Financial Impact of Climate Change

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Contents

Introduction

This short course introduces participants to the financial risks and impacts associated with climate change. Participants will explore a range of risk pathways that link climate and economic systems, including:

- physical risks related to direct exposure to climate hazards in the value chain;
- transition risks arising from abrupt transitions to a low-carbon economy;
- systemic risks transmitted throughout the economy;
- extreme risks arising from the complex dynamic nature of climate-economy systems.

Topics will be explored through the use of case study examples, group-based analysis and problem solving. The learning is supported by readings, videos and live, interactive online sessions. Participants are encouraged to share their own knowledge and expertise in group-based discussion forums.

Upon completion of the course, participants will have a foundational understanding of the relationship between climate change and the economy. Participants will develop their ability to identify climate-related financial risks within their own organizations—critical groundwork for effective planning and decision-making for mitigation and adaptation.

As an introductory course, this course is suited to those with limited previous experience in climate-related finance or economics. However, a basic understanding of climate science is presumed.

Discussion

Please tell us a little bit about yourself – your professional background and current role, and maybe a little bit about your reasons for taking this course. Here's some other questions you might consider as you introduce yourself:

- Have you encountered climate change issues as part of your work?
- Have you had direct experience applying climate change scenarios within your work–especially applying those scenarios to any kind of financial analysis?
- What do you personally hope to get out of the course?

One of the benefits of sharing is that it helps build a network. Please feel free to share your social media links and contact information.

Intro to Adaptation Learning Network

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PART I

MODULE 1: PHYSICAL RISKS

Module Overview

Physical risks arise when climate-related hazards (extreme weather events, wildfire, sea-level rise, etc.) interact with vulnerable human and natural systems. When those risks materialize, they can have a range of financial impacts on an organization, including (for example): direct costs for restoration and repair, lost sales revenues, declining consumer demand, and increased financing and insurance costs.

In this module, we'll use case study examples to explore physical risks of climate change for private and public organizations in the face of a range of potential climate hazards. We'll explore both direct physical risks (i.e., those related to an organization's own vulnerabilities) and indirect risks (i.e., those that materialize elsewhere in an organization's value chain, such as with its suppliers, transportation infrastructure, consumers, etc.)

Module Objectives

By the end of this module, you will:

1. Identify direct and indirect physical impact pathways that link climate with private and public value chains;
2. Understand "risk" as the dynamic interplay between hazards, exposure, vulnerability, damage and loss;

3. Interpret basic climate data and forecasts to formulate conclusions regarding risk levels and projections.

Reading and Resources

Readings & Resources

A primer for investors and lenders on insurers' natural catastrophe models for extreme weather perils. In Cambridge Institute for Sustainability Leadership (CISL). (2019). *Physical risk framework: Understanding the impacts of climate change on real estate lending and investment portfolios*.

Task Force on Climate-related Financial Disclosures. (n.d.) *Examples of climate-related risks and opportunities and potential financial impacts.*

The Expert Panel on Climate Change Risks and Adaptation Potential. (2019). *Canada's top climate change risks.* Council of Canadian Academies. [Chapter 2, pp. 8 – 26].

Woetzel, J., Pinner, D., Samandari, H., Engel, H., Krishnan, M., Boland, B., & Powis, C. (2020). *Climate risk and response: Physical hazards and socioeconomic impacts*. McKinsey Global Institute. **[Excerpts only].**

Data sources

World Bank Group. (2021). Climate Change Knowledge Portal (Canada). https://climateknowledgeportal.worldbank.org/country/canada/climate-data-projections

Reference resources

EM-DAT Glossary. (n.d.). Centre for Research on the Epidemiology of Disasters. https://www.emdat.be/Glossary

General classification. (n.d.). Centre for Research on the Epidemiology of Disasters. https://www.emdat.be/classification

World Bank Group. (2018). *Glossary of terms and definitions*. Climate Change Knowledge Portal. https://climateknowledgeportal.worldbank.org/themes/custom/wb_cckp/resources/data/CCKP_Glossary_Oct_2018.pdf

Introduction

In Module 1, we'll be exploring the first of three main pathways by which climate impacts the economy. **Physical risks** arise when climate and weather events interact with physical assets and infrastructure in a manner that results in either direct costs (through property damage) or indirect costs (through disruptions in business operations)

When we think about direct physical risks, we often think only of those physical assets that we own—our stores, our facilities, our inventory. However, every node in a business's value chain—from raw materials extraction to customer sales and service—can be exposed to **direct risks** from climate and weather hazards.

Regardless of whether those direct risks expose our suppliers, employees, customers, or the transportation infrastructure that links us all together, the impact may very well cascade onto business operations, costs and revenue stability. These are the **indirect risks** arising from the value chain's exposure to direct risk in the value.

Direct and Indirect Risks

Figure 1.1 provides examples of direct and indirect risks associated with climate and weather hazards.

Figure 1.1 highlights two important points:

1. The geospatial distribution of physical risk exposure expands beyond the location of owned assets. As such, a comprehensive risk analysis must consider the full geographic extent of the value chain.
2. Protecting one's own property may not be sufficient to avoid the impact of climate and weather events. Community resiliency (including business's role in promoting and contributing to it) is an important strategy for adaptation.

Like businesses, governments and public agencies are exposed to both direct and indirect risks. Public infrastructure (like roads, utilities, buildings) can be directly exposed to climate and weather events. Direct damage to public infrastructure can then result in indirect risks through the impairment of a government's capacity to deliver essential services to its citizens (e.g., emergency services, healthcare, disaster relief, etc.).

The Anatomy of Risk

A climate risk materializes when hazard, exposure, and vulnerability interact to produce damages and loss. The Intergovernmental Panel on Climate Change IPCC (2012, p. 69) defines each of the first three elements as follows:

Hazard	“The possible, future occurrence of natural or human-induced physical events that may have adverse effects on vulnerable and exposed elements.
Exposure	“The inventory of elements in an area in which hazard events may occur.”
Vulnerability	“The propensity of exposed elements such as human beings, their livelihoods, and assets to suffer adverse effects when impacted by hazard events.”

When a vulnerable element is exposed to a hazard, some quantifiable amount of damage and loss is suffered. Though businesses are often most concerned with the financial value of damages and loss, public agencies and governments are concerned with a broad range of losses (such as loss of human life, displacement, etc.)

SOURCE: Cardona, O.D., M.K. van Aalst, J. Birkmann, M. Fordham, G. McGregor, R. Perez, R.S. Pulwarty, E.L.F. Schipper, and B.T. Sinh, 2012: Determinants of risk: exposure and vulnerability. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.

Catastrophe Models

Actuaries (professionals who study, measure and predict risk) use mathematical simulation models called *catastrophe models* (or *Cat Models*, for short) to produce estimates of damages and losses along with the probability of their occurrence.

Watch the videos, below, for an explanation of how Cat models work (full screen recommended)

Read more about how actuaries use catastrophe models (like the one introduced in the video) in Chapter 2 (pp. 16 – 21) of CISL’s *Physical risk framework:* A primer for investors and lenders on insurers’ natural catastrophe models for extreme weather perils. In Cambridge Institute for Sustainability Leadership (CISL). (2019). *Physical risk framework: Understanding the impacts of climate change on real estate lending and investment portfolios.*

Climate, Hazard and Loss

Climate change can result in increasing frequency and intensity of hazards, resulting in an increase in associated damage and loss. This video illustrates the relationship between climate-related hazard and various measures of financial impact.

