnerable to weather than solar power generation [Manitoba Hydro]. For example, in winter peaking markets such as Manitoba and Québec, peak energy demand

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[1] Surface roughness acts as a friction force that reduces wind speeds. High roughness areas are generally associated with slower winds and pronounced stilling.[6]

occurs during extreme cold spells, but wind turbines may have to be stopped at very cold temperatures (e.g. < -30°C) to avoid damage [Manitoba Hydro]; extreme cold events will however become less frequent with climate change.

The location of wind potential is usually away from load centers and therefore the vulnerability of transmission lines should also be considered. This is not a trivial matter as the planning and construction of additional transmission lines can be a much longer, arduous and capital-intensive process than the construction of new wind farms[4]. This makes the integration of large scale wind power to the existing transmission network a challenge, with possible consequences on congestion and overall grid efficiency.[12] There are however co-benefits to the construction of new redundant transmission lines, such as a decreased vulnerability to extreme events (see Adaptation of energy assets - Bipole III example).

A potential shift in birds migratory pattern (timing and pathways) caused by climate change is an additional issue and may affect the site selection of wind farms. Stricter regulation, the use of smart radar technology and ultrasonic repellents are increasingly used in North America to reduce avian mortality [Manitoba Hydro].

CAVEATS

The intermittency of wind generation means that load-following generators must compensate by rapidly ramping up or down power production, which for thermal energy often leads to efficiency penalties.[13] This can be mitigated by adding storage to the grid, either in the form of batteries or water in hydroelectric reservoirs [Techno-centre éolien].[14]

EXPERT’S COMMENTS

- The resilience of wind farms to convective storm would be manufacturer specific and depend on the safety factor of all components that may be affected by weather (i.e. tower, blades, nacelle, and foundation). [Manitoba Hydro]

- Therefore, if climate change increases both average temperature and average moisture content, the reduction in wind power will be even more pronounced. As an example, over time our wind farms have produced around 16% more energy from October through March, compared to April through September. Wind variations and other factors have contributed as well, but obviously air density plays a substantial role in seasonal variation. [Manitoba Hydro]

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3. NUCLEAR ELECTRICITY GENERATION

DESCRIPTION

Electricity generation from nuclear power does not emit carbon and has been proposed as a solution to reduce GHG emissions. In 2014, 15% of the total electricity in Canada was generated from nuclear energy produced in Ontario and New Brunswick.[1] Nuclear plants have relatively low operating costs but very high capital costs, making their LCOE strongly dependent on borrowing rates, which reveals the risk perceived by investors.[2,3]

INTERACTIONS BETWEEN ADAPTATION AND MITIGATION

As with other thermal plants, nuclear plants require large volumes of water for cooling[2] and are usually located in coastal regions or near rivers or lakes. Nuclear plants can thus be exposed to sea level rise, storm surges and flooding.[4] In Canada, Point Lepreau (NB) is potentially exposed to sea level rise and hurricanes, but no estimate of the actual vulnerability was found in the public literature. The situation is similar for the other nuclear reactors located on Lake Ontario and Huron, potentially exposed to flood risks, but whose actual vulnerability could not be quantified. The Canadian Nuclear Safety Commission is likely in possession of detailed vulnerability studies for each generating station.

Similarly to other thermal generators, nuclear plants lose efficiency as the coolant (water or air) warms.[5] A study based on European plants shows that “a rise in temperature of 1 ° C reduces the supply of nuclear power by about 0.5% through its effect on thermal efficiency; during droughts and heat waves, production losses may exceed 2.0% per Celsius degree because power plant cooling systems are constrained by physical laws, regulations and access to cooling water”.[6] Although these losses are marginal, they would occur at times of highest load in regions where peak load is reached in summer. During the 2003 European heatwave, 17 reactors owned by Électricité de France operated at reduced capacity or were turned off.[7]

According to European consultations with senior managers of electric utilities, “higher surface water temperature can lead to cooling problems”, “extreme ambient air temperatures are a low threat”, “flooding is seen as the most harmful climate change effect on the operation of nuclear facilities”, and “the main costs of climate change results from the reduced efficiency of the nuclear power plant”.[8] In Canada, discussions with Ontario Power Generation reveal that the Pickering station has its cooling water intake near the surface and could be affected by rising surface water temperatures; the Darlington intake is located near the lake bottom and is less exposed; air temperature is also perceived as a low threat; flooding from Lake Ontario is unlikely, but flooding from intense precipitation was a risk for Pickering and Darlington that drove recent protection investments; and that the main costs would likely come from Pickering having to de-rate to maintain the station’s cooling capability and comply with its Environmental Compliance Approval. [OPG]

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[2] Nuclear plants use water to cool and condense steam that has gone through the turbines.

