Journal of Futures Studies
2022,Vol. 27(1) 29-40
DOI: 10.6531/JFS.202209_27 (1).0003

Article

Accelerating Climate Change: An Exploration of Cascading Future Implications

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Abstract

The impacts of climate change have accelerated significantly in recent decades. This paper explores the cascading effects of accelerating climate change using a participatory Futures Research method. The Implications Wheel® method was used to identify and score possible higher-order implications of three key direct impacts of accelerating climate change: Increasing crop failures; more frequent, severe, and longer-lasting heatwaves; and more frequent, intense, and larger wildfires. Analysis of the many second- and third-order implications that were generated revealed implications with significance for proactive planning, surprising insights, major emergent themes, and a handful of potential high-impact wild cards.

Keywords

Accelerating Climate Change, Implications Wheel®, Participatory Methods, Cascading Impacts

Introduction

Scientific awareness that anthropogenic emissions of carbon dioxide and other greenhouse gases could alter our planet's climate dates to the 19th century, but scientific understanding of climate change and its impacts have advanced slowly (Weart, 2008). Consensus and concern among scientists began to form in the 1970s and 1980s as climate science advanced and landmark studies were published (e.g., Sawyer, 1972; Hansen et al., 1981). The year 1988 was a turning point in the science of climate change, with NASA scientist James Hansen's historic testimony before the US Congress (Sinclair, 2018) and the formation of the Intergovernmental Panel on Climate Change.

In recent decades, both scientific understanding and the observable impacts of climate change have accelerated rapidly. The impacts already affect many aspects of life on Earth. A large-scale review conducted by Mora et al. (2018, p. 1062) found "… traceable evidence for 467 pathways by which human health, water, food, economy, infrastructure and security have been recently impacted by climate hazards such as warming, heatwaves, precipitation, drought, floods, fires, storms, sea-level rise and changes in natural land cover and ocean chemistry."

The economic costs inflicted by climate change have been noted by the insurance industry at least since the 1980s (Lowe, 2005). As the impacts of climate change multiply, evidence of accelerating economic costs is mounting. The National Oceanic and Atmospheric Administration (NOAA) compiles an annual database of billion-dollar weather and climate disasters going back to 1980 which includes every natural disaster that caused at least one billion dollars in damage (Smith, 2021). The most recent report reveals that 2020 was an historic year for large weather and climate disasters in the United States: 22 separate billion-dollar disasters occurred across the country, surpassing the previous annual record of 16 which occurred in both 2011 and 2017. The combined cost of the 22 events in 2020 was estimated to be a staggering $95 billion in economic damage, and these estimates do not include the much more difficult to quantify social and ecological costs of climate disasters. If concentrations of greenhouse gases continue

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Received: 26 July 2021 and Accepted: 15 August 2021

to rise over the next several decades and the impacts of climate change accelerate, the social, economic, and ecological costs will also accelerate.

This paper provides an example of how a participatory Futures Research method can be used to explore the cascading effects of accelerating climate change. The Implications Wheel® is a "smart group" method developed by futurists to uncover potential unanticipated consequences of change (Bengston, 2016). The exploration was part of a University of Minnesota Honors Program seminar which used the perspectives and methods of Futures Studies to focus on climate change futures. The authors of this paper are the students and instructors of that class.

The paper is organized as follows: The next section highlights key evidence for the accelerating pace and impacts of climate change. This is followed by a description of the method. A summary of the main findings from the Implications Wheel exercise is then presented, and a concluding section briefly outlines possible extensions of the study.

The Accelerating Pace and Impacts of Climate Change

A growing body of evidence suggests that climate change has accelerated in recent decades and that it will likely continue to accelerate. For example, the Arctic climate has been changing rapidly according to NOAA's annual Arctic "report card" (Thoman et al., 2020). Summarizing this report, Harvey (2020, p. 1) stated that "Temperatures are rising, ice is melting, snow is disappearing and the region's delicate ecosystems are rapidly evolving. It's already not the same place it was a few decades ago, and it won't be the same place a few more decades into the future." Average temperatures in the Arctic have been rising at least twice as fast as the global average (Thoman et al., 2020).