Modeling Risk

Most small to medium sized enterprises and, indeed, many large organizations lack the resources and capacity to fully implement a catastrophe model of their own (though open-source Cat model applications are freely available to those with the courage!).

However, understanding the relationship between hazard, exposure, vulnerability and loss can still be useful when thinking about, identifying and ranking risks within any organization. You can start identifying your climate-related risks, for example, by asking yourself questions like these:

Module	Questions to consider...
Hazards	• What climate-driven hazards have occurred here before that could threaten assets or disrupt operations? • How often have they occurred in the past? • What climate-related elements drive those hazards (e.g., temperature, precipitation...)? • How are anticipated climate changes expected to affect the frequency and intensity of the hazard in the future? • What other elements of the value chain (suppliers, employees, customers, infrastructure) might be exposed to climate-related hazards
Exposure	• Which elements of the value chain are in proximity to potential hazard? For example... • Locations within a flood plain or low-lying coastal area? • Locations near to an urban/wildland interface? • Locations near to or within areas prone to tropical cyclone • Locations at risk of excessive hot days or drought • Locations on unstable slopes

Vulnerability	• What is the capacity to take defensive actions to protect property (e.g., temporary barriers against flooding, rapid relocation of inventory)? • What level of redundancy (e.g., in suppliers, in production sites, etc.) is in place? • What emergency supplies are on hand (e.g., excess inventory)? • What emergency services are available in the event of a disaster, and what is their capacity? • What is the likelihood of a hazard great enough to destroy all assets? • What is the likelihood of a hazard great enough to disrupt operations for 1 day? 1 week? 1 month? 6 months? • What are the terms, coverage, and limitations of current insurance policies? How much loss is insured?
Damage	• What is the total value of assets at risk? • What is the present value of future income that those assets can generate? • How much income is generally earned on each day of operations? • What are the costs of downtime (in terms of sales, productivity, and reputation losses and recovery costs)?

Even without quantifiable data on the probability and extent of losses, the Cat model framework highlights two important elements:

1. Shifts in the hazard function brought about by climate change will, in many cases, result in an increase in the probability and extent of losses.
2. Climate adaptation strategies that target exposure and vulnerability can offset the increase in the hazard function, reducing the losses associated with climate risks.

Changing Climate - Changing Risk

It may surprise you to learn that Germanwatch's *Climate Risk Index* for 2020 ranks Canada as the country 9th most affected by climate change in the world! According to Environment Canada, Canada is warming at twice the global rate on average, and between 3 – 4 times the global rate in parts of western and northern Canada.

The table below summarizes the major projected changes in Canada's climate:

Projected changes in Canada's Climate

Temperature	
Seasonal temperature	The largest increases in air temperature are projected for northern Canada in winter. In summer, the largest increases are projected for southern Canada and the central interior. The magnitude of projected warming varies substantially by emission scenario.
Extremes in daily temperature	Increases in the frequency and magnitude of unusually warm days and nights, and decreases in unusually cold days and nights, are projected to occur throughout the 21st century.
Long-duration hot events	The length, frequency, and/or intensity of warm spells, including heatwaves, are projected to increase over most land areas.
Rare hot extremes	Rare hot extremes are projected to become more frequent. For example, a 1-in-20 year extreme hot day is projected to become about a 1-in-5 year event over most of Canada by mid-century.
Precipitation and Other Hydrological Indicators	
Seasonal precipitation	Increases in precipitation are projected for the majority of the country and for all seasons, with the exception of parts of southern Canada, where a decline in precipitation in summer and fall is projected.
Heavy precipitation	More frequent heavy precipitation events are projected, with an associated increased risk of flooding.
Rare precipitation events	Rare extreme precipitation events are currently projected to become about twice as frequent by mid-century over most of Canada.
Streamflow	Increases in winter streamflow are projected for many regions in southern Canada. Mean annual streamflow is projected to decrease in some regions of Alberta and Saskatchewan, while projections for other regions vary across different scenarios.
Snow Cover	
Snow-cover duration	Widespread decreases in the duration of snow and ice cover are projected across the Northern Hemisphere, with the largest changes in maritime mountain regions, such as the west coast of North America.

Snow depth	Maximum snow accumulation over northern high latitudes is projected to increase in response to projected increases in cold-season precipitation.
Permafrost	
Ground temperature	Warming of the permafrost is projected to continue at rates surpassing those observed in records to date. Because much of the Arctic permafrost has a low average temperature, it will take many decades to centuries for colder permafrost to completely thaw.
Sea Level	
Global sea-level rise to 2100	Estimates of the magnitude of future changes in global sea level by the year 2100 range from a few tens of centimetres to more than a metre.
Global sea-level rise beyond 2100	Projections beyond 2100 indicate continuing global sea-level rise over the coming centuries and millennia. Global sea-level rise may eventually amount to several metres.
Relative sea-level change	Patterns of change along Canadian coastlines will continue to be influenced by land uplift and subsidence as well as by changes in the oceans. Sea-level rise will continue to be enhanced in regions where the land is subsiding, and sea level is likely to continue to fall in regions where the land is rapidly rising. Regions where the land is slowly rising may experience a transition from sea-level fall to sea-level rise.
Sea-Ice Extent	
Arctic summer sea ice	A nearly ice-free summer is considered a strong possibility for the Arctic Ocean by mid-century, although summer sea ice may persist longer in the Canadian Arctic Archipelago region.
Lake Ice	
Ice-cover duration	With the continued advance of ice cover break-up dates and delays in ice-cover freeze up, ice-cover duration is expected to decrease by up to a month by mid-century.

Reproduced from Warren & Lemmen (2014) in The Expert Panel on Climate Change Risks and Adaptation Potential. (2019). *Canada's top climate change risks*. Council of Canadian Academies. You can read the full report here.

For an overview of global climate trends and risks, read

Section 2 *A changing climate and resulting physical risks* (pp. 48 – 59) in Woetzel, J., Pinner, D., Samandari, H., Engel, H., Krishnan, M., Boland, B., & Powis, C. (2020). *Climate risk and response: Physical hazards and socioeconomic impacts*. McKinsey Global Institute.

Activity: Predicting Damage and Loss

Activity

In this activity, you'll be using climate projections obtained from the World Bank's Climate Change Knowledge Portal to predict the corresponding changes in damage and loss values for one of four scenarios. Each scenario is drawn from one of the top 12 climate risks in Canada (Expert Panel on Climate Change Risks and Adaptation Potential):

- Whitehorse Grocery (transportation disruption risk due to land subsidence caused by permafrost thaw)
- Pemberton Cabins (property loss due to wildfire)
- Clark Acres Farm (crop damage due to drought)
- Windsor Care Home (heatwave exacerbated by power outage)

You can also access the scenarios in the Appendix.

Here is your task:

1. Open the Climate Change Knowledge Portal, *Climate Data – Projections* for Canada.
2. From the *Variables* drop-down list, select the

variable that corresponds to the climate driver in your scenario.

