Chapter 3
On the Future of Industrial Safety Research

Julien Etienne

Abstract In this chapter, I ask what climate change does to industrial safety and what that means for the future of industrial safety research. Climate change already leads to and will cause more Natech events, that much is clear. Whether industry can adapt to prevent those is not. Engineering voices have recently stated that a handful of industries will need to be upgraded to withstand extremes, because they cannot be stopped at will and because they are critical. By contrast, the economical and rational response elsewhere will be to shut down when environmental conditions are too difficult (e.g., during a heatwave) and restart after. When and why make those trade-offs are key questions for industrial safety researchers. Besides, how far critical infrastructures can be "climate-proofed" largely depends on adaptation limits: the point at which it is neither physically nor socially feasible to adapt anymore. As adaptation becomes a key issue for industrial safety, so do adaptation limits. The challenge of thinking about industrial safety and climate change grows further when one considers that much of what is ahead is unknown. The weather extremes we are experiencing are only an appetizer on the menu we have cooked for ourselves. That challenges industrial safety research to the core. It shatters our illusions of control. It undermines our understanding of safety as an outcome of human–technology interactions. To wake up to that reality means shedding old ideas and embracing others. That is uncomfortable. It exposes researchers to controversy and practitioners to challenge. No one said it was going to be easy.

Keywords Extreme weather · Natech · Shutdowns · Adaptation limits · Control

J. Etienne (✉)
Independent Consultant; Professional Fellow, Centre for Analysis of Risk and Regulation, London School of Economics and Political Science, London, UK
e-mail: julienetienne.consult@gmail.com

C. Bieder et al. (eds.), *Climate Change and Safety in High-Risk Industries*, SpringerBriefs in Safety Management, https://doi.org/10.1007/978-3-031-56995-1_3

3.1 What Does Climate Change Mean for Industrial Safety and Safety Research?

It would be naïve to assume that all who ask this question share the same understanding of what climate change is and entails. Some see climate change as an agenda, such as sustainability or net zero, before seeing it as a set of physical facts. They tend to understand it through the demands emerging from government, business, NGOs or consumers. When the physical reality of climate change is acknowledged and physical facts are at the forefront, its likely implications, all the way to the “climate endgame” of global catastrophe (Kemp et al. 2022), are too often ignored, despite being hammered out time and again by the United Nations, the IPCC and prominent scientists. In fact, the latter’s messages on the speed at which warming happens and the urgency of response are taken up at the margins of society only, but rarely at the center. That is true of academia too, outside climate and, more generally, Earth system sciences. There are politics at play, even a cultural war, as is most obvious in the USA. Those who speak of the worst impacts are often belittled or ostracized as radicals, ideologues or militants. Most persuasively, Bruno Latour has argued that climate change is at the heart of the political divisions that characterize the New Climatic Regime (Latour 2018).

Therefore, to address the question at the heart of this volume is to expose oneself to controversy. I will come back to that. But first, we need to think clearly, and for that, one needs to push aside emotions, interests (professional or otherwise), politics and the fear of social judgment and stay alert to the scourge of “the failure of imagination” that too many post-accident studies have noted.

3.2 What Climate Change Does to Industrial Safety

As I strive to follow these precepts, it seems to me that the core insights of climate science that matter most for our discussion are the following.

First, climate change—and other breaches of planetary boundaries (water cycle, nitrogen and phosphorus cycles, biodiversity, etc.)—is driven by the exponential growth of human activity. Many scientists argue, relying on empirical trends for support, that a “Great Acceleration” began in the 1950s (Lenton 2016; Steffen et al. 2015) and continues to this day, leading to ever greater impacts on the Earth system: greenhouse gas emissions, habitat destruction, soil erosion and biodiversity loss.

Second, climate change is a process unfolding at planetary scale: a complex, nearly closed system with profound inertia (e.g., Abraham et al. 2022). This means that, even if the emissions driving global warming were to stop altogether, the excess energy accumulated in the system to date remains there and the feedback processes it contributes to will continue to transform environmental conditions for centuries. This is what the IPCC calls “committed” climate change.

Third, key Earth system components that limit warming, either because they reflect solar energy back to space (ice caps) or absorb and/or store CO_2 (forests, permafrost), are failing rapidly because of the warming that has already happened. Some have likely passed critical thresholds already (McKay et al. 2022; Kim et al. 2023). As the Earth system passes these “tipping points”, major drivers of further warming emerge: positive feedback loops integral to the Earth system that humanity has no tested ability to influence.