CAVEATS

Nuclear power could play a role in mitigating climate change but it faces four unresolved barriers to widespread adoption: safety concerns exacerbated by past accidents, management of radioactive wastes, association of nuclear technology with security risks, and higher initial costs than competing technologies.[9] Although numerous solutions exist to address some of these risks (fast breeders, small modular reactors,[10,11] molten salt reactor[12,13]), no unique solution can solve them all[14]. In recent years, nuclear power has been in steady decline almost everywhere worldwide.[15]

EXPERT'S COMMENTS

- In the context of climate change, renewables are in expansion and traditional nuclear plants cannot ramp rapidly to accommodate the intermittency of renewable generators. This may be dependent on emerging/future nuclear technologies (non-uranium, modular, etc.). [Manitoba Hydro]

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4. SOLAR ELECTRICITY GENERATION

DESCRIPTION

Among RE resources, solar energy has the highest technical potential worldwide, defined as the achievable energy generation that gives an upper-boundary estimate of the development potential.[1,2] In Canada, solar potential is in general larger than that of Germany, which had the largest installed PV capacity in the world as of 2014,[3] and is at its maximum in the Prairies.[4] Although fast growing, solar still contributes a modest input to the Canadian energy production, the total installed capacity being currently less than 2 GW.[3,5] The two main technologies for the generation of electricity are photovoltaic (PV) technology, by far the most common; and solar thermal technology or concentrated solar power (CSP).[2,6] Solar electricity can be produced through distributed small individual- (rooftop), community-scale PV arrays or centralized large utility-scale PV or CSP plants.[2,6] Average operating lifetime for both PV and CSP is 25 to 30 years.[7,8]

INTERACTIONS BETWEEN ADAPTATION AND MITIGATION

Except for maintenance, the operation of solar installations generates no GHG emissions.[9] In Canada, rain and snow precipitations prevent the accumulation of dirt on the modules and no regular cleaning is required [Natural Ressources Canada]. Some water is required for thermal engines cooling,[2,10,11] and as such CSP would face issues similar to those of other thermal generators with respect to water constraints.

PV systems are vulnerable to changes in mean conditions, such as increased precipitation, humidity and cloudiness (reduced output) as well as extreme events such as hail, lightning strikes, strong winds, and very high temperatures (reduced output and material damage).[12,13] In Canada, PV panels' tilt is such that hail is not a concern [Manitoba Hydro]. On the other hand, past trends suggest an increase in the number of days with precipitation[14] and increased cloudiness in the Prairies.[15] For snowfall, past observations suggest a decrease in Southern Canada and an increase in northern and northeastern Canada,[14] consistent with climate projections up to 2050.[16] Snow must be cleared for solar panels to function efficiently. These PV vulnerabilities to climate change are considered minor[2,12,17] and can be reduced through careful design and specifications for system location and components such as more robust structure, heat-resistant PV modules, dry cooling systems and rough-surfaced PV modules with improved output under diffuse light.[12,17] In addition, technology development including new materials and storage capacity, can also reduce the impact of these vulnerabilities [Manitoba Hydro], and can potentially mitigate the intermittent and variable nature of solar energy, which is a barrier to wider solar use.

Long transmission lines linking generating stations to load centers are exposed to extreme weather events and thus potentially vulnerable to climate change (winds, freezing rain, fires). Distributed PV systems can hence potentially improve grid resilience to power outages when they are designed with a stand-alone capability and paired with storage capacity.[12,18] As distributed systems are usually located close to the load, they reduce grid congestion, avoid transmission and distribution losses and reduce the social costs of grid failures.[10,18] Conversely, intermittency due to clouds and daily and seasonal variability can cause integration challenges in terms of reliability, grid stability and balancing, dispatch and transmission.[19–24] Proposed solutions include improved weather forecasting, reserve management, microgrids and micro-inverters, as well as geographic dispersion of solar facilities.[19–21] High penetration of solar power can also impact power quality and lead to efficiency penalties.[7] Grid balancing is easier with distributed PV systems and partially mitigated by the correlation between PV peak production and peak loads in regions with high cooling demand.[22,23]

CAVEATS

Solar technology is in rapid development, and the materials and techniques that will be used a few years from now may have a different vulnerability profile than existing technology on which this factsheet is based.

EXPERT'S COMMENTS

- Since they are covered by tempered glass, current solar panels are resistant to hail. [Manitoba Hydro]
- PV panels are modular systems that are more easily transported and installed and require less maintenance than wind turbines – these are all important considerations for remote communities [Manitoba Hydro].