3. Drop a pin on the map at the location where your scenario takes place so that the database returns data for your specific location.
4. Create a table and record the mean value and the 90^{th} percentile value for each of the four date ranges and each of the four RCP scenarios.
5. Interpret the impact those projections would have on the organization's costs of damages and loss.
6. Post your table and analysis to the Module 1 discussion forum.
7. Comment on the analyses provided by at least two others in the cohort.

Here is a brief video orientation to the Climate Change Knowledge Portal database.

Conclusion

Physical risks arise from an organization’s exposure and vulnerability to climate-related hazards. If those risks materialize, organizations face damages and loss due to physical damage to assets and/or infrastructure and/or to operational losses due to disruptions in sales, production, order fulfillment, etc.

The catastrophe modeling framework sheds light on the dynamics of climate risks. It illustrates the pathway via which the changing climate causes increases in costs. It also highlights that an organization can mitigate its climate risks by managing exposure and vulnerability through comprehensive climate adaptation strategies.

PART II

MODULE 2: TRANSITION RISKS

Module Overview

Module 2 focuses on so-called "transition risks"—risks arising from the process of transitioning (possibly rapidly) to a low-carbon economy in response to climate change. Transition risks can arise from changes in policy, technology, and market conditions. The financial risks of transition include increased input prices and operating costs, abrupt changes to asset values, and deterioration of competitiveness and market share.

In this module, we'll apply a range of policy, technology and market scenarios to uncover the transition risk exposure of some sample organizations.

Module Objectives

By the end of this module, you will:

1. Understand the financial and economic risks that arise from transitions to low-carbon economies and identify the transition risk pathways;
2. Identify *climate policy relevant sectors* and predict the impact on these sectors of a variety of climate policies;
3. Understand how transition risks can be indirectly transmitted through the economy by way of financial assets and debt;
4. Predict the impact of various policy scenarios, ranging

from gradual, orderly transition to rapid, reactive and disorderly transition;

5. Understand the role of climate-related financial disclosure in promoting orderly transition through adequate risk pricing of financial assets.

Readings And Resources

Readings & Resources

Bank of England. (2015, October 1). *Breaking the tragedy of the horizon – climate change and financial stability – speech by Mark Carney [Video]*. YouTube.

Carney, M. (2015, October 1). *Breaking the tragedy of the horizon – climate change and financial stability [Speech transcript]*. *Bank of England.*

Hausfather, Z. (2018, April 19). *Explainer: How 'Shared socioeconomic pathways' explore future climate change*. Carbon Brief.

Semieniuk, G., Campiglio, E., Cercurre, J., Volz, U., & Edwards, N.R. (2021). Low-carbon transition risks for finance. *WIREs Climate Change, 12*(1).

Data sources

International Institute for Applied Systems Analysis. (2018). *SSP Public Database (v. 2.0)* [Database]. https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=30

Overview

Unlike physical risks that arise from direct and indirect exposures to climate-related hazards, transition risks arise from human responses to climate change. In particular, as humans recognize the imperative of shifting to a low-carbon economy, and as policies, consumer choices, investment, and innovation pathways reorient toward decarbonization, large-scale changes will occur in the economy. The low-carbon economy will produce new winners and new losers, and—for those on the loss side (including their investors, suppliers, customers and employees)—the transition will produce serious and perhaps insurmountable challenges.

Energy is at the core of our modern economy. Over the past 3 – 4 decades, we have made significant progress reducing the energy intensity of the goods and services we consume (either as businesses, as public bodies, or as consumers). Nevertheless, our dependence on energy remains. Eighty-one percent of our energy comes from fossil fuels and, thus, fossil fuels are deeply embedded within our current economic system.

However, if we are to achieve the global warming target of the Paris Agreement (2.0C), a dramatic shift away from our carbon-based economy is necessary. And decarbonization will inevitably disrupt the status quo, along with those sectors with business models that depend on the status quo for its success.

Transitions like the ones necessitated by climate change have happened throughout the history of market economies (for example, as disruptive, game-changing innovations arise). When those transitions are disorderly and abrupt, the consequences can be far reaching. However, it is possible to manage the necessary transition to a low-carbon economy in a manner that is orderly and predictable, and that minimizes the worst outcomes.

But only if we start soon!...

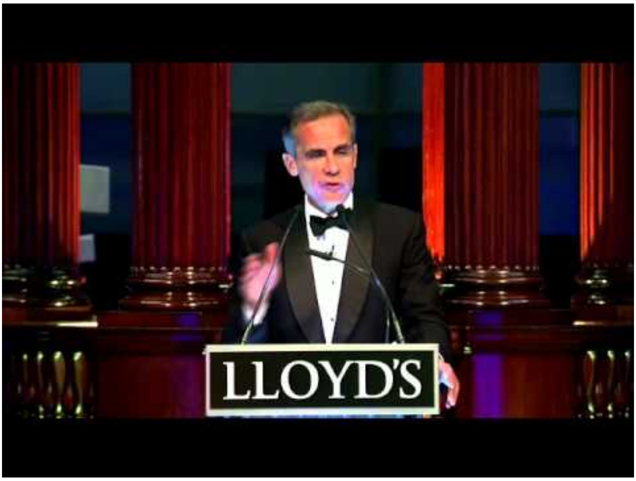
This module explores transition risks that arise from the low-carbon transition.

Transition Risks and the Financial Sector

Our discussion thus far on transition risks have alluded to the fact that transition—especially if rapid and disorderly—can have a significant negative effect on financial assets (like the corporate shares of climate policy relevant sectors). The risk in the real side of the economy can thus be transmitted throughout the financial economy, impacting investors both private and public, both retail and institutional. As such, the consequences can have far-reaching effects throughout the whole economy, and likely will not stay limited to the directly impacted sectors.

Mark Carney—former Governor of the Bank of Canada (2008 – 2013) and the Bank of England (2013 – 2020)—has been outspoken on the systemic implications of transition risks. In his 2015 speech to executives from Lloyd's of London (an insurance market located in London), Carney reviews the risks associated with climate change, with particular attention to transition risks and to climate-related financial disclosures that may help attenuate the worst consequence of transition to a low-carbon economy.

Watch the speech here before continuing.



A YouTube element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/financialimpactclimatechange/?p=70

You can also follow along using the transcript from the speech, available here.

Activity

Activity

This activity involves using data to formulate observations and conclusions regarding an economic sector's exposure to transition risks under various socioeconomic scenarios. Below are the tasks required:

1. Read the overview and descriptions of the five *Shared Socioeconomic Pathways* (SSPs). The SSPs will be combined with RCPs (Representative Concentration Pathways, used in Activity 1) to generate the scenarios we'll use in this activity.
2. Choose a climate policy relevant sector of the economy that interests you.
3. Open the SSP database and go to the IAM Scenarios tab (IAM stands for *Integrated Assessment Model)*
4. In the menu for **Model/Scenarios** choose SSP1 – 1.9, SSP2 – 1.9 and SSP5 – 1.9. (Review the SSP storylines to understand the underlying assumptions of the three models; the number refer to the RCP scenario for RCP1.9—the pathway consistent with a global warming target of 1.5C.)
5. In the Menu for **Variable**, choose Climate/Temperature/Global Mean and note the projected warming trend over time.