These insights are crucial for making sense of current and future extreme weather trends. I am referring to how temperatures, wind, moisture, storms, droughts and other phenomena fluctuate much more frequently away from the mean, as a result of global warming (Rodell and Li 2023). Extreme weather also means aberrant events, outside the range of known human experience: tropical storms hitting Ireland (Ophelia, in 2017), a temperature high of 49.5 °C in British Columbia, Canada (Lytton, in 2021), the flooding of one third of Pakistan (in 2022), to name only a few. The three insights mentioned earlier imply that this trend will continue and worsen for decades to come and likely not in a linear fashion. The actual path is unknown, but we can be sure of ever greater fluctuations as time goes on.

3.2.1 How Can Safety Be Managed Given the Path of Ever Greater Fluctuations Anticipated by Climate Scientists, and Can It Be Managed at All?

It is worth dwelling first on the safety challenges *we can foresee*. Global warming makes multiple technological accident scenarios increasingly likely. Droughts pose significant challenges for industrial processes that need cooling. They reduce water supply in case of fire. Heatwaves raise cooling needs beyond design expectations. They affect workers’ capacity to carry out their tasks, to respond to unexpected events and therefore make human error more likely. Heatwaves may make stored substances that react exothermically more dangerous. Buckling rails and roads and melting tar may interrupt supply of raw materials but also make it more difficult or impossible for emergency services to reach a site in case of an accident. It could affect the structural integrity of site platforms. Droughts and heatwaves create conditions for wildfires that may reach industrial sites. Excessive air temperature makes it difficult and, beyond a certain point, impossible, for planes or helicopters to take off and fly at low altitude, also undermining emergency response capacity. Flooding and submersion may close off emergency routes, precipitate uncontrolled shutdown of hazardous processes, threaten the continuous cooling of certain stored materials (peroxides) by shutting down generators and lead to contamination of the wider environment if containment of hazardous substances is breached. High winds and storms can shut down power lines and damage buildings.

Ever more frequent and severe extreme weather events are projected to lead to increasingly frequent “Natech” events: technological accidents triggered by natural disasters (Mesa-Gomez et al. 2020; Piatyszek et al. 2017; Pilone et al. 2021). This is all the more likely as natural disasters are not only more frequent,[1] but several of them may hit a given area in close succession (e.g., drought, heatwave, wildfires, then flooding and landslide; De Ruiter et al. 2020). The climbing trend in Natech events is already perceptible in accident databases (e.g., Baraer 2021).

3.3 To Avoid Natechs, Should Hazardous Industries Shut Down or Upgrade?

In the UK, engineers, the chemical industry and industrial safety regulators have discussed these challenges in several recent publications (IMechE 2023; Environment Agency 2023; CIA 2021), offering tools and setting out recommendations. All state the urgent need for adaptation across hazardous industries.

The IMechE report focuses on cooling needs and how those could be addressed across sectors during heatwaves. It points out that the economics of adaptation will make it impossible to upgrade installations across all sectors. Indeed, it would be extremely onerous to install/upgrade and operate cooling systems across all the sectors that require them, so that they may withstand temperature highs of 50 °C or more. The authors expect instead that, in those sectors where shutdown is a relatively safe option, activity would stop for as long as very high temperatures last. The argument could be extended to other hazards associated with extreme weather. For example, it would not be possible for emergency services to tend to all industries and residential areas threatened by a major wildfire. There too, shutdown would be the economical response.

There are further dimensions to the unaffordability of adaptation. Ever more frequent and extended shutdowns will likely dampen the revenues of the businesses affected. That will, in turn, make the latter less financially capable of investing in adaptation as time goes by. The carbon neutrality agenda will add further pressure too: "some plants will have to close" (Pisani-Ferry 2021: 2).

Conversely, shutdown is both hugely onerous and hazardous in some sectors. Oil refining, gas processing and bulk chemical manufacturing are all process activities that operate continuously. The IMechE report sets them apart. Shutdown and restart at such facilities are complex, planned and can be highly hazardous: many process safety accidents at oil and gas, and chemical manufacturing facilities have happened during shutdown and restart (CSB 2021). Besides, they are also costly not only to the companies operating the sites but to the many third parties impacted. The IMechE report states that shutdown would not be the answer to extreme heat there. Instead, these facilities will need to adapt because "it is vital that their integrity and productivity is maintained in a future environment characterised by an overall increase in ambient temperatures and intense heat events" (IMechE 2023: 3).

---

[1] www.visionofhumanity.org/global-number-of-natural-disasters-increases-ten-times; accessed on 20 May 2023.