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5. GAS-FIRED ELECTRICITY GENERATION

DESCRIPTION

Natural gas is often hailed as a bridge fuel, producing less emissions than coal or oil, and allowing a smooth transition toward carbon-neutral electricity generation. In Canada, the National Energy Board (NEB) projected an increase in gas-fired generation capacity from 22GW in 2014 to 38GW by 2040.[1] The low cost of natural gas, small footprint of plants, low capital costs and short construction times of these plants make them attractive to investors in liberalized energy markets. Gas turbines come in different varieties (single cycle, combined cycle) focusing on flexibility or efficiency, and have an approximate lifetime of 30 years.[2] Compared to coal power plants, combined cycle gas turbine (CCGT) emit 50% less GHG per kWh and require less water for cooling.[3]

INTERACTIONS BETWEEN ADAPTATION AND MITIGATION

Gas-fired electricity generation efficiency is sensitive to air temperature. An increase in ambient temperature decreases the differential with the combustion temperature and, as a result, reduces the efficiency of gensets[3], boilers and turbines.[4] This means that gas-fired generators run more efficiently during winter than summer, and that projected increases in temperature would reduce the average efficiency for a given turbine, especially during summer [Manitoba Hydro]. In Canada, an increase of 2°C in mean temperature is projected at the 2050 horizon, and could reach 5°C during winter for northern regions.[5] Reported values for efficiency losses vary greatly, from 0.5% to 4% for a 5°C warming.[4,6,7] These losses might be compensated through continued development in efficiency improvements. In 1992, combined cycle plants efficiency ran up to 52%, while efficiencies of over 60% were reached in 2016.[8,9]

Beyond generation, assessment of gas-fired power plant vulnerabilities should also take natural gas supply into consideration.[4,6,10,11] Risks to natural gas infrastructure and operations include floods and erosion, leading to the exposure of underground pipelines, storms and ground instability due to permafrost melt. For example, Northeastern BC is reporting more frequent floods and landslides, increased variability in weather conditions and an increase in the frequency and magnitude of forest fires.[11] These changes can potentially affect the maintenance of access roads, drilling pads and pipelines. Access to resources can also be negatively affected by changes in the landscape.[12] In Alaska, thawing of permafrost already decreased the number of extraction days from 200 to 120 days per year.[13] However, an ice-free summer would yield greater access to Arctic offshore resources.[14]

The impact of climate change on water resources is already a challenge for the gas sector. Water consumption for natural gas extraction is close to zero for conventional wells but between 1.9 and 7.5 l/MMBtu for shale gas.[15] Water usage restrictions during droughts can complicate

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[3] Engine-generator, a combination of a fuel engine with an electric generator.

logistics of exploration activities, as it occurred in 2010, 2012 and 2014 in British Columbia, when natural gas companies had to truck in water from large rivers instead of relying on small nearby tributaries.[16]

CAVEATS

Emission figures from gas-fired electricity generation do not always include an accurate estimation of fugitive emissions, which consist of leaks occurring during extraction, transportation, storage and distribution of natural gas. Because natural gas is composed primarily of methane, a short-lived GHG whose global warming potential is 34 and 108 times greater than CO_2 over 100 and 10 years respectively,[17] these leaks may contribute substantially to the climate change impacts of gas-fired electricity generation. Leakage estimates vary greatly, but at mid- to high-range values they would make emissions from natural gas fired generation higher than those of coal over short time scales.[18–20] A large percentage of fugitive leaks occurs at a small number of locations, sometimes referred to as “super-emitters”. Reducing leakage from such large-emitters would drastically reduce fugitive emissions and therefore increase the climate benefits of switching from coal to gas [Manitoba Hydro].[21,22] For example, a recent leak from a natural gas storage facility in California released an estimated 96 000 metric tonnes of methane, equivalent to approximately 2.0 $MtCO_2e$ of emissions.[23]

EXPERT’S COMMENTS

- With low natural gas prices, it would likely be much more economical to continue using existing CCGT plants rather than strand those assets and build new renewables. [Manitoba Hydro]
- From a generation perspective, CCGT is more resilient to climate change than other low-GHG energy sources. It is less exposed to weather with enclosed generation installations and distribution networks usually buried underground. Resource extraction may be less resilient and might have to deal with issues of permafrost melt and future resource availability. [Manitoba Hydro]

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6. METHANE EMISSION REDUCTION IN OIL AND GAS SECTOR

DESCRIPTION

In Canada, methane emissions from the oil and gas industry account for an estimated 6% of GHG emissions and are the largest source of anthropogenic methane emissions.[1] Compared to CO_2, methane has a much higher GWP but remains in the atmosphere only for about 12 years before being oxidized into CO_2 and water. The GWP of methane thus closely depends on the time horizon considered, averaging 34 over 100 years but reaching 86 over the first 20 years after emissions.[2] Measures to reduce methane emissions hence significantly lower the radiative forcing[3] on relatively short time scales.

INTERACTIONS BETWEEN ADAPTATION AND MITIGATION

Emissions in the oil and gas sector come from fugitive emissions (leaks) or intentional venting and flaring. Leak sources include valves, connectors, compressor seals, pump seals, pressure relief valves and open-ended lines and can be due to normal wear and tear, improper assembly, defects, corrosion, etc.[4] Plastic piping is increasingly used in Canada to avoid corrosion problems that occur with steel pipes, which could be amplified by an increase in air humidity [Manitoba Hydro].

The Canadian industry has been active over the past two decades reducing fugitive emissions [Manitoba Hydro]. Reductions are achieved with frequent inspections, maintenance and equipment replacement programs, as well as technological improvements. There is no evidence that these measures modify the vulnerability of the sector to climate change. The impact on gas-fired generation itself has been explored in the "gas-fired electricity generation" overview.