6. In the menu for **Variable**, choose Economic Indicators/Price|Carbon. Notice the different carbon price trajectory for the three SSP scenarios
7. Consider the transition risk exposure of the economic sector you chose in Step 1 in each of the three scenarios. Answer the following questions:

    a. Which scenario poses the greatest transition risk and which the least?
    b. What are the implications of each scenario for investors in your sector?
    c. Referring back to the storylines, what are the socioeconomic conditions that generate the lowest transition risks?

8. Post your observations and conclusions to the Module 2 discussion forum.
9. Read observations posted by others and comment on at least two.

Transition Risk Pathways

Semieniuk et al. (2019) identify how climate-responsive policies, technologies and consumer preferences impact both the real economy (in which goods and services are produced and traded) and the financial economy (which deals with financial assets, investment, banking and insurance). Economy-wide interactions amplify and transmit the effects to companies, households and governments. Feedback loops can exacerbate the situation.

Before continuing, read Semieniuk, G., Campiglio, E., Cercurre, J., Volz, U., & Edwards, N.R. (2021). Low-carbon transition risks for finance. *WIREs Climate Change, 12*(1). Though the complete article makes an important contribution to understanding transition risks, section 4 (pp. 6 – 13) are critical to interpreting the diagram above.

Transition Timing

The carbon budget, along with research on the costs of climate change and on the costs of delayed action, suggest that delays in implementing a strong policy response will result in future policy transitions that will necessarily be both more rapid (giving the economy less time to adapt) and more stringent (creating greater transition impacts). And those transition costs will incur on top of greater climate damage costs that will arise because of delays in our response

Please watch the video below for a discussion of implications of transition timing.

Carbon Policy Relevant Sectors

Battiston et al (2017) used the term "carbon policy relevant sectors" to describe sectors of the economy that are particularly vulnerable to changes in carbon policy (such as the introduction or rapid increase of a carbon tax, or regulations prohibiting extraction or use of certain resources). These sectors are particularly important in assessing climate transition risks, since—under business-as-usual—they are the sectors that are likely to experience the most negative impacts of climate policy.

To determine which sectors are climate policy-relevant, analysts typically use three main criteria (see Battiston, 2017, 2020):

- The extent to which a sector contributes directly and/or indirectly to GHG emissions;
- The sector's sensitivity to the cost implications of climate policy (e.g., energy-intensive sectors whose international competitiveness would diminish under certain climate policies, like stringent carbon taxes);
- The role, if any, that the sector plays in the climate value chain.

Using these criteria, Battiston et al. have identified five broad carbon policy relevant sectors:

Fossil Fuels

This is likely the most relevant sector, insofar as the business model within the sector necessarily includes revenues derived from fossil fuel extraction and refining. Though individual oil and gas companies have adaptation options—such as divestiture of oil reserves and reinvestment in alternative energy—the sector as a whole cannot diversify against it transition risks.

Utilities

Electrical utility companies may have significant exposure to climate policy depending on their dependence on combustion of fossil fuels for electricity generation. Those that do use fossil fuels extensively will be vulnerable to policies that affect the fuel inputs. Figure 1, below, shows the level of dependence on fossil fuels for electricity generation in each Canadian province and territory.

Source: The main electricity sources in Canada by province. Energyrates.ca. *https://energyrates.ca/the-main-electricity-sources-in-canada-by-province/*

Energy-intensive sectors

Primarily, it is manufacturing and some mining that falls under this category. This sector is included as a climate policy relevant sector because of its vulnerability to energy prices.

The EU has prepared a list of energy-intensive sectors that it deems at high risk for "carbon leakage" when exposed to policies like carbon tax. Carbon leakage occurs when production shift from a country with high emissions charges to a country with more lenient policies, due to an inability to compete with imported substitutes when high carbon prices are imposed. The EU list provides a good sense of the range of sector that fall under this category. The list is available here.

Other energy-dependent sectors

Transportation, buildings (including construction and maintenance), agriculture, forestry and fisheries are also included in the list of climate policy relevant sectors, due to their vulnerability to changes in carbon prices that affect the price of fuel inputs.

Unlike the energy-intensive sectors in manufacturing and mining which are dependent on the electricity grid and therefore unable to diversify away from fossil fuels (unless their electricity providers do so), these other energy-dependent sectors do have some capability to diversify away from fossil fuels. In the transportation sector, for example, adaptation can include switching to hydrogen fuel-cell electric vehicles (FCEV). Agriculture can switch to organic fertilizers and away from the commercial nitrogen fertilizers that account for a significant percentage of the energy use at a conventional farm.

Stranded Assets

The term "stranded assets" is used to describe assets that lose their value due to changes in the market and/or regulatory environment. The term is often used to describe the transition risk to carbon policy relevant sectors that may not be able to use their assets to produce revenue and are therefore required to write down the value of their assets in their financial books. Some examples might include:

- an oil and gas company forced to leave a portion of its reserves unexploited;
- a pipeline company whose pipeline is underutilized due to falling demand (and therefore producing less revenue);
- a car manufacturer whose factories and equipment are all designed to produce combustion engines while demand for gas-powered vehicles falls.

Writing down the value of stranded assets can have a significant impact on a business's bottom line. In the following video, we take a look at how stranded assets in an oil and gas company can undermine the company's financial position (including its share price), leading to falling share prices and investors' (including large, institutional investors') loss of wealth.

These transition costs can be substantial. And, in their wake, inevitably some companies in policy relevant sectors will succumb, resulting in significant knock-on effects for employees, creditors, and whole communities. Some of these costs will be inevitable if we are to achieve our target of holding global warming below 2-degrees Celsius.

However, the level of disruption and instability that these transitions can potentially create can be managed through orderly policy-making with adequate signalling of future policy levels.

Transition risks and disclosure

In the Mark Carney video, he discusses the role of corporate disclosure of climate-related risks. Full disclosure of risks ensures that investors have adequate information about a company's exposure to climate related risks (both physical and transition risks). With adequate information, investors can build a full understanding of risk into their valuation of a company's shares.

Climate-related financial disclosures enable financial markets to calibrate to an acceptable level of risk, reducing the risk of financial instability that might otherwise arise from large-scale losses and write-downs of assets related to climate change. They might also enable more economically efficient allocation of financial capital.

When Mark Carney was the Chairman of the Financial Stability Board of the Bank for International Settlements, he commissioned a report on climate-related financial disclosures. The Task Force on Climate-related Financial Disclosure. The Task Force provided recommendations on disclosures in the areas of governance, strategy and risk management, as well as metrics to assess risks and opportunities and targets used to manage risks and report on performance.

Below is a summary of the Task Force's recommendations.

Source: Task Force on Climate-related Financial Disclosures. (2017). *Recommendations of the Task Force on Climate-related Financial Disclosures*. (p. 14) This table is Copyright © 2021 Task Force on Climate-related Financial Disclosures

SSP Storylines

Shared Socioeconomic Pathways – or *SSPs* – are storylines that describe alternate socioeconomic scenarios for how the future could unfold. They include potential trajectories of population and economic growth along with greenhouse gas emissions. Each SSP describes if and how a certain *representative concentration pathway* (RCP) could be achieved, given the socioeconomic characteristics and policy assumptions of the future it represents. Some SSPs are incompatible with more ambitious global warming limits of 1.5C and 2.0C.