Rising temperatures in the Arctic are causing accelerating and even abrupt thawing of permafrost, triggering the release of greenhouse gases – carbon dioxide, methane, and nitrous oxide – into the atmosphere (Turetsky et al., 2019). Permafrost is thawing much more rapidly than climate change models have predicted. Arctic soils hold more than twice as much carbon as the atmosphere, raising concern about a surge of greenhouse gases and a further acceleration of global warming.

The rise of "mega-fires" is another indicator of accelerating climate change. The number, size, and intensity of wildland fires have increased significantly in many parts of the world in recent decades, and this trend is expected to continue to increase due to projected climate change (Stephens et al., 2013). Like thawing permafrost, carbon emissions associated with mega-fires are also positive feedbacks to climate change (Adams, 2013).

Recent research suggests that the strength of hurricanes, the amount of rain they dump, and how quickly they intensify has increased over the past four decades (Kossin et al., 2020). Hurricanes are expected to continue to intensify as the earth continues to warm. The severity and in some cases the frequency of other weather-related natural disasters – such as tornadoes, drought, rain and flooding, and heatwaves – have increased (Gronewold, 2020).

Heatwaves are the deadliest climate risk, but their devastation is not always immediately obvious. Extreme temperature events have been increasing in frequency, duration, and magnitude. The World Health Organization reports that the number of people exposed to extreme heat around the world increased by 125 million between 2000 and 2016, and more than 70,000 deaths were attributed to the 2003 heatwave in Europe (World Health Organization, 2021). The number of cities exposed to extreme temperatures – defined as average summer highs of 95F or higher – is projected to almost triple by 2050 (Rosenzweig et al., 2018). The urban heat island effect makes heatwaves worse in cities, but non-urban communities are also severely affected by extreme heat events.

The recent clustering of years that set records for hottest average global temperature is another indicator of accelerating climate change. By NOAA's calculation, the last seven years rank as the hottest seven globally and they estimate that most of the years in the coming decade are highly likely to rank as top 10 warmest years (Arguez et al., 2020). NASA calculates that 2020 was tied with 2016 for the hottest year on record while NOAA, using a different measurement approach, placed it as the second hottest (Thompson 2021). It is noteworthy that the record-setting heat of 2020 came without the significant El Niño event that helped boost global temperatures to a new record in 2016.

A recent study analyzed satellite data from all of the planet's more than 200,000 glaciers and found they have

lost a stunning 267 billion tons of ice per year over the last two decades, and the rate of loss is accelerating significantly (Hugonnet et al., 2021). The study estimated that meltwater from the glaciers accounted for 21 percent of sea level rise since the year 2000. Glaciers are thought to be a good indicator of the progression of climate change – like a canary in a coal mine – because they are highly sensitive to changes in temperature.

Finally, some scientists argue that the IPCC's 2018 special report underplays the likelihood of accelerating global warming in the coming decades. For example, Xu et al. (2018) point to three trends — rising greenhouse-gas emissions, declining air pollution (and therefore less aerosols such as sulfates, nitrates, and organic compounds that reflect sunlight and help keep the planet cooler), and natural climate cycles — that will combine to increase the pace of change over the next 20 years and make climate change "… faster and more furious than anticipated" (p. 30).