IMechE's report thus sets out a trade-off: some industries will shut down when it is too hot, while everything needs to be done to keep the others running. IMechE's report references the issue of criticality, though only briefly. And yet, it makes the point clearly: it will not be feasible to adapt all industries so that they may operate safely during heatwaves. This raises the key question of *who defines what is critical to keep operating safely while environmental conditions deteriorate, and why?* This, I argue, is an urgent question that safety researchers could help address.

3.4 Physical and Social Limits to Adaptation

IMechE's call for cooling upgrades at some industries raises the engineering and commercial challenge of upgrading or redesigning some facilities for extreme, never yet experienced conditions. This leads to the question of **adaptation limits**, a concept absent from the EA, CIA and IMechE's discussion, but increasingly present in the climate science literature (IPCC 2023). There are *physical* (e.g., temperature highs, sea levels) and *social* adaptation limits: points where risks become intolerable (Martin et al. 2022). These boundaries might seem far away. And yet, some of them, the IPCC reported in 2023, have already been reached (IPCC 2023).

There is the matter of **physical** limits: the IMechE report hints at engineers' goal of upgrading commercial installations so that they may withstand weather extremes beyond any design parameters in existence. How one feels about that challenge depends largely on one's core beliefs in human ingenuity, technological progress, engineering prowess and innovation. It is, however, also a matter of time. For how long can engineers push installations to withstand ever more chaotic and extreme conditions? Many, like Vaclav Slim, doubt that it would be possible to transform industry (and that implies both mitigation and adaptation) in the very short amount of time this transformation must happen.[2] In other words, it may be that social limits will be met *before* physical limits.

Social limits to adaptation are not only economic, but the economic limits alone are daunting. Upgrading equipment and shouldering the considerable energy consumption required to maintain operations during ever more intense heatwaves are already unaffordable to many. As conditions worsen, it will become unaffordable to more and more players. Climate-driven shutdowns will reduce revenue and increase costs, depleting returns. Stress on installations from extreme weather will lead to higher maintenance costs. Cost pass-through to customers will drive economic activity down.

[2] www.latimes.com/business/story/2022-09-05/the-energy-historian-who-says-rapid-decarbonization-is-a-fantasy; accessed on 20 May 2023.

As global warming progresses, more natural disasters will also hit installations, destroying some of them partially or entirely.[3] The mounting costs of natural disasters are well documented already (United Nations Office for Disaster Risk Reduction 2022). As they climb further, they will make insuring businesses against safety risks increasingly unprofitable, leading to insurer exit. This is seen already with homeowner insurance: “When risks increase, we should expect that insurers will retreat much faster than homeowners, as is happening now in California”.[4] While there have been calls for public–private partnership[5] to insure against climate change, state-backed insurance schemes in the USA have progressively been replacing private insurance schemes, taking on the liabilities private insurers now consider too big for them. Such liabilities add to the costs of climate disasters these states are bearing and will impact the credit worthiness of public entities in the eyes of lenders.

Already, least-developed countries cannot keep up[6] with the damage caused by extreme weather. Poor areas in wealthy countries hit by consecutive disasters (such as Kentucky in the USA) are running out of capacity to rebuild,[7] while some US cities are being bankrupted by climate disasters.[8] Wealthier regions will reach their limits too as the impacts and the costs of disasters increase.[9] Several economists have warned that the crippling costs of climate disasters could trigger sovereign debt crises (Dibley et al. 2021; Zenios 2022).

The limits to adaptation are therefore also limits to the many layers of infrastructures and resources that have historically cushioned hazardous industries against the consequences of disaster: capital, insurance and the state. As global warming progresses, such limits are being pushed forward, not back.

3.5 Interim Conclusion

The discussion so far has meant to reframe the industrial safety goal in the rapidly deteriorating environmental conditions of a changing climate:

---

[3] For example, wildfires have hit fossil fuel operations in Alberta in the Spring of 2023. www.nytimes.com/2023/05/17/climate/canada-wildfires-fracking-oil-gas.html; accessed on 20 May 2023.

[4] Testimony of Benjamin J. Keys, Ph.D., Hearing on “Risky Business: How Climate Change is Changing Insurance Markets”, United States Senate Committee on the Budget, March 22, 2023, page 5. Accessible at: www.budget.senate.gov/imo/media/doc/Dr.%20Benjamin%20J.%20Keys%20-%20Testimony%20-%20Senate%20Budget%20Committee.pdf.

[5] www.theinsurer.com/close-quarter/kunreuther-climate-change-uninsurable-if-left-to-the-private-sector-alone; accessed on 3 July 2023.