Here are brief definitions of each of the five shared socioeconomic pathways, reproduced from The IIASA SSP Database *Supplementary note for the SSP data sets*. (Login required: See link under *Readings and Resources*)

SSP Storylines

SSP1 – Sustainability: This is a world making relatively good progress towards sustainability, with sustained efforts to achieve development goals, while reducing resource intensity and fossil fuel dependency. Elements that contribute to this are a rapid development of low-income countries, a reduction of inequality (globally and within economies), rapid technology development, and a high level of awareness regarding environmental degradation. Rapid economic growth in low-income countries reduces the number of people below the poverty line. The world is characterized by an open, globalized economy, with relatively rapid technological change directed toward environmentally friendly processes, including clean energy technologies and yield-enhancing technologies for land. Consumption is oriented towards low material growth and energy intensity, with a relatively low level of consumption of animal products. Investments in high levels of education coincide with low population growth. Concurrently, governance and institutions facilitate achieving development goals and problem solving. The Millennium Development Goals are achieved within the next decade or two, resulting in educated populations with access to safe water, improved sanitation and medical care. Other factors that reduce vulnerability to climate and other global changes include, for example, the successful implementation of stringent policies to control air pollutants and rapid shifts toward universal access to clean and modern energy in the developing world.

SSP 2 – Middle of the Road (or Dynamics as Usual, or Current Trends Continue, or Continuation, or Muddling Through): In this world, trends typical of recent decades continue, with some progress towards achieving development goals, reductions in resource and energy intensity at historic rates, and slowly decreasing fossil fuel dependency. Development of low-income countries proceeds unevenly, with some countries making relatively good progress while others are left behind. Most economies are politically stable with partially functioning and globally connected markets. A limited number of comparatively weak global institutions exist. Per-capita income levels grow at a medium pace on the global average, with slowly converging income levels between developing and industrialized countries. Intra-regional income distributions improve slightly with increasing national income, but disparities remain high in some regions. Educational investments are not high enough to rapidly slow population growth, particularly in low-income countries. Achievement of the Millennium Development Goals is delayed by several decades, leaving populations without access to safe water, improved sanitation, medical care. Similarly, there is only intermediate success in addressing air pollution or improving energy access for the poor as well as other factors that reduce vulnerability to climate and other global changes.

SSP 3 – Fragmentation (or Fragmented World): The world is separated into regions characterized by extreme poverty, pockets of moderate wealth and a bulk of countries that struggle to maintain living standards for a strongly growing population. Regional blocks of countries have re-emerged with little coordination between them. This is a world failing to achieve global development goals, and with little progress in reducing resource intensity, fossil fuel dependency, or addressing local environmental concerns such as air pollution. Countries focus on achieving energy and food security goals within their own region. The world has de-globalized, and international trade, including energy resource and agricultural markets, is severely restricted. Little international cooperation and low investments in technology development and education slow down economic growth in high-, middle-, and low-income regions. Population growth in this scenario is high as a result of the education and economic trends. Growth in urban areas in low-income countries is often in unplanned settlements. Unmitigated emissions are relatively high, driven by high population growth, use of local energy resources and slow technological change in the energy sector. Governance and institutions show weakness and a lack of cooperation and consensus; effective leadership and capacities for problem solving are lacking. Investments in human capital are low and inequality is high. A regionalized world leads to reduced trade flows, and institutional development is unfavorable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity. Policies are oriented towards security, including barriers to trade.

SSP 4 – Inequality (or Unequal World, or Divided World): This pathway envisions a highly unequal world both within and across countries. A relatively small, rich global elite is responsible for much of the emissions, while a larger, poorer group contributes little to emissions and is vulnerable to impacts of climate change, in industrialized as well as in developing countries. In this world, global energy corporations use investments in R&D as hedging strategy against potential resource scarcity or climate policy, developing (and applying) low-cost alternative technologies. Mitigation challenges are therefore low due to some combination of low reference emissions and/or high latent capacity to mitigate.

Governance and globalization are effective for and controlled by the elite, but are ineffective for most of the population. Challenges to adaptation are high due to relatively low income and low human capital among the poorer population, and ineffective institutions.

SSP 5: Conventional Development (or Conventional Development First): This world stresses conventional development oriented toward economic growth as the solution to social and economic problems through the pursuit of enlightened self-interest. The preference for rapid conventional development leads to an energy system dominated by fossil fuels, resulting in high GHG emissions and challenges to mitigation. Lower socio-environmental challenges to adaptation result from attainment of human development goals, robust economic growth, highly engineered infrastructure with redundancy to minimize disruptions from extreme events, and highly managed ecosystems.

PART III

MODULE 3: SYSTEMIC RISKS

Module Overview

Module 3 explores systemic risks—risks that impact entire economies. Besides the scope of the potential impacts, one of the characteristics of systemic risk is that it is difficult—if not impossible—to diversify against the risk. So, even organizations that otherwise have relatively low exposure to physical and transition climate risks are likely to be impacted, should the systemic risks materialize.

In this module, we'll examine three inter-related systemic risks: financial stability; macro-economic stability (e.g., GDP, price levels, unemployment, interest rates); and, public budgetary failure. We'll explore how these three system-level risks interact with each other, and with the physical and transition risks identified in Modules 1 – 2.

Module Objectives

By the end of this module, you will:

1. Understand the systemic economic risks posed by climate change to fiscal sustainability (public budgets), GDP, and financial system stability;
2. Consider the importance of collective action in light of non-diversifiable risks
3. Identify the influence exerted by socio-political responses

to climate change on the magnitude and timing of systemic impacts;

4. Use Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs) to develop scenarios with which to assess exposures to systemic risks over time.

Readings and Resources

Readings & Resources

Kompas, T., Pham, V.H., Che, T.N. (2018). The effects of climate change on GDP by country and the global economic gains from complying with the Paris Climate Accord. *Earth's Future*, *6*(8).

Prudential Regulation Authority. (2015). *The impact of climate change on the UK insurance sector*. Bank of England. [Excerpts only]

Prudential Regulation Authority. (2018). *Transition in thinking: The impact of climate change on the UK banking sector.* Bank of England. [Excerpts only]

Schuler, P., Oliveira, L.E., Mele, G., & Antonio, M. (2019). Managing the fiscal risk associated with natural disasters. In Pigato, M.A., (Ed). *Fiscal Policies for Development and Climate Action*. World Bank Institute. [Excerpts only].

Data sources

International Institute for Applied Systems Analysis. (2018). *SSP Public Database (v. 2.0)* [Database]. https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=30

Overview

In Module 3, we're exploring more pervasive financial impacts of climate change—those that impact financial stability, public budgets and the macroeconomy. These system-wide impacts and risks are important because they have a tendency to impact whole economies, rather than just specific economic sectors or industries. That means that even businesses with little or no direct exposure to physical or transition risks may still be impacted.

One key factor influences many of these system-level impacts: correlated risk. Typically, our economy, the financial sector and governments are able to withstand some adversity, especially if it is limited to certain sectors or certain geographic regions. We can depend on unaffected areas of the economy to offset or moderate the impact of that adversity. In other words, these institutions' risks are diversified.