CAVEATS

In March 2016, Canada and the United States committed "to reduce methane emissions by 40-45 percent below 2012 levels by 2025 from the oil and gas sector, and explore new opportunities for additional methane reductions".5 Given past efforts by the Canadian industry to reduce known emissions from the distribution network, future reductions could be achieved by upgrading large compressor stations or by targeting the extraction processes. For example, the oil industry flares gas because it is often not economical to recuperate. Also, a large fraction of emissions are due to a few sources, so locating those large emitters will be key in reducing emissions [Manitoba Hydro].

EXPERT’S COMMENTS

- The U.S. infrastructure is much older than in Canada and regulations more lax, so fugitive emission estimates from the U.S. cannot be directly translated to Canada. [Manitoba Hydro]
- Fugitive emissions are accounted for in the cap and trade market. [Coop Carbone]

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7. ADAPTATION OF ENERGY ASSETS

DESCRIPTION

In Canada, investments of $386.0 are planned for 2012-2035 for the natural gas sector[1] and additional investments of $293.8 billion are planned for 2010-2030 for infrastructure in the electricity sector.[2] With rising GHG concentrations and associated climate impacts, two questions arise: are those investments "climate-resilient", and do they contribute significantly to GHG emissions? In fact, many energy companies and nations around the world have already started to adapt by hardening, refurbishing, upgrading, relocating, elevating or improving the design of existing or new assets. These adaptation measures can be undertaken as part of risk management processes, in response to new state or industry standards, as a part of national adaptation strategies[3] or in addition to scheduled baseline investments.[4]

INTERACTIONS BETWEEN ADAPTATION AND MITIGATION

According to the fourth IPCC report, "the effect of increased emissions due to adaptation is likely to be small in most sectors in relation to the baseline projections of energy use and greenhouse-gas emissions".[5] Indeed, "adaptation-related construction comprises only a small part of total annual construction, and the construction industry itself represents a small part in the annual energy balances of most countries".[5] Linkages are in fact quite limited given the large scope of projects in the energy sector. [Manitoba Hydro]

Nevertheless, adaption of energy infrastructure to climate change can be made practical and cost-effective if implemented during initial construction or reconstruction; whether voluntarily or through building codes.[6] For example, in the UK Western Power Distribution put in place a program to replace distribution poles that have reached their end-of-life by longer poles to accommodate increased line sagging.[7] In Iceland, Landsvirkjun is installing larger turbines in new hydropower plants to account for projected glacier melt.[8] These instances of integration of adaptation measures in regular management of assets have the potential to reduce the financial and carbon footprint of climate change adaptation. Another way for infrastructure to be cost effective is to be "climate ready". For example, ADB in Vietnam planned space for additional cooling equipment at the new O Mon IV thermal power station. This equipment will be added in the future as temperature rise to comply with environmental regulation and to avoid a loss in cooling efficiency.[9] This approach has the advantage of delaying emissions from construction.

Infrastructure investments can also be recouped by targeting measures that have co-benefits. For instance, the main purpose of the Bipole III transmission line under construction in Manitoba is to increase the grid reliability between the Lower Nelson river complex and load centers. That line, combined with the new proposed Manitoba-Minnesota transmission line, also offers co-benefits by adding exchange capacity with the U.S. grid, providing import options in case of droughts in the prairies, and potentially reducing U.S. emissions from thermal generating station (GS)[10] [Manitoba Hydro]. Moreover, instead of being installed in the same corridor as Bipole I and II, the new Bipole III line is located such that the probability of an extreme meteorological event hitting all corridors at once is reduced.

CAVEATS

The preceding discussion does not address the costs and carbon footprint of inaction. ExxonMobil and Colonial Pipeline deploying generators to supply electricity to pipelines after extreme events is an example of reactions to weather disruptions that exceeded infrastructure capacity.[11,12] Whether it is more effective, money wise and emission wise, to protect against those events or to prepare for and manage partial failures is a question that involves the social and economic costs of outages and degraded service quality.[13] Indeed, service interruptions vary greatly in their impacts depending on the time of occurrence, duration, magnitude, warning time, frequency, persistence and spatial coverage. Decisions to invest in measures that improve the reliability of the energy system should balance the overall costs to both energy providers and consumers, and consider criteria such as urgency, no-regrets characteristics, co-benefits and effects on climate change mitigation.[14] It may very well be that preparing and adapting for more frequent outages, for example using distributed storage, is a better strategy than trying to avoid interruptions at all costs.

