PERMAFROST

ESTIMATES GLOBAL CLIMATE IMPACT

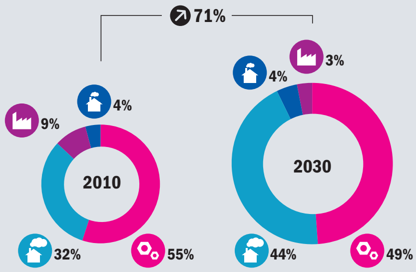
2010 EFFECT TODAY

USD **LOSS** PER YEAR **30 BILLION**

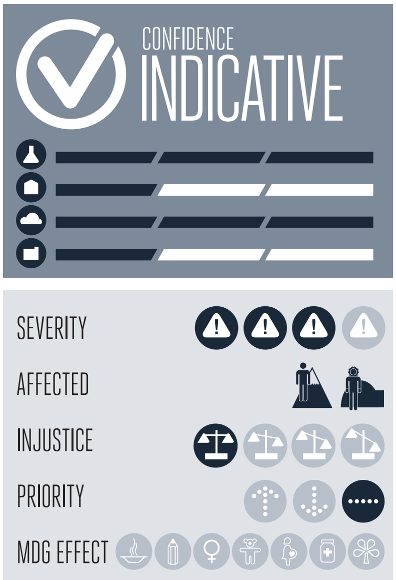
2030 EFFECT TOMORROW

USD **LOSS** PER YEAR **150 BILLION**

ECONOMIC IMPACT



CONFIDENCE
INDICATIVE



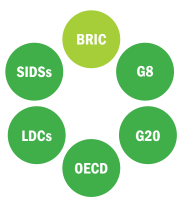
- One-quarter of the northern hemisphere's land is permanently frozen or frozen for extended periods
- The planet's warming has been most rapid in the far north, where rising heat simply melts permanently frozen land
- Infrastructure of every kind, from buildings, roads, and railways, to pipelines, airports, and power lines come under stress or are damaged when the rate of melting is accelerated
- The entire infrastructure of the far north and the world's coldest zones is affected
- Overall, the effect is estimated to accelerate by around 10–20% the rate of wear and tear on all exposed infrastructure in the near term

RELATIVE IMPACT

HOTSPOTS

2010	$	2030
15,000	RUSSIA	75,000
9,250	CHINA	65,000
600	MONGOLIA	4,000
1,750	CANADA	3,500
400	PAKISTAN	2,000

GEOPOLITICAL VULNERABILITY



Economic Cost (2010 PPP non-discounted)
Developing Country Low Emitters
Developed
Developing Country High Emitters
Other Industrialized

$ = Losses per 10,000 USD of GDP

Change in relation to overall global population and/or GDP

$ = Millions of USD (2010 PPP non-discounted)

Permafrost thawing is one impact of climate change that does not spare some of the world's most advanced and industrialized countries. In some places rising heat is causing dry lands to degrade into desert. In the coldest parts of the world, the heat is instead causing land to melt and sink, damaging infrastructure as it subsides (Larsen and Goldsmith, 2007). Every conceivable type of infrastructure is at risk as permafrost melts, including buildings, roads, railways, and oil pipelines (Xu et al., 2010; Lin, 2011M; Feng and Liu, 2012). Preserving this infrastructure as growing heat adds to the stress is a major challenge for engineers and a serious cost for local communities (McGuire, 2009). In Alaska, for instance, two-thirds of the state roads budget is spent on permafrost repair alone (Stidger, 2001). In worst case scenarios, it is estimated that extreme permafrost thaw could force the relocation of entire communities (Romanovsky et al., 2010). Permafrost thawing through accelerated infrastructure replacement and repair will impose significant cost burdens on the world's coldest communities.

CLIMATE MECHANISM

As temperatures rise, regions nearer the poles are heating up the fastest (IPCC, 2007). Much of the land within the Arctic Circle is frozen on a permanent basis, or for more than 1–2 years. The permafrost region currently covers about one-quarter of earth's land area (Nelson et al., 2002); however, it is home to only a fraction of the world's population (Hoekstra et al., 2010). One-quarter of the land area of the northern hemisphere has a subterranean layer of ice built up under the soil which can melt when temperatures rise (Anisimov, 2009). The warming planet thaws otherwise permanently frozen land, destabilizes it, alters its ecosystem, and compromises the structural integrity of any buildings or infrastructure that have been constructed in these zones (Romanovsky et al., 2010). In this way, climate change is already accelerating the process by which key infrastructure in these areas requires repair or replacement (Larsen and Goldsmith, 2007).