Method: The Implications Wheel

In this study, the Implications Wheel was used to explore possible implications of three key aspects of accelerating climate change. The Implications Wheel is a highly structured version of the widely used futures wheel foresight method and is designed to identify and evaluate possible direct and indirect consequences of change using a participatory group process (Barker, 2011; Schreier, 2005). Developed by futurist Joel Barker, the name of the method comes from the wheel-like structure that emerges as the group process proceeds. The change of interest is placed at the center of the wheel, and first-, second-, and third-order implications of the change are generated by participants and flow outward from the center like the spokes of a wheel. The process facilitates "cascade thinking," described by Barker and Kenny (2011, p. 2) as "how one event or implication leads to multiple possibilities, each of which in turn leads to additional possibilities." Gaining an understanding of cascading change can help planners and decision makers consider a range of potential long-term and indirect effects of change in order to prepare for it. Implications Wheel exercises have been carried out in many fields on a wide range of topics (Bengston 2015).

An Implications Wheel exercise can be carried out in-person, with participants together in the same place at the same time, or online and asynchronously using the Implications Wheel cloud-based software (https://www.implicationswheel.com). Due to the Coronavirus pandemic, this Implications Wheel was conducted online and asynchronously. The exercise included total of 17 participants (10 female and 7 male) from diverse disciplinary backgrounds that included the sciences, social sciences, and humanities.

The change at the center of this Implications Wheel exercise was: "Accelerating climate change: Lack of serious and coordinated action to address the climate crisis results in accelerating impacts." This center issue was identified in part through an ongoing horizon scanning project (Hines et al., 2019). A large number of scanning hits related to the accelerating pace of climate change and its impacts have been posted in the horizon scanning database by a diverse team of scanners. Many of the horizon scanning hits focused on the effects of accelerating climate change on agriculture, heatwaves, and wildfires. These three broad areas of impact were selected as the first-order or direct implications for exploration using the Implications Wheel method. Taken together, these three first-order implications encompass three dominant land uses: Agricultural, urban, and wildland. The first-order implications were specified as follows:

- Crop failures increase in many regions due to changes in agro-climate conditions
- More frequent, severe, and longer-lasting heatwaves affect many areas, especially large urban centers
- Wildfires increase in frequency, intensity, and size

These three broad first-order implications are clearly a limited subset of the many possible direct impacts of accelerating climate change (e.g., see Mora et al., 2018). This focus was necessary to keep the study manageable: The direct and indirect impacts of climate change increasingly touch every aspect of natural systems and our lives, and a comprehensive exploration was beyond the scope of this study.

With this center and set of three first-orders, the Implications Wheel exercise consisted of two online rounds of identifying higher order (second- and third-order) implications and one scoring round. Before the online exercise, participants were briefed about the central issue and first-orders. They were then given instructions about how to generate implications (i.e., a set of rules that help ensure useful implications and timely completion of the exercise). During the exercise, participation was asynchronous. Participants were able to access the online

platform, contribute implications, and score them at any time.

The question posed during the first round was: "If this first-order implication occurs, what might happen next?" Participants generated a set of possible second-order implications for each first-order. When identifying second-order implications, participants were instructed to assume that the preceding first-order implication is occurring and will continue, and to generate implications that are a direct consequence of the first-order with no important intervening events. Participants were encouraged to think broadly and to identify positive and negative, high and low probability implications. The goal was to generate a wide-ranging set of possible implications and not inhibit creative, outside-the-box thinking. After the initial round generating second-order implications was completed, the process was repeated to identify a set of third-order implications for each second-order.

Following identification of implications, an online scoring round took place in which participants scored each first-, second-, and third-order implication for desirability and likelihood. Scoring identifies the most significant implications and points out potential opportunities and pitfalls for planning and policy (Schreier, 2005). Each implication was scored on an 11-point desirability scale from +5 (highly positive) to -5 (highly negative), from the point of view of desirability for future generations. Perceived likelihood was scored on a 9-point scale from 1 (highly unlikely) to 9 (highly likely).

In addition to the standard desirability scores, participants could also assign special scores to implications they considered to have momentous impacts. An implication thought to have an extraordinarily positive impact is termed a "triumph" and was assigned a score of +50 by participants; an implication considered to have extraordinarily negative consequence is referred to as a "catastrophe" and was scored -50. These scores are arbitrary but serve the purpose of making triumphs and catastrophes stand out as categorically different from the other implications.