EXPERT’S COMMENTS

- It is easier to make investment in the adaptation of infrastructure if you have co-benefits. For example in James Bay, where inflows could increase by 10-15%, installing larger turbines would also provide more flexibility to the system. [Ouranos]
- The concept of rigid standards sounds difficult to implement, and very costly if imposed by regulation. Also, it may be desirable to have climate-adaptation standards come through industry guideline associations, such as CDA, etc. [Manitoba Hydro]
- Many design standards are based on historic data (ex: high and low temperatures, flood risk, tornado risk). As we understand climate change better, we could modify our historically-based assumptions to incorporate the potential implications of climate change. [Manitoba Hydro]

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8. DISTRICT ENERGY SYSTEMS

DESCRIPTION

District energy (DE) systems support the transfer of energy as steam, hot water or chilled water from a central plant that is then piped underground to multiple buildings for space heating, domestic hot water, air conditioning and light industrial processing.[1] Because DE systems can leverage economies of scale, these systems are generally very efficient and can remove the need for standalone building individual boilers, furnaces, chillers or air conditioners, which saves on valuable building space, equipment capital costs and operating costs.[2]

The type of energy source used in a DE system can include conventional energy sources (natural gas and oil), alternative sources (solar power, geothermal energy, biogas, biomass) or residual heat from industrial processes. A DE system is flexible and can switch from one energy sources to another, for example from natural gas to biomass [Manitoba Hydro]. It may also produce electricity, an arrangement commonly called combined heat and power (CHP) or cogeneration.[1,3] With CHP, short term heat storage can be used to handle timing differences between power, heat and cooling demand, and maximise the production of electricity during peak-demand hours.[4] There are approximately 128 DE systems operating in Canada operational as of 2014 (heating, cooling or CHP).[5]

INTERACTIONS BETWEEN ADAPTATION AND MITIGATION

DE systems are less susceptible to extreme weather events and other infrastructure failures that impact electricity distribution, as a result of the systems being buried underground.

Virtually all DE systems have a reliability factor of “five nines” (99.999%).[6,7] To date, there have been no rolling “heat-outs” or major power interruptions reported in North America related to DE systems [QUEST]. In fact, there are several instances where despite storms and flooding that shut down power, DE systems maintained operations [QUEST]. As a result, DE can provide communities with some protection against economic losses from prolonged energy outages.[6]

However, depending on where a DE system is located, it may still be at risk of floods from storm surges, extreme rainfall, high winds or extreme extended cold weather, which can damage the distribution equipment.[7]

CAVEATS

The costs and benefits of DE are closely tied to the energy mix and electricity costs, urban density and building size (thermal energy load). DE is also most cost-effective for campuses, mixed use developments, large buildings or high-density residential zones, and less cost effective where there is a low thermal load demand, such as in low density developments.[9,10] What makes DE economically viable is the level of thermal energy load which is often related to the mix and types of building uses. There are many situations where DE can be economical even in smaller communities, especially where there are medical and university campuses. [QUEST]

In Canada, the low cost of energy from traditional sources, such as hydropower and natural gas, along with the majority of new development being lower density, has contributed to the slow growth of DE systems.[9] Also, in many cases, the financial viability of a DE system tends to be better for new development. For instance, a feasibility study in Quebec identified that it was cost-effective for a DE systems to be developed in a new community or a community with an established geothermal system, but less cost-effective for buildings already heated with electricity [Coop Carbone].

EXPERT'S COMMENTS

- DE schemes are one of the most effective means for integrating renewable energy sources into heating and cooling sectors. Solar thermal, geothermal, bioenergy, waste heat and natural, free, cooling systems can benefit from the economies of scale that district energy provides.[11] [Professor Ralph Sims, Massey University, New Zealand and member of the Scientific and Technical Advisory Panel of the GEF]

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9. BIOENERGY

DESCRIPTION

Bioenergy is energy derived from biofuels, produced directly or indirectly from organic material (biomass) including plant materials and animal waste.[1] It can be solid, liquid or gaseous. Biofuels can either be used directly as a primary fuel for electricity, heat generation and combined heat and power (e.g. residual forest biomass), or as a feedstock to produce refined secondary fuels (e.g. biodiesel) for transportation. When produced in a sustainable manner, bioenergy has a significant mitigation potential and allows 80 to 90% of emission reductions in comparison to fossil fuel.[2] There is a "green advantage" in Canada to use bioenergy because of its wide vegetated land and well-established forest and agricultural industries.[3]

There are three generations of biofuels distinguishable from the source from which the fuel is generated (not its structure). First generation biofuels are produced from food crops: sugars, animal fats, and vegetable oils (e.g. corn, soybean, wheat, sugar cane), and can be easily extracted. Second-generation biofuels, also known as advanced biofuels, are made from sustainable feedstock excluding food biomass: lignocellulosic biomass of woody crops, agricultural residues or waste. The third generation is associated with algae-based processes.[4] Biofuels can be converted to energy by combustion processes (direct and co-fired), thermochemical processes (gasification and pyrolysis) and biochemical processes (landfill gas, anaerobic digestion, ethanol and biodiesel) [Manitoba Hydro].