IMPACTS

The impact of climate change on infrastructure in affected permafrost zones is estimated globally at 30 billion dollars a year in 2010. With the expected increase in temperatures through to 2030, losses associated with permafrost thawing are estimated to grow as a share of global GDP, amounting to approximately 150 billion dollars a year.

Countries worst affected include the US (because of Alaska), Canada, China (because of Tibet), Mongolia, Russia, and a number of Central Asian states (because of the Himalayas). As climate change intensifies, the same group of countries continues to be affected.

The largest total losses are incurred in Russia, China, Mongolia, and Canada. Losses for Russia and China are currently estimated at around 20 and 10 billion dollars respectively, and should grow to over 60 billion dollars each year by 2030.

Mongolia, Kyrgyzstan, and Bhutan are estimated to suffer the most severe effects as a share of GDP, with Mongolia and Kyrgystan's losses at over 4% of GDP by 2030, and Bhutan's in excess of 1% of GDP.

Some 10 million people are estimated to be affected by the impact of climate change on permafrost globally, a number that will more than double to nearly 25 million by 2030.

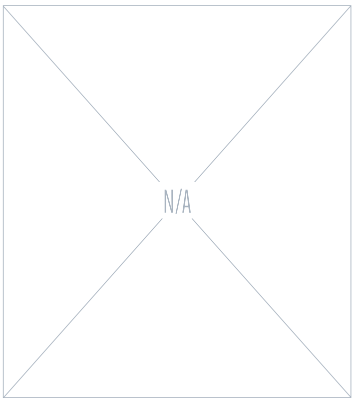
THE BROADER CONTEXT

Dealing with some degree of oscillation in permanently frozen land in the coldest zones of the planet is normal (Wei et al., 2009). It is the acceleration in these processes that incurs additional costs as temperatures rise. While the northernmost or coldest regions of the planet are sparsely inhabited, oil and gas exploitation has grown in permafrost regions in and around the Arctic Circle. Planned or constructed high value infrastructure in these regions will face growing risks (Pavlenko and Glukhareva, 2010). The same is true for the multi-billion dollar China–Tibet railway, built over partially unstable land across the Tibetan ranges and plateaux (Yang and Zhu, 2011).

VULNERABILITIES AND WIDER OUTCOMES

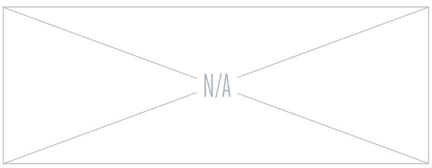
Communities and governments maintaining expensive public infrastructure in lower-middle income countries, such as Kyrgyzstan in Central Asia, will face a major development challenge in tackling accelerated infrastructure erosion. There is a lack of clarity on the extent to which insurance

BIGGER PICTURE

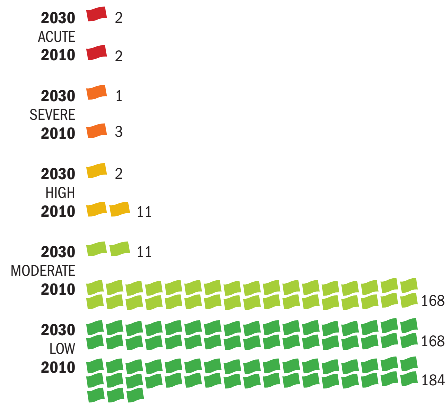


SURGE

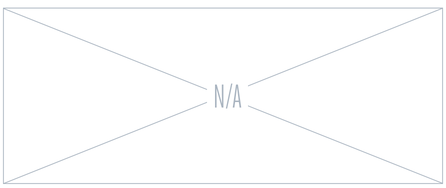
OCCURRENCE



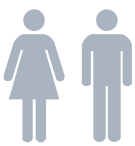
VULNERABILITY SHIFT



PEAK IMPACT



GENDER BIAS



INDICATOR INFORMATION

MODEL: Hoekstra et al., 2010; Nelson et al., 2001

EMISSION SCENARIO: UKTR GCM-based scenario (Nelson et al., 2001)