Results and Discussion

This section summarizes the main findings, including the number of first-, second-, and third-order implications generated, the valence of implications (positive, negative, and neutral), highly significant implications, surprising individual insights, major emergent themes, and triumphs and catastrophes.

Number of implications

From the three pre-selected first-order implications, a total of 29 second-order and 113 third-order implications were identified by participants (fig. 1). The large number of third-order implications is a result of the structure of the Implications Wheel. Participants generate multiple second-orders for each first-order, and multiple third-orders for each of the many second-orders, resulting in exponential growth in implications as the process moves out from the center. This structure shifts the focus from direct and shorter-term implications of change to higher-order and longer-term implications. Schreier (2011) compared different approaches to generating possible implications of change and found that unstructured brainstorming produces the opposite of the pattern shown in Figure 1, i.e., a preponderance of first-order implications and few second- and third-order implications. This suggests that people's natural tendency is to focus on more obvious direct and short-term impacts of change and that tools such as the Implications Wheel can be an effective way to shift attention to longer-term and cascading possibilities.

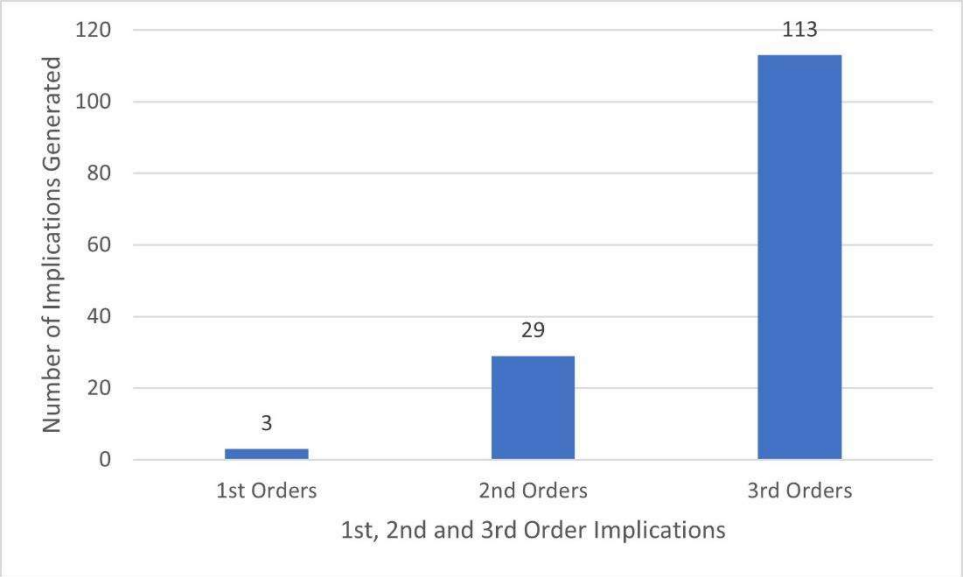

Fig. 1: Number of first-, second-, and third-order implications of accelerating climate change generated.

Valence of implications

Out of the total 145 first-, second-, and third-order implications, 61 percent were scored as negative and 39 percent were scored either positive or neutral (fig. 2). Neutral scores included a narrow range around zero on the 11-point desirability scale, i.e., scores of -1, 0, and +1 were counted as neutral. The relatively large share of positive and neutral implications may be surprising given the obvious undesirability of accelerating climate change and the fact that all three first-order implications are highly undesirable. This illustrates how a strongly negative future development can result in many unanticipated positive consequences and opportunities in the long-term. The converse is also true: A positive change can produce unanticipated negative consequences and challenges.