INTERACTIONS BETWEEN ADAPTATION AND MITIGATION

The biomass resource potential might be impacted by climate change through temperature increases, rainfall pattern changes and increased frequency of extreme events; but if the increase of temperature does not exceed 2°C, expected impacts are limited.[2]

Agriculture is considered as one of the most vulnerable systems to climate change.[5] In Canada, climate change may have positive and negative impacts on agriculture, and consequently on bioenergy derived from crops. The warming may provide longer growing and frost-free season that can increase the productivity of crops especially for southern and central Canadian prairies.[6] Also, the increase of CO_2 itself has an impact on certain crops yield and could increase growth for some varieties like soybean, wheat and rice [Manitoba Hydro].[7] However, negative impacts are also expected with an increase of extreme events like the 2001 and 2002 droughts and the 2010 and 2011 floods that resulted in a 50% reduction of crop yields.[6] Other environmental impacts are associated with biofuel production from agricultural crops. Biofuel production may put pressure on stressed resources - such as water - thus reducing climate resilience.[8] Conversely, water availability constraints would impact water-intensive biofuel industries such as ethanol production [Manitoba Hydro].

Canadian forest biomass has already been affected by climate change and the most visible impacts are due to increases in the frequency of fires, droughts, severe storms and damaging insect and disease attacks.[9] The increased length of the growing season is positive for crop productivity, but it may act like a barrier for wetlands where harvesting is done only on frozen grounds.[9]

Impacts of climate change on waste (2nd generation) and algae-based processes (3rd generation) are less clear as they are still in different stages of research and development.

In general, GHG emissions and climate vulnerabilities are not equivalent for all biofuel types. The harvesting process, the feedstocks, the type of combustion and gasification system, the infrastructure types, and the land-use changes, are examples of factors that may impact differently the GHG balance and the anticipated vulnerabilities of this sector [Manitoba Hydro]. The impacts of biofuels on climate change mitigation and adaptation are highly project-specific and therefore no sharp conclusion can be made regarding emission reduction or the contribution of all biofuels towards climate resilience.

CAVEATS

Even if dedicated energy crops are being grown on marginal land for bioenergy (i.e. switchgrass, miscanthus, hemp, cattails, etc.) [Manitoba Hydro], the production of biofuels could affect food prices if it competes with food crops for available land. More processes are being put in place to avoid this, for instance corn stover (leaves and stalks) are being used instead of the fruit of the corn for making bio-based ethanol [Manitoba Hydro]. Their net impact on climate change mitigation and resilience will depend on whether producers comply with criteria like life cycle GHG reductions, including land use change, and social standards.[10]

EXPERT'S COMMENT

- If a forest is cleared to use the forestry products as biofuel, if the forest's growth rate is very slow, or if the land has turned to be used into something else rather than replanting; this would all have impacts on GHG's emissions. The rate of tree growth has a huge impact on whether or not carbon neutrality could be achieved. [Manitoba Hydro]
- There is strong evidence that both bioethanol and biodiesel have significant impacts on reduction of CO_2, CO, NOx and SOx. Biodiesel contributes to significant reductions in particulate emissions compared with petroleum diesel. [University of Manitoba]

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10.CARBON CAPTURE AND STORAGE

DESCRIPTION

Carbon capture and storage (CCS) can capture 90% of the CO_2 emitted from the use of fossil fuels in the power generation and industrial processes. This CO_2 is then permanently stored underground in depleted oil and gas fields and deep saline formations.[1,2] CCS is used at industrial scales to enhance oil recovery (EOR) from oil fields, but is also considered as a solution to reduce atmospheric GHG concentrations. There were 15 large-scale CCS projects under operation worldwide in 2015.[3] In November 2015, Quest launched in Alberta the first large-scale project in North-America to store CO_2 exclusively in a deep saline formation (capture of 1 Mtpa of CO_2).[3]

CO_2 capture systems require significant amounts of energy for their operation. This reduces net plant efficiency and requires more fuel to generate each kilowatt-hour of electricity produced. The increase in fuel consumption using best current technology ranges from 24 to 40% for new supercritical pulverised coal (PC) plants, 11 to 22% for combined cycle gas turbine (CCGT) plants, and 14 to 25% for coal-based integrated gasification combined cycle (IGCC) systems compared to similar plants without CCS.[4]

INTERACTIONS BETWEEN ADAPTATION AND MITIGATION

The three stages of CCS (capture, transport and storage) might be affected by climate change differently. Depending on the approach used, CO_2 capture might involve a significant increase in water consumption (between 32-93% for large power stations of 1GW) required for cooling processes and therefore it is vulnerable to water availability, and to a greater occurrence of droughts.[5,6]

Climate risk exposure for CO_2 transport through pipelines is similar to that of hydrocarbon pipelines.[7] Risks include floods and erosion, which both can expose underground pipelines, and ground instability due to permafrost melt (see Gas-fired generation).

Concerning storage, CCS is relatively new and therefore not much is known about possible climate change impacts on long term storage integrity. It can be hypothesized that due to the depth at which carbon is stored, the impacts of climate change would be significantly damped and delayed.