BASE DATA: Larsen and Goldsmith, 2007; UN CHS, 2010; US CB website, 2000

= 5 countries (rounded)

Acute Severe High Moderate Low

policies are valid for permafrost erosion damage (Mills, 2005; Williams, 2011). Insurance coverage is growing, as incomes of developing countries expand, suggesting that for many of the worst affected areas, including Tibet, Mongolia, and Kyrgyzstan, a lack of insurance will heighten the impact of these changes (Kharas, 2010). Permanently frozen land also stores around half of the potential soil-derived emissions of greenhouse gases (GHGs), mostly in the form of methane, a highly potent GHG. As such, there is mounting concern that, as they thaw, the permafrost regions could become a major unmanageable driver of global climate change (Tarnocai et al., 2009).

RESPONSES

Adaptation to the thawing of permafrost is a challenge. Future planning might make non-essential infrastructure projects in transition zones less of a priority. For all existing infrastructure, there is a predictable accelerated depreciation and replacement cost that must be faced (Larsen and Goldsmith, 2007). Unlike sea-level rise, changes are likely to come faster, and no wall can prevent the retreat of frozen land which, as it thaws, will decimate any built infrastructure in affected areas. However, for certain types of infrastructure, such as pipelines or railways, measures can be taken to mitigate the extent of destabilising effects, especially when designing new infrastructure (Xu et al., 2010; Wei et al., 2009).

Public resources may be considered, for instance, to subsidise or back insurance schemes which allow risk to be managed in a more long-term framework, buffering communities from abrupt losses and enhancing the resilience of highly exposed groups (Verheyen, 2005). In worst cases, community relocation may be necessary (Romanovsky, 2010).

THE INDICATOR

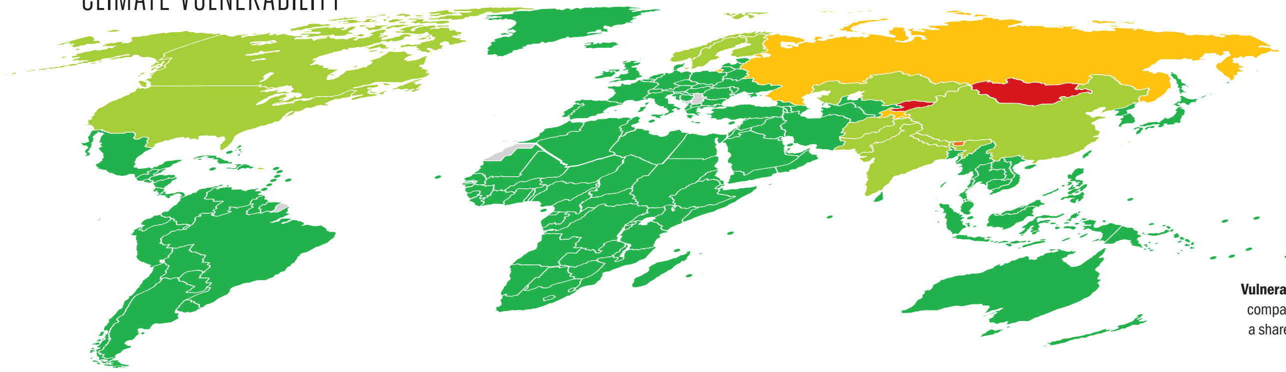
The indicator is understood to be moderately robust. This is because clarity on the climate signal in one of the fastest warming regions of the world is pronounced, and the IPCC's stance on the possibility of extensive damage stemming from permafrost erosion is firm (IPCC, 2007). However, permafrost damage is for now a niche research area at best, and the indicator's robustness is compromised by being based on only one study and model from Alaska (Larsen and Goldsmith, 2007). Further uncertainties relate to the extrapolation of the damage estimations through income (GDP) metrics and population-weighted adjustments in order to simulate the damage effects in the other countries. Assumptions were also made by proxy for non-public infrastructure based on capital values of private infrastructure at risk, which could be an area for further improvement. Given the potential scale of the damage, the topic remains a clear research priority for additional enquiry in all respects.