[6] www.bbc.co.uk/news/world-58080083; accessed 20 May 2023.

[7] www.nytimes.com/2022/07/30/us/kentucky-flooding-natural-disasters.html; accessed on 20 May 2023.

[8] www.nytimes.com/2021/09/02/climate/climate-towns-bankruptcy.html; accessed on 20 May 2023.

[9] www.forbes.com/sites/chloedemrovsky/2022/07/13/the-cost-of-disasters-is-increasing-in-2022/; accessed on 20 May 2023.

- Climate change means more frequent and intense extreme weather, increasing the likelihood of Natech events all around the globe.
- Continuous, safe operations in an increasingly chaotic and extreme environment require that installations be modified to withstand such conditions. Adaptation will be expensive to develop, install and operate, in a manner many businesses will find unbearable.
- Where adapting installations will not be feasible, temporary shutdown is the most likely response to the safety risks posed by extreme weather. Intermittent operations, with more frequent shutdowns and start-ups, will likely become the norm across many sectors.
- Since adaptation to enable continuous, safe operations will not be feasible across all industries, trade-offs need to be made, and "critical" industries defined.
- Social limits to adaptation could be reached before physical limits, as climate change undermines the institutions and depletes the resources (capital, insurance, state support) that have historically helped cushion industry against the consequences of disasters.

3.6 Away with the Illusion of Control (Again)

These insights, which can inspire the research agenda of safety scholars, speak to what we can foresee. Yet, there is considerable uncertainty on what ongoing changes to the Earth system—which have no known precedent—will lead to; for example, the ongoing slowing down of deep-sea circulation currents caused by the melting of freshwater ice caps on the poles could lead to *other* dramatic changes to weather patterns (Li et al. 2023). There is much about the fluctuations we will experience soon that we do not know about. That, and the horizon of unstoppable warming climate science has drawn, has further, even more fundamental implications for safety research and how we answer the question: *how can safety be managed given the path of ever greater fluctuations anticipated by climate scientists, and can it be managed at all?*

Philosopher Pierre Caye (2008) has argued that our ever more chaotic world renders our morality obsolete, because that is a morality of mastery and control: either our own mastery or control or that exercised by others whom we depend on and trust (engineers, risk managers, regulators). That morality crumbles when we cannot take the stability of the world for granted anymore. Its claim to making sense of our place in the world weakens when our ability to effectuate our intent diminishes; when our aims to build and repair are denied by the elements relentlessly; and when the space in which we effectively have control shrinks as climate change presses us ever more closely against the wall of adaptation limits.[10]

[10] Caye writes (my translation): "Initially powerless in the face of nature, man is arriving now to experiencing his own powerlessness towards his own actions, as if his quest for mastery and domination was eternally doomed to fail" (2008: 20).

Safety research uses concepts that speak to ideals of control: "safety performance", "high reliability", "safety management systems", "layers of defense" and "human error". It is not that safety scholars believe in absolute safety: from normal accidents (Perrow 1984) and the limits of safety (Sagan 1993) to epistemic accidents (Downer 2019), we know that "accidents happen". And yet, safety research (or safety science) has been about understanding what makes man-made systems safe and identifying ways they can be made safer. If we cannot anchor our understanding of safety in the idea of control, then we need a new morality, one for a fluctuating, unstable world. More than ever, "to manage is not to control" (Landau and Stout 1979). And that morality needs a new perspective on the world, for we are not prepared for it. To quote Karl Weick, we need to "drop our tools", stop "hold[ing] onto concepts, checklists, and assumptions that (…) weigh [us] down, reduce [our] agility, and blind [us] to what is happening right here and now and how [we] can cope with it" (Weick 2007: 6).

The authors of the IMechE report recognize this, to an extent, when advocating for momentous change to teaching at engineering schools and departments. They write: "current technical training and education provision for engineers was designed on the assumption of a climate-stable future" (IMechE 2023: 58). That future being forfeit, training and education for engineers need to be redesigned, this time for a rapidly warming climate. Mechanical engineers are not the only ones asking themselves fundamental questions about the way they think, research and teach. In a rich introspective piece and a completely different field, the International Law Association (2023) has also asked itself, among other things, whether it should embrace an Earth system's perspective: a striking departure from a purely legal perspective on the world.