The following chain of implications generated in the exercise illustrates the shifting valence of implications, i.e., how a negative first-order can produce a positive second-order, and then subsequently produce a negative third-order:

- First-order: Crop failures increase in many regions due to changes in agro-climate conditions (-5 desirability)
- Second-order: Accelerated national R&D programs to develop genetically engineered crops requiring less water and exhibiting greater heat tolerance (+4 desirability)
- Third-order: Companies seize this opportunity to create proprietary crops, forcing farmers to pay hefty premiums for crops they can grow reliably (-4 desirability)

Shifting valence of implications is often found as the process moves out from the center and further into the future, suggesting the importance of digging deeper than the direct consequences of change to uncover a wider range of possibilities. Potentially important challenges and opportunities for long-term planning and decision making often lie beyond the immediate impacts of major change.

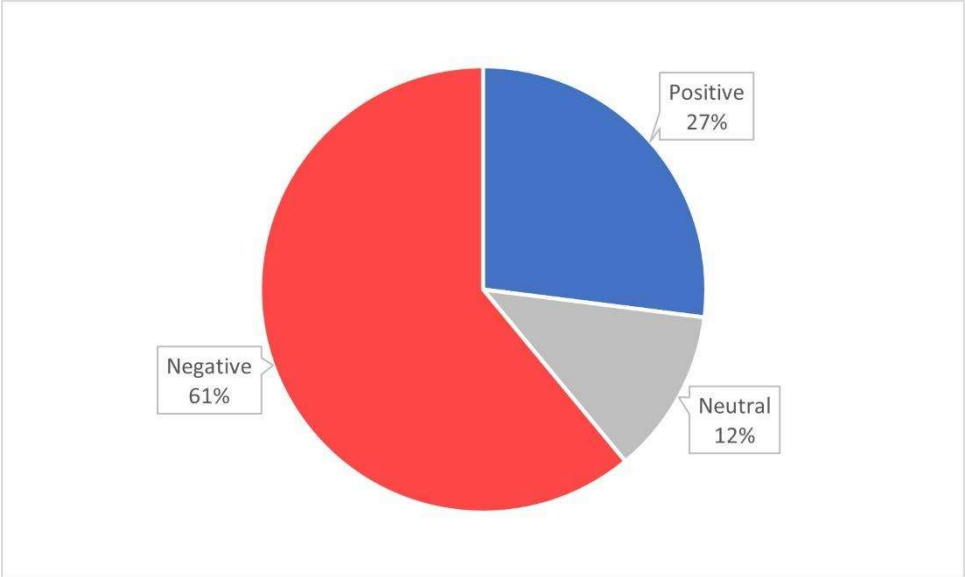

Fig. 2: Share of positive, neutral, and negative implications of accelerating climate change.

Highly significant implications

Two types of highly significant implications can be distinguished based on how they were scored. First, "likely strong negatives" (LSN) are implications scored as highly likely (7, 8 or 9 on the 9-point likelihood scale) and strongly negative (-4 or -5 on the 11-point desirability scale). LSN implications indicate possible future developments that planners, managers, and policy makers may want to avoid by developing initiatives to decrease their likelihood of occurring and/or ameliorate their undesirable effects. Participants scored a total of 18 implications as likely strong negatives, such as the following example in which a chain of first-, second-, and third-order implications are all LSNs:

- First-order: More frequent, severe, and longer-lasting heatwaves affect many areas, especially large urban centers (-4 desirability, 8 likelihood)
- Second-order: Plants and animals not suited for extreme heat become endangered or extinct (-4 desirability, 8 likelihood)
- Third-order: Keystone species that go extinct will force other species that depend on them to go extinct (-4 desirability, 7 likelihood)

The following example of cascading LSNs illustrates how implications often interact across the "arcs" of an Implications Wheel (each first-order and the implications that follow it constitute an "arc" of the final wheel) and across domains: Wildfires affect agricultural systems which in turn affect economic systems:

- First-order: Wildfires increase in frequency, intensity, and size (-5 desirability, 8 likelihood)
- Second-order: Wildfires spread into agricultural areas on a regular basis, destroying crops and farms (-4 desirability, 7 likelihood)
- Third-order: Massive loss in crop production causes food prices to dramatically increase (-4 desirability, 7 likelihood)