CAVEATS

The intergenerational climate benefits of CCS are closely tied to leakage rates from CO_2 stores.[8,9] Studies suggest that seepage rates below 1% are necessary for CCS to be an effective mitigation measure.[10,11] While current reservoirs in operation appear to satisfy this constraint, large scale adoption of CCS may involve trade-offs between proximity and leakage rates.

EXPERT'S COMMENTS

- The monitoring of CCS is an issue and it is difficult to ensure permanent sequestration and guarantee the integrity of infrastructure. [Coop Carbone]

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11.ECONOMIC INSTRUMENTS

DESCRIPTION

Beyond policies, a number of economic instruments are available to governments to support GHG mitigation or adaptation to future climate conditions. A central idea of economic instruments is to have economic actors partially internalize the costs of future climate impacts, so that the externalities of carbon emissions are taken into account when buying goods and services. The internalization process also seeks to transfer to emitters the decision on how best to reduce emissions.

This internalization is key because mitigation and adaptation costs exceed public budgets and will have to be also borne by private actors.[1,2] For a given actor, the costs of climate change impacts can be borne directly, for example by paying to repair damages to one's property or by insuring against future damages, , or indirectly through carbon pricing mechanisms. There is however no strong consensus on the social cost of carbon and estimates range from a few dollars to over $300.[3]

INTERACTIONS BETWEEN ADAPTATION AND MITIGATION

In Canada, Alberta set up in 2007 the Specified Gas Emitters Regulation (SGER), an instrument to price emission intensity above a baseline level, allowing for carbon offsets, allowance trading or monetary contribution to the Climate Change and Emissions Management Fund (CCEMF) at a rate of 15$/ton of allowance credit.[4] Proceeds from this fund are in principle used both for mitigation and adaptation, but in practice less than 4% of funds were allocated to adaptation initiatives, the bulk going to renewable energy projects and technological innovations in the oil and gas sector.[5] Alberta announced in their 2016 budget, that a carbon price will be implemented through a new carbon levy on transportation and heating, for all type of fuels emitting GHG. In 2017, it will be applied at the rate of 20$/ton and 30$/ton for 2018.[6] The revenue from this tax will partially fund mitigation and adaption options like renewable energy, bioenergy, green infrastructure, and increasing building energy efficiency.[6]

In 2008, British Columbia introduced a carbon tax priced at 10$/ton that progressively increased to 30$/ton in 2012 and froze thereafter. The tax is revenue neutral, meaning that it is balanced by reductions in other taxes. Therefore, it does not specifically fund mitigation or adaptation initiatives. The current increase in provincial emissions suggests either that the tax rate is not high enough to drive further reductions, or that other policy instruments are necessary to drive change in behavior.

In 2013, Québec held its first auction under a cap-and-trade system linked with California through the Western Climate Initiative; Ontario and Manitoba have recently announced they will take part in this carbon market. The money raised from these auctions by the Québec government goes into the Fonds Vert, a fund dedicated to both mitigation and adaptation projects that is allocated to ministries according to the priorities defined in the Plan d'Action sur les Changements Climatiques. This fund has recently been criticised by the Auditor General of

Quebec (Guylaine Leclerc),[7] in part due to a lack of clear indicator to evaluate and compare the performance of adaptation projects.

In Ontario, current legislation earmarks the funds from the cap and trade auction to be held in 2017 for "carrying out or supporting greenhouse gas reduction initiatives, particularly initiatives that relate to the sectors of the Ontario economy to which the regulations apply" and appears to rule out adaptation efforts.[8] In Ontario, guaranteed prices or Feed-In Tariffs (FIT), have been used to promote renewable energy production from wind and solar generators. These tariffs guarantee energy producers prices above market value. The program has been criticized by the Auditor General of Ontario (Bonnie Lysyk) for being "one of the main contributors to the surplus power situation Ontario has faced since 2009, in that it has procured too many renewable projects, too quickly, and at too high a cost."[9] By distorting market pressures and prescribing technological choices, FIT may lead to suboptimal generation choices and divert resources away from other priorities.

Although not specifically intended as a mitigation measure, another tool used by governments to support energy production is limited liability clauses. For example, in Canada as of 2016, nuclear operators are liable for damages up to $750 million (the amount will increase to 1 billion over the next two years[10]); damages exceeding that amount would be borne by taxpayers. While this reduces capital costs for nuclear reactors by reducing the risks faced by investors, setting liability limits to low values can dilute the operator's incentives to reduce vulnerabilities.

Similarly, because GHG mitigation and climate adaptation technologies are relatively new, they are perceived as risky by investors, and developers can only borrow capital at high interest rates from markets. Governments can spur investments in such technologies by offering loan guarantees to green or climate bonds[11], whose funds are dedicated to climate mitigation and adaptation investments. Such guarantees lower the interest rates paid by investors. Historically, large infrastructure or military spending efforts made intensive use of government-backed bonds[4]. Because such bonds are considered extremely safe, they can unlock large investments from risk averse institutions such as pension funds.