But, since climate change has the capacity to simultaneously increase a broad range of risks (both physical and transitional), there is increased likelihood that systemically-important institutions will face compounding damages from materialized risks against which it is difficult to diversity (since those risks share the same main driver—climate change).

Even if those institutions are robust enough to withstand the challenges, they may nevertheless be less efficient or less able to fulfill their typical role in the economy. Indeed, the way that banks, insurers and governments respond to compounding damages may actually exacerbate a struggling macroeconomy.

In this module, we'll take a closer look at banks, insurers, governments and the macroeconomy as a whole to explore the financial risks transmitted through these key economic institutions.

The Financial System

The financial system is comprised of banks, insurance companies, stock exchanges along with the various financial instruments they use. They play a critical role in the economy by facilitating exchange of funds between various participants to enable activities such as saving and borrowing, investing, and risk sharing. By lending out savings to those who can make productive use of it, banks enable a substantial amount of economic activity that would not otherwise occur. Likewise, by managing risk, insurers provide a more stable environment for investment.

When issues or crises arise in the financial system, liquidity problems can occur that may result in a reduction of access to personal or corporate credit. That has an effect on the "real" economy, undermining consumer and corporate demand by, for example, decreasing debt-financed consumption and capital investment.

The climate crisis can impact the financial system through both physical and transition risks, but also from feedback loops that can amplify the effect of an initial shock, leading to economy-wide effects.

For example, borrowers may suffer losses to their assets through exposure to physical or transition risks, which may undermine their capacity to service their debt obligations. Loan defaults increase, and banks reassess the loan-to-value ratio (ratio of the amount of a loan to the value of the assets against which the loan is secured) of their lending portfolio. To reduce their own risk exposure, banks pull back on their lending volume (e.g., by increasing their interest rates or changing their criteria for creditworthiness). With fewer loans issued, transactions that might otherwise contribute to the economy are forgone, due to a lack of debt capital to finance those activities. Economic activity slows further, potentially impacting other lenders and their capacity to repay their debt.

Insurance

We'll start our exploration of climate and the financial system with the insurance sector. The insurance industry plays a critical role in the growth of the economy. It provides stability to the economy by reducing volatility (e.g., sudden losses) associated with uncertainty and decision-making, encouraging investment and innovation when otherwise, risk aversion might prevent it.

The following video provides a brief overview of the insurance sector and its relationship to climate-related risk.

If you'd like to read more about climate change and the insurance sector, read more in *The impact of climate change on the UK insurance sector* . Scan pages 23 – 56 only, and feel free to skip sections that cover topics that you already understand.

Banking

The banking sector also plays a central role in the economy. Banks facilitate the transfer of funds from those who save (depositors) to those in need of financial capital (in the form of loans and investments). By doing so, banks enable personal and corporate investment that contribute to demand and productivity growth.

Watch the video below for a brief overview of climate-related risks to the banking system.

Read Section 3.3 Financial risks from climate change facing the UK banking sector (pp. 21 – 37) in *Transition in thinking: The impact of climate change on the UK banking sector.*

The Macroeconomy

In general terms, macroeconomics measures the aggregate performance of a nation's economy. It is made up of several related "markets" within a country: the goods and services market (which determines output and the price level/inflation), the labour market ((un-) employment and the wage rate), the money (bond) market (interest rates), and the foreign exchange market (trade balance and currency exchange rate). Often, when we wonder whether or not our national economy is doing well or poorly, we look to these macroeconomic markets for indicators.

The pervasive nature of climate risk means that every aspect of the macroeconomy is vulnerable. Recession, high unemployment, price volatility, declining productivity—these are all potential outcomes as climate risks materialize.

Supply-side shocks arising from climate-related hazards (like price volatility, damage to the capital stock, falling labour productivity) can increase the costs of economic output, creating inflationary pressures in affected areas of the economy. Demand-side shocks (e.g., through loss of personal wealth, or investment uncertainty) can create recessionary pressures.

The following video provides a basic overview of the potential macroeconomic consequences of climate change.

If you are interested in seeing some estimates of climate-related GDP forecasts produced by macroeconomic models, have a look at this article: Kompas, T., Pham, V.H., Che, T.N. (2018). The effects of climate change on GDP by country and the global economic gains from complying with the Paris Climate Accord. *Earth's Future, 6*(8). You can skip through the background and methodology sections. Scroll down to Table 1 on p. 1161 to see the estimates of a 3^{o} scenario on GDPs over the long run. Table 2 (p.1165) shows GDP impacts in four global warming scenarios.

This study uses a Computable General Equilibrium (CGE) model. The government of Scotland has a very accessible description of these models on its website, available here.

Public Budgets

The public budgets used by various levels of government to fulfill their civic role are not only directly exposed to climate risk (e.g., through critical infrastructure), but also indirectly exposed via the economy as a whole.

On the revenue side, public budgets are dependent on various taxes which are, in turn, dependent on such things as personal incomes, corporate profits and property values—any of which can be impacted by climate change. On the expense side, spending pressures on everything from healthcare to infrastructure repair will likely increase as the effects of climate change intensify.

These budgetary challenges can be exacerbated in the event that sovereign, provincial and/or municipal bonds are repriced due to investors' perception of risk (i.e., increasing the costs of financial government activities). And it could also be compounded by increases in litigation against governments for negligence claims (e.g., inadequate infrastructure, issuing development permits in areas of known risk).

Please watch the following video for an overview of the interaction between climate change and public budgets.

For more information on public budgets and fiscal risks, read pages 133 – 138 in chapter 4 (“Managing the Fiscal Risks Associated with Natural Disasters”) in *Fiscal Policies for Development and Climate Action*. Table 2 on p. 134 provides a summary of some of the main macroeconomic risks and contingent liabilities.

Activity

Activity

In the activity for this module, we'll be exploring how these systems-wide risks might affect a particular industry, sector or organization. For the purposes of this activity, please use the following scenario:

Imagine that it's 2060. Until ten years prior, relatively little progress had been made toward reductions in fossil fuel dependency (SSP2). Global mean temperatures exceeded the 2^{o} target around the year 2045. Throughout much of 2040's, extreme weather events caused very high economic losses across many sectors and many countries. Images of human suffering and stories of business bankruptcies dominated the landing pages of online news outlets. Shortly after 2050, the governments of most medium and high-income countries joined in radical policy reforms, aimed at aggressively decarbonizing the economy. Measures include a $US(2020) carbon tax of over $900/t CO2, and widescale decommissioning of coal, oil and gas leases.

1. Identify an industry, sector or organization to use as an example for this activity.
2. Consider the probable impact of the scenario described above to the financial and government

sectors, and to GDP, employment and incomes.

3. If the system-level impacts you described in Step 2 were to materialize, what would be the likely consequences to the industry, sector, or organization you chose in Step 1.
4. Post your forecasts and conclusions in the Discussion Forum for Module 3.
5. Read and engage with examples posted by others.