The second type of highly significant implication is "unlikely strong positives" (USP), scored as both unlikely (1, 2 or 3 likelihood) and strongly positive (+4 or +5 desirability). USP implications call for planning and policy interventions to increase the likelihood of these desirable changes occurring. Participants only scored one implication as an USP, but 24 implications were strong positives, more than 16 percent of all implications. The one implication scored as an USP demonstrates the possible effects of accelerating climate change on the distribution of political power within a country, leading to a highly desirable reduction in political polarization:

- First-order: More frequent, severe, and longer-lasting heatwaves affect many areas, especially large urban centers (-4 desirability, 8 likelihood)
- Second-order: Shifts in American geo-political power as populations in hotter areas move to more climate resilient parts of the country (0 desirability, 6 likelihood)
- Third-order: Political polarization lessens, and partisan tactics are reduced (+5 desirability, 3 likelihood)

Surprising individual insights

Some individual implications did not fall into the LSN or USP categories due to their scores but nevertheless merit examination because they provide insights about possible unanticipated and surprising futures. These surprising individual insights are unexpected implications of accelerating climate change that planners and policy makers may not be considering. An example is the possibility of heatwaves leading to increased deforestation and forest fragmentation:

- First-order: More frequent, severe, and longer-lasting heatwaves affect many areas, especially large urban centers
- Second-order: Significant migration out of urban areas in the South and into cooler areas in the North
- Third-order: More forests are cleared to develop more suburban and exurban communities in the North

Forest fragmentation and deforestation due to climate migration would be a positive feedback that further accelerates climate change. Being aware of this possibility, urban and forest planners and policy makers could monitor migration patterns and proactively develop strategies to avoid development that will result in forest fragmentation and deforestation, e.g., by promoting denser rather than sprawling development, enacting forest protection measures, and a range of other policies and programs (Bengston et al., 2004).

Another example of a surprising individual insight is crop failures leading to more land for natural habitats and biodiversity, a potential opportunity that natural resource managers could prepare for proactively:

- First-order: Crop failures increase in many regions due to changes in agro-climate conditions
- Second-order: Innovative agricultural techniques like aquaponics and vertical farming are widely adopted
- Third-order: Former agricultural lands are converted into habitats for wildlife and native plants

A final example, also stemming from the crop failures first-order, is a third-order that exacerbates inequality in society:

- First-order: Crop failures increase in many regions due to changes in agro-climate conditions
- Second-order: The variety of food available to humans decreases
- Third-order: A diverse and well-balanced diet is only available to the wealthy

Many other surprising individual insights were found throughout the second- and third-order implications that were generated by participants. The Implications Wheel method is an effective way to uncover unanticipated and surprising higher-order implications of change that are unlikely to be "on the radar" of planners and decision makers.

Major emergent themes

Many broad themes emerged from the large number of implications of accelerating climate change, like the themes and issues that emerge from analysis of focus group or interview transcripts. The "open coding" method of qualitative content analysis was used to identify major themes. This involved a process of repeated and careful reading of the implications, developing an outline of recurring themes, and cross-referencing each theme back to the original implication. See Strauss and Corbin (1998) for details on the open coding method.

Figure 3 lists and ranks the emergent themes by the number of implications expressing each theme. These themes turned up in multiple places within the Implications Wheel structure, i.e., they arose from multiple first- and second-order implications. This lends support to the validity and importance of the themes, similar to group-to-group validation in focus groups (Morgan, 1997). The three most common themes were all undesirable: Economic, social, and ecological costs (fig. 3). Examples of implications expressing each of these negative themes include:

- Economic costs: Food prices increase significantly (produce, grain-based products, meat) due to lower supply (second-order)
- Social costs: Huge numbers of people are left homeless (third-order)
- Ecological costs: In areas affected by megafires, soils are damaged by the extreme heat and become hydrophobic, leading to greater water runoff (second-order)