Concerning adaptation, although there have been suggestions for adaptation credits[12], the main instruments by which actors internalize the potential costs of weather related risks to their assets or activities are taxes (e.g. Maryland's tax on impervious surfaces), incentives (e.g. Toronto's Eco-Roof program) and insurance. Indeed, "power outages are an emerging insurance risk for end users as well as energy suppliers" and insurance has been argued to be more effective than public-sector efforts to encourage loss-reducing behaviors.[13] In fact, the insurance sector is well positioned to push for adaptation measures that have mitigation benefits. For example, measures that extend the habitability of structures, and thus insure losses, during power outages, heatwaves or other natural disasters (e.g. insulation, natural daylighting and reduced roof albedo), also reduce building energy consumption.[13]

CAVEATS

Although economic instruments receive considerable attention, their influence may be limited. For example, California expects that only 15% of its mitigation target will be reached through the cap-and-trade mechanism it shares with Québec. The remaining 85% will be attained through complementary policies such as vehicle fuel efficiency standards, energy efficiency, renewables

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[4] During war time, Canada offered "Victory bonds" that were subscribed by individuals and institutions and had enormous success.

portfolio standard, etc.[14] The same argument can probably be made for carbon taxes: the rate required to significantly reduce emissions might be outside what is politically realistic to achieve. This is especially true as long as there is no common commitment[15] across neighboring provinces and states and there are risks that economic activity leaks from carbon taxing legislations to non-taxing legislations.

The same conclusions can probably be drawn for economic instruments used to promote adaptation, such as tax credits, subsidies or taxes. Depending on the context and design of these instruments, their capacity to reach a specific adaptation target may be limited without additional regulatory enforcement.[16]

EXPERT'S COMMENTS

- Regulations are likely more important than pricing at the current time. [Institut québécois du carbone]
- Carbon markets initially focused on volumes of CO_2 emissions, but there are now voluntary standards that integrate co-benefits in CO_2 credits, improving the social acceptability of mitigation measures. [Coop Carbone]

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12. CONCLUSION

At a time where the overwhelming majority of climate finance goes toward mitigation,[5] the integration of adaptation concerns into mitigation policy can be an effective way to future-proof investments, reduce risks to investors and communities and lower the overall costs of climate change. Another argument in favor of this integration is that the inclusion of adaptation goals "would increase the attention given by mitigation projects to local issues, […], making them more appealing to local communities".[6]

Beyond the physical and technical caveats discussed in this document, there are also potential hurdles to the tight integration of mitigation and adaptation goals for project developers. One is the risk of creating overly complex projects that attempt to engage with stakeholders with disparate and diverging interests. Another is the added burden of applying to two often different and siloed funding sources. Also, developers that focus on adaptation might feel that what little adaptation funding is available is diverted toward mitigation projects that incorporate adaptation objectives.[6]

From a more general point of view, many argue that we should not talk about the integration of adaptation in mitigation policy or vice-versa, but rather focus on mainstreaming climate change concerns into development policy and planning.[6] Policies that immediately improve health, transportation, lower energy costs or alleviate poverty are much more likely to garner wide public and political support than climate change policies with distant benefits.

In the factsheets presented here, the focus was voluntarily narrowed to energy concerns. While this drastically simplifies the issues, it also misses potential positive and negative side-effects in other sectors that would inevitably be part of policy discussions. For example, transition from fossil fuels to renewables would stir debates around land-use, air pollutants and health impacts as well as regional economic development. Conversely, an analog discussion about mitigation in the agriculture or transportation sectors would reveal repercussions on the energy sector.

Even in the specific energy context, the syntheses presented in this document don't do justice to the complexity of the issues presented. For one, they simply outline potential interactions without diving into implementation aspects that are critical to the success of such large scale, complex endeavors. Second, although the ideas and technologies presented are evolving rapidly, we refrained from extrapolating their potential into the future or trying to imagine novel solutions to avoid introducing personal biases into the results.

For example, researchers are now able to create materials that radiate heat in the frequency band the atmosphere is transparent to. What this means is that a panel made from such a material passively cools itself below ambient air temperature by shedding its heat directly into space, even when exposed to direct sunlight.[7] Among the many cooling applications arrays of such panels could have, one would be to increase the efficiency of thermal generators and reduce their vulnerability to water usage restrictions and heatwaves.

There would be many other such innovations that would reduce emissions, increase our adaptive capacity and reduce the overall environmental footprint of human activities. The challenge is to spur an energy transition toward a near-zero carbon energy infrastructure that remains flexible and open to new, yet unimagined solutions.

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Ouranos was born from the shared vision of the Government of Quebec, Hydro-Québec and Environment Canada, with financial support from Valorisation-Recherche Québec in 2001. Incorporating a network of some 450 scientists and professionals from various disciplines, the consortium focuses on two main themes: climate science and vulnerabilities, impacts and adaptation. Its mission is the acquisition and the development of knowledge on climate change and its impacts, as well as socio-economic and environmental vulnerabilities, in order to inform policy makers about climate change and advise them on how to identify, evaluate, promote and implement local and regional adaptation strategies.