PART IV

MODULE 4: RISK UNDER DEEP UNCERTAINTY

Module Overview

Module 4 examines the challenges of quantifying financial risk given the complex dynamic nature of the climate-economy system, and explores how underpricing risk can result in decision-making that is, at best, sub-optimal, and at worse, potentially catastrophic. Unlike the risks normally encountered by an organization, climate risks are characterized by a higher probability of extreme impacts that are not only financial, but also existential.

When financial models fail to account for the likelihood of extreme values, climate change risk will be underpriced. As a result, decision-makers (governments, businesses, households) may make less-than-optimal choices that can exacerbate, rather than mitigate, the climate crisis (for example, by delaying or watering down action).

In this module, we'll explore the complex dynamic nature of climate and economies, and consider various models for decision-making under deep uncertainty.

Module Objectives

By the end of this unit, you will:

1. Understand the uncertainty arising from the complex dynamic nature of climate systems, socio-political

systems, and the inter-relationships between them;

2. Define the “tail risks” in hazard distributions and understand the implications of “fat tails” on adaptation decision-making;
3. Identify examples of models for decision-making under deep uncertainty (adaptation pathways, real options, robust decision making);
4. Contemplate the relevance of the *precautionary principle* when the probability of catastrophic outcomes are greater than zero.

Readings and Resources

Readings & Resources

McSweeney, R. (2020). *Explainer: Nine 'tipping points' that could be triggered by climate change*. Carbon Brief.

van Ginkel, K.C.H., Wouter Botzen, W.J., Haasnoot, M., Bachner, G., Steininger, K.W., Hinkel, J., Watkiss, P., Boere, E., Jeuken, A., de Murieta, E.S., & Bosello, F. (2020). Climate change induced socio-economic tipping points: Review and stakeholder consultation for policy relevant research. *Environ. Res. Lett. 15.*

Watkiss, P., Hunt, A., Blyth, W., & Dyszynski, J. (2015). The use of new economic decision support tools for adaptation assessment: A review of methods and applications, towards guidance on applicability. *Climatic Change, 132*(3). **[Excerpts only].**

Overview

Throughout this course, we have been (explicitly or not) incorporating probabilistic methods to formulate conjectures about future states of the world. That approach is typically considered appropriate when exact quantities or values cannot be reliably determined, but the range and distribution of values can. Recall, for example, that in Module 1 we used a hazard distribution function as the basis for our simulations regarding the frequency and extent of exposure in our catastrophe models. Incorporating probability distributions in this way enables us to incorporate uncertainty into our predictions, and to explore (and prepare for) potential variability in outcomes.

But what happens when those probability distributions are not fully understood? Or are wrong? What happens if they change over time, or reach a point they no longer accurately describe reality?

We can think of those possibilities as deep uncertainty: situations in which adequate probabilistic information, or agreement about the *correct* probabilities, is lacking. Deep uncertainty is unsettling. It limits our capacity to make predictions about the future, which therefore undermines our capacity to make good decisions to meet that future.

In this module, after exploring two examples of how our probabilistic method could potentially let us down, we'll look at decision-making models that are less reliant on probability distributions, but that can produce meaningful and adaptive strategies even amidst deep uncertainty.

Climate surprises: Fat tails

Here, we're interested in cases in which climate change does not proceed in an orderly, gradual and predictable way but, rather, presents us with surprises: an extreme weather event that our probability distributions suggest should occur very rarely, if ever; or, a sudden abrupt shift in the state or dynamics of the climate system itself.

If we wish to predict the probable frequency of future events, we'd like our probability distributions to take on a familiar and reliable bell-shape with a clearly defined central tendency within a fairly narrow range of values beyond which their likelihood approaches zero. That distribution would look similar to the red curve in the diagram below.

But what if the actual distribution looks more like the one illustrated with the violet curve? In that curve, the likelihood of extreme high values does not fully dissipate. Some likelihood of their occurrence remains. The violet curve is a "fat-tailed distribution."

As Nordhaus (2011) points out, if a normal distribution applies to the likelihood of an event's occurrence, then an unusually large event will only be slightly larger than historical events. But, fat-tailed distributions can produce outliers that are many times greater than historical events. Nordhaus illustrates the difference by comparing the distribution of women's heights (a normal distribution) with the distribution of earthquake intensities (a fat-tailed distribution): "If you thought earthquakes had a normal distribution, such a tail event [as the 2011 Fukushima earthquake] would be equivalent to observing a twenty-foot-tall woman striding down the street" (Nordhaus, 2011, p. 249.)

The figure below clearly illustrates the higher probability of "surprises" (events that deviate substantially from normal variation) if the likelihood of an event follows a fat-tailed distribution compared to a normal distribution. It illustrates that, with a fat-tailed distribution, even values that are many standard deviations above the mean have probabilities that are not trivial. In the context of climate, those tail surprises could include unimaginably extreme weather events (heatwaves, precipitation events, storms, hurricanes, typhoons).

The implications of fat-tailed distributions for forecasting financial impacts or for making adaption decisions are significant. If we base our models on averages or the "middle of the distribution" (Weitzman, 2009) and we assume that extreme outliers are too unlikely to be relevant to policy- or strategy-making, we risk both grossly underestimating (human and financial) risks and grossly. Some (for example, Weitzman, 2009, 2011) even go so far to question whether fat-tailed distributions render our typical cost-benefit models obsolete.

Climate surprises: Tipping points

Another possibility that throws a wrench into probabilistic modeling is the risk of an abrupt change in the climate system itself—a change either in the equilibrium state of the system or in its system dynamics. Such a change implies a corresponding sudden shift in the probability distribution for events that are produced by the system (like extreme weather).

Many of our adaptation planning models and our financial impact forecasts are based on an assumption that the climate will change gradually—perhaps gradually enough for us to adapt or alter our socioeconomic response to it. However, there are good reasons to question that assumption. For example, the paleoclimate record includes many such examples of abrupt changes in ocean and air circulation, and extreme extinction events (National Research Council, 2013).

These abrupt changes are generally seen as the consequences of crossing some threshold or "tipping point" beyond which changing system dynamics draw the system toward a new equilibrium. Common examples of tipping points in climate systems include loss of Arctic sea ice, which diminishes ice albedo, leading to increased temperatures, faster sea ice lost, and further diminished albedo. Or permafrost thaw that results in the release of methane into the atmosphere, increasing the atmospheric stock of greenhouse gasses, accelerating global warming and further permafrost thaw. Note that both these examples involve feedback loops in the climate system that result in an amplification of the initial disturbance.

For a list and description of some important climate tipping points, see McSweeney, R. (2020). *Explainer: Nine 'tipping* *points' that could be triggered by climate change*. Carbon Brief.

Some climate scientists suggest that some climate tipping points have already been activated, and that we are dangerously close to activating others. The authors of one such study conclude, "If damaging tipping cascades can occur and a global tipping point cannot be ruled out, then this is an existential threat to civilization. No amount of economic cost–benefit analysis is going to help us. We need to change our approach to the climate problem" (Lenton, T.M., et. al. (2019). Climate tipping points—too risky to bet against. *Nature*.) Notice the similarity of Lenton's conclusion to Weitzman's conclusion regarding fat-tailed distributions.

Tipping points are also possible in socioeconomic system as well, including technology and adaptation systems. For a brief overview of some of these tipping points, read van Ginkel et al, Climate change induced socio-economic tipping points: Review and stakeholder consultation for policy relevant research Section 3 (pp. 3 – 7) only.