But the next three most frequently expressed themes were positive: Innovation / climate action, economic benefits, and ecological benefits. For example:

- Innovation / climate action: Agricultural businesses invest heavily in environmentally-friendly technology (third-order)
- Economic benefits: The need for new green cooling technology will create many jobs (third-order)
- Ecological benefits: Forests and national parks revert to a wilder state and endemic species thrive (third-order)

Other emergent themes shown in Figure 3 are wide-ranging and often contradictory or indicate trends and countertrends: Health costs and health benefits, decreased food supply and increased food supply, and increased conflict/unrest and decreased conflict/unrest. Uncovering contradictory themes and countertrends is common in Implications Wheel exercises. The opposing themes suggest a high degree of uncertainty about how a future of accelerating climate change could unfold and therefore the need to build resilience into social-ecological systems to prepare a future with fundamental uncertainties.

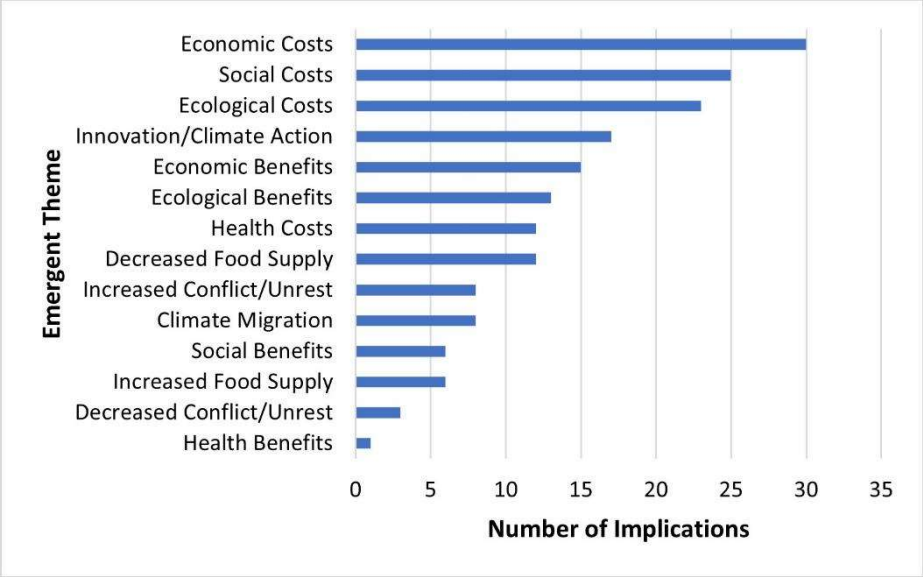

Fig. 3: Major emergent themes and the number of implications expressing each theme.

Wild cards – triumphs and catastrophes

Some of the implications generated in Implications Wheel exercises are potential game-changers with extraordinarily strong positive or negative impacts. These low-probability, high-impact events are often referred to as wild cards in the Futures Research literature (Mendonça et al., 2004). Although wild cards are rare, extensive empirical research has shown that people consistently underestimate the size of the class of rare events (Makridakis et al., 2010; Tversky & Kahneman, 1974). In other words, although individual wild cards are rare events, collectively they are more common than most people think and are a regular driver of change in social-ecological systems.

As mentioned earlier, high-impact wild card implications receive consensus scores of +50 for positive "triumphs," and -50 for negative "catastrophes." In this study, only two implications were scored as catastrophes,

both stemming from the "crop failures" first-order. The first catastrophe was rioting and mass casualties due to food shortages:

- First-order: Crop failures increase in many regions due to changes in agro-climate conditions
- Second-order: Food shortages in many of these regions become regular occurrences
- Third-order: Food shortages result in riots and mass casualties around the world (catastrophe: -50)

The second catastrophe was even more dire, involving nuclear war and widespread devastation:

- First-order: Crop failures increase in many regions due to changes in agro-climate conditions
- Second-order: Elevated threat of international war as nations become desperate to feed their populations
- Third-order: Nuclear war breaks out, devastating large portions of the world (catastrophe: -50)

It is a significant leap from "elevated threat of international war" to "nuclear war breaks out," but the method is designed to explore possible implications of change, including low-probability, high-impact wild cards.