ESTIMATES COUNTRY-LEVEL IMPACT

COUNTRY	$ 2010	$ 2030	Persons 2010	Persons 2030
ACUTE				
Kyrgyzstan	400	1,750	450,000	850,000
Mongolia	600	4,000	550,000	1,000,000
SEVERE				
Bhutan	45	250	20,000	40,000
HIGH				
Russia	15,000	75,000	4,500,000	9,500,000
Tajikistan	100	500	150,000	250,000
MODERATE				
Afghanistan	20	100	90,000	200,000
Canada	1,750	3,500	350,000	700,000
China	9,250	65,000	4,500,000	9,500,000
Finland	15	30	3,750	7,750
India	100	550	85,000	150,000
Kazakhstan	200	800	75,000	150,000
Nepal	65	300	150,000	300,000
Norway	100	200	20,000	40,000
Pakistan	400	2,000	350,000	750,000
Sweden	85	150	20,000	40,000
United States	650	1,250	90,000	200,000
LOW				
Albania				
Algeria				
Angola				
Antigua and Barbuda				
Argentina				
Armenia				
Australia				
Austria				
Azerbaijan				
Bahamas				
Bahrain				
Bangladesh				
Barbados				
Belarus				
Belgium				
Belize				
Benin				
Bolivia				
Bosnia and Herzegovina				
Botswana				
Brazil				
Brunei				
Bulgaria				
Burkina Faso				
Burundi				
Cambodia				
Cameroon				
Cape Verde				
Central African Republic				
Chad				
Chile				
Colombia				
Comoros				
Congo				
Costa Rica				
Cote d'Ivoire				
Croatia				
Cuba				
Cyprus				
Czech Republic				
Denmark				
Djibouti				
Dominica				
Dominican Republic				
DR Congo				
Ecuador				
Egypt				
El Salvador				
Equatorial Guinea				
Eritrea				
Estonia				
Ethiopia				
Fiji				
France				
Gabon				
Gambia				
Georgia				
Germany				
Ghana				
Greece				
Grenada				
Guatemala				
Guinea				
Guinea-Bissau				
Guyana				
Haiti				
Honduras				
Hungary				
Iceland				
Indonesia				
Iran				
Iraq				
Ireland				
Israel				
Italy				

$ Additional economic costs due to climate change (million USD PPP) - yearly average

CLIMATE VULNERABILITY



CLIMATE UNCERTAINTY

COUNTRY	$ 2010	$ 2030	2010	2030
Jamaica				
Japan				
Jordan				
Kenya				
Kiribati				
Kuwait				
Laos				
Latvia				
Lebanon				
Lesotho				
Liberia				
Libya				
Lithuania				
Luxembourg				
Macedonia				
Madagascar				
Malawi				
Malaysia				
Maldives				
Mali				
Malta				
Marshall Islands				
Mauritania				
Mauritius				
Mexico				
Micronesia				
Moldova				
Morocco				
Mozambique				
Myanmar				
Namibia				
Netherlands				

COUNTRY	$ 2010	$ 2030	2010	2030
New Zealand				
Nicaragua				
Niger				
Nigeria				
North Korea				
Oman				
Palau				
Panama				
Papua New Guinea				
Paraguay				
Peru				
Philippines				
Poland				
Portugal				
Qatar				
Romania				
Rwanda				
Saint Lucia				
Saint Vincent				
Samoa				
Sao Tome and Principe				
Saudi Arabia				
Senegal				
Seychelles				
Sierra Leone				
Singapore				
Slovakia				
Slovenia				
Solomon Islands				
Somalia				
South Africa				
South Korea				

COUNTRY	$ 2010	$ 2030	2010	2030
Spain				
Sri Lanka				
Sudan/South Sudan				
Suriname				
Swaziland				
Switzerland				
Syria				
Tanzania				
Thailand				
Timor-Leste				
Togo				
Tonga				
Trinidad and Tobago				
Tunisia				
Turkey				
Turkmenistan				
Tuvalu				
Uganda				
Ukraine				
United Arab Emirates				
United Kingdom				
Uruguay				
Uzbekistan				
Vanuatu				
Venezuela				
Vietnam				
Yemen				
Zambia				
Zimbabwe				

Additional persons affected due to climate change - yearly average