Decision-making under deep uncertainty

Given the deep uncertainties with which the climate and its coupled systems are fraught, the question arises of whether—and how—decision-making can proceed. This is an especially important point when the kind of decision-making we're contemplating is in regard to climate adaptation.
The first video in this module's series is a brief overview of uncertainties in the climate system, and the implications of this for adaptation planning.

Three decision frameworks

Here, we'll survey three decision-making models that have been proposed for situations of deep uncertainty: Real Options; Adaptation Pathways; and Robust Decision Making (RDM).

Before viewing the videos, read sections 3.5 – 3.11 (pp. 406 – 410) in Watkiss, P., Hunt, A., Blyth, W., & Dyszynski, J. (2015). The use of new economic decision support tools for adaptation assessment: A review of methods and applications, towards guidance on applicability. *Climatic Change, 132*(3). These sections provide a brief overview to each of the three methods. (NOTE: Watkiss et al use the term "Adaptive Management" rather than "Adaptation Pathways").

Real Options

The first of the three decision models we'll look at is the Real Options approach. Real options focus on the value of preserving future choices by choosing strategy pathways that maximize flexibility. The example used in this video is based on an example provided in Her Majesty's Treasury' Supplementary Green Book Guidance (2009), as reported in The Mediation Project. (n.d.). *Decision support methods for climate change adaptation: Real options analysis*.

Adaptation Pathways

Our second model is Adaptation Pathways. Adaptation Pathways define a broad range of sequential actions that achieve the decision-makers' goal, and enables planners to both configure an action sequence to align with preferred decision principles, and builds in future decision points that support timely switching between strategies. The video below provides a brief overview of the approach. The Singapore drainage example is drawn from Buurman, J. & Babovic, V. (2016). Adaptation Pathways and Real Options Analysis: An approach to deep uncertainty in climate change adaptation policies. *Policy and Society, 35*(2), 137-150.

Robust Decision Making

The final example is the Robust Decision Making model. It is a model that—rather than predicting the future and crafting a strategy to meet that future—starts with strategy/decision-making, and then stress-tests the strategy against a broad range of scenarios. In the introduction video, below, the examples and illustrations were adapted from Rand Corporation. (n.d.). The robust decision making framework. and Hadka, D. (2015, October 1). *Introducing OpenMORDM*.

Light-touch approaches

Though each of the methods described above require some amount of technical competency to implement, Watkiss and Cimato (2016) observe that many planners—without fully implementing these methods—use each approach to inform the way they approach decision-making under uncertainty. Watkiss and Cimato call this the "light touch approach".

The table below provides a few examples of how each method can "lightly" be incorporated into thinking to improve decision-making.

Method	Light-touch ap
Real options	• Consider "foothold" activities that open up pote the future • Explicitly consider trade-offs between "all-in" st capacity to make choices in the future • Use decision-tree structures to think through a • Trace out possible outcomes and decision poin
Adaptation Pathways	• Identify near-term actions and future continge • Prioritize options on the basis of timing and ph • Understand failure points (tipping points) and i points are nearing
Robust decision making	• Apply "robustness" as a criterion for assessing c • Use expert judgment to stress-test strategies a uncertainties that determine a strategy's succe

Adapted from U.K. Department for Environment, Food and Rural Affairs. (2020,

November). *Accounting for the effects of climate change: Supplementary green book guidance* *and* Watkiss, P., & Cimato, F. (2016, May). The economics of adaptation and climate-resilient development: Lessons from projects for key adaptation challenges. *Centre for Climate Change Economics and Policy Working Paper, No. 265.*

The end of cost-benefit analysis

As noted in the introduction, certain aspects of deep uncertainty—particularly fat-tailed distributions and climate tipping points—result in non-negligible probability of global catastrophe. Both Weitzman (fat tails) and Lenton et al. (tipping points) conclude that the kind of cost-benefit analysis (CBA) that many decision makers rely on (for climate adaptation planning, but also a wide variety of other applications) is rendered obsolete by the kind of deep uncertainties related to fat tails and tipping points.

Weitzman, perhaps, states this most clearly in his Dismal Theorem (2009). Here, he argues that the disutility of extreme climate (i.e., the liability associated with damaged) is essentially unbounded (unlimited). In other words, at the extreme of the fat tail are infinite losses (for human purposes) with non-zero probabilities. This suggests a willingness to pay to avoid extreme damages should reasonably be very, VERY large.

The result?… Either a cost-benefit analysis (CBA) will endorse arbitrarily costly (unfeasible) projects, or it must truncate (or ignore) areas in the tail of the probability distribution that represent such global catastrophes. In the former case, results are meaningless because we're unlikely to trade infinite wealth to eliminate an unlikely, but possibly infinite loss. In the latter case, our CBAs under-represents the full risk to which we're exposed and, as such, may result in insufficient endorsement for adaptation measures.

Both Weitzman and Lenton et al. seem to imply that financial analysis through cost-benefit analysis is an inappropriate approach—that we need some other decision criteria to determine what, and how much, adaptation action is appropriate to our circumstances. Though neither explicitly mention the precautionary principle, others have proposed it as a more appropriate decision criteria in situations of deep uncertainty and non-negligible probability of global catastrophe.

Many of you are, no doubt, very familiar with the precautionary principle. Though it has been articulated in many different ways, the Wingspread Consensus Statement is, perhaps, the most clear statement of the principle as it might apply to climate change.

Wingspread Consensus Statement on the Precautionary Principle (2013, August 5)

"We believe existing environmental regulations and other decisions, particularly those based on risk assessment, have failed to protect adequately human health and the environment – the larger system of which humans are but a part.

"We believe there is compelling evidence that damage to humans and the worldwide environment is of such magnitude and seriousness that new principles for conducting human activities are necessary.

"While we realize that human activities may involve hazards, people must proceed more carefully than has been the case in recent history. Corporations, government entities, organizations, communities, scientists and other individuals must adopt a precautionary approach to all human endeavors.

"Therefore, it is necessary to implement the Precautionary Principle: When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically."

Activity

Activity

For this week's activity, I'm asking that we all reflect on the limitations of financial approaches to decision-making in light of deep uncertainty and non-negligible probabilities of catastrophic losses.

Things to consider in your reflection:

1. How should deep uncertainty be represented in decision-making?
2. To what extent are financial decision-making models suitable for decisions under deep uncertainty, and to what extent might they endorse insufficient action undertaken within inadequate timelines?
3. Would the precautionary principle be a more suitable decision criteria than cost-benefit? Or another decision-making principle?
4. Do we rely on financial models because they are salient to stakeholders and more reliably motivate action? If so, are they a necessary evil in the area of climate action?
5. After your reflect on these topics, post a brief summary of your insights to the Moodle discussion board for Module 4. It is not necessary to address all of the above points in your

contribution.

Appendix

Case Studies

- Whitehorse Grocery (transportation disruption risk due to land subsidence caused by permafrost thaw)
- Pemberton Cabins (property loss due to wildfire)
- Clark Acres Farm (crop damage due to drought)
- Windsor Care Home (heatwave exacerbated by power outage)