No implications received a triumph consensus score, but there were several near triumphs, i.e., implications that were scored as +50 by at least one participant. For example, following the wildfire first-order and a second-order that involved massive destruction of property due to wildfires, a third-order implication turned positive and was a potential triumph:

- First-order: Wildfires increase in frequency, intensity, and size
- Second-order: Massive destruction of homes, businesses, infrastructure, and other economic assets due to wildfires
- Third-order: New buildings, neighborhoods and communities are designed to survive wildfires (e.g. farther spacing, fire-resistant building materials) (received one +50 score)

Strongly positive implications such as these have the potential to be social or technological tipping points. According to Otto et al. (2020), climate change initiatives that induce positive tipping points have the potential to bring about disruptive change that could lead to a rapid reduction in greenhouse gas emissions. Sharpe and Lenton (2021, p. 1) take this point one step further, maintaining that "… activating one tipping point can increase the likelihood of triggering another at a larger scale, and so on" and such "upward-scaling tipping cascades" could hasten progress in overcoming climate change. An example is the following chain of wildfire implications in which a second-order potential triumph led to two more near triumphs:

- First-order: Wildfires increase in frequency, intensity, and size
- Second-order: Large scale destruction prompts state leaders to take firm and decisive action on climate change, prompting federal government to follow suit (received one +50 score)
- Third-order: The government's unified stance on the effects of climate change effectively neutralizes the climate change denial movement (received one +50 score)
- Third-order: Bipartisan cooperation on combating climate change becomes commonplace, reducing political polarization (received one +50 score)

Conclusions

A strength of the Implications Wheel method is the large number of possibilities that are produced. Creativity researchers have found that the sheer quantity of ideas generated is a key to finding valuable insights (Michalko, 2006). Generating and analyzing many possible implications increases the likelihood that ideas useful for informing planning and policy will result. Even this small-scale Implications Wheel exercise identified 142 possible second- and third-order implications of accelerating climate change. Many additional higher-order implications would be uncovered in a large-scale exercise that begins with an expanded and more comprehensive set of first-order implications. Given the numerous indicators that climate change is already accelerating and that this acceleration will likely continue in the coming decades, the issue deserves more systematic attention from scientists and social scientists who study the effects of climate change.

In addition to increasing the number of first-order implications in a large-scale exercise, other extensions of this research could produce additional foresight about the potential consequences of accelerating climate change. For example, enlisting a greater diversity of participants would generate a wider range of implications with new

insights. Extensive research has shown that diverse groups with many perspectives and backgrounds are more effective at solving complex problems than non-diverse groups or the best individual experts (Page, 2007). Carpenter et al. (2009) argue that "... consideration of a wide range of perspectives is a hallmark of resilient decision making in the face of unexpected change."

Another extension of this research would be to score the desirability of implications from additional and diverse points of view, such as indigenous groups, national security perspectives, or the interests of the poor. Bringing in other stakeholders with different points of view about the desirability of implications would likely uncover additional dimensions of the social consequences of accelerating climate change and additional insights for decision making.

The cascading impacts of accelerating climate change and the mounting social, economic, and ecological costs imply a growing need for better foresight to guide decision making and policy now in order to help avert a worsening climate crisis in the long run. Foresight methods such as the Implications Wheel can increase understanding of the dynamics of cascading change and identify unanticipated pitfalls and potential leverage points to achieve a more resilient future.

Acknowledgements

The authors thank Dr. Leif DeVaney for helpful comments on an earlier version of this paper.

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