3.7 Letting Go of False Ontologies

Safety research is about a man-made world in which technology and humans interact against a passive décor. That "ontology" was wrong already 30 or 40 years ago, when leading contributions to the field were produced: the décor, then as now, was determined by complex processes, which sustained and regulated the conditions for human existence, and therefore industry too. We ignored and did not understand those processes. And yet, "like it or not, and whatever we may do to the total system, we shall continue to be drawn, albeit unawares, into the Gaian process of regulation" (Lovelock 2016: 120). An ontology that assumes the physical world is passive and malleable at will is obviously wrong today, because the décor is clearly no longer passive. It is no décor. As Latour, among others, has put it, it is an actor that re-acts to what we humans do, in ways that, so to speak, put us back in our place.[11]

[11] "The Earth system reacts henceforth to your action in such a way that you no longer have a stable and indifferent framework in which to lodge your desires for modernization" (Latour 2018: 84).

Hence, there is a case for us in the safety research community—engineers, sociologists, ergonomists, political scientists, organization scientists and more—to embrace Earth system science (Lenton 2016) too. Earth system science challenges our ways of seeing and thinking the world. Bruno Latour, among others (e.g., Tsing, Haraway, Stengers, Morton), has written essential pages on what this entails, that I will not parrot here.

There is not only an intellectual case to embrace Earth system science. There is also a necessity, for, let us face it, we are not choosing to let climate change into our work and lives. Rather, climate change forces itself on us. Latour was keen to highlight that climate change is a power that the 175 states signatories of the 2015 Paris accord reckoned with, or else they would not have signed that treaty. The IMechE, CIA and EA reports all show how engineers, chemical industry businesses and regulators are facing to the facts, in their own way.

3.8 Preparing for Controversy

This leads me to a few final thoughts about the future of safety research. Researchers pride themselves on their distance from politics. Controversies abound in academia, but academic controversies are not the same as political controversies, and scholars have generally steered from the latter to avoid being considered militants. Yet, the idea that scholars, whichever discipline they affiliate themselves to, can avoid being drawn into political controversy on the matter of climate change is foolish. The considerable sums of private money that have been spent on discrediting climate science, by entities which had full knowledge of climate change based on their own, internal research, amply demonstrates this.[12] The politicized responses to the flurry of studies demonstrating ever more rigorously the role of various human activities in climate change and biodiversity loss further illustrate how inescapable the politicization of climate science is.

At a minimum, safety researchers working on climate change issues need to prepare for controversy, and that, inevitably, means reflecting on whether safety research contributes or not to perpetuating the root causes of climate change. Indeed, the core industries safety researchers have worked on are at the heart of the problem. Fossil fuel extraction and processing play an outsized role in driving climate change, ocean acidification and aerosols pollution. Fossil fuels and chemical processing drive the dramatic overshooting of the recently measured planetary boundary for novel entities (Persson et al. 2022). The chemical industry together with mining plays also a major role in the breakdown of biogeochemical flows (principally phosphorus and nitrogen). Transportation contributes greatly to aerosols pollution and, for air travel in particular, climate change.

[12] Latour (2018).

From an Earth system's perspective, these industries are responsible for overshooting the planetary boundaries that define the safe conditions for human existence. This, in turn, transforms how we safety researchers have understood, after Rasmussen (1997), the boundaries of safe operations, and how we as a community define (and defend) safety.

3.9 If Research Shifts, Will Practice Too?

This chapter has dealt with the future of industrial safety research. But what about the future of industrial safety practice?

The implications of climate change for practitioners, in terms of risks and operational decisions, are here. In the Summer of 2023, the Hawaiian wildfires led utilities in several US states (including California) to announce they would henceforth shut down the electrical grid when conditions would be ripe for wildfires (as they were in Hawaii). Pre-emptive shutdown has arrived and will inevitably spread.

It is not unusual in industry to occasionally stop activity to manage the ebb and flow of demand. Shutting down some or all production activity for safety and maintenance reasons is also frequent, though this would generally be scheduled and managed to avoid or minimize interfering with commercial operations. Shutdown commanded by extreme weather events will interfere with demand and commercial operations, however. And that puts safety engineers in a peculiar position toward their production colleagues, leading to potentially tense and unpleasant conversations.[13] Learning to live with extreme weather within industry will therefore have to be a cross-company thing. It cannot be just the safety staff that educate themselves to the new world. Production staff too needs to be brought up to date. Emergency services may well prove an ally here: they too can clarify for all at an industrial site that, in an extreme weather situation, one that potentially triggers compounded disasters (e.g., an extreme heatwave causing wildfire, water scarcity and infrastructure failure), they would have their hands full and possibly tied.[14] Their ability to respond to an industrial accident would be limited.

I have argued that, in the face of climate change, industrial safety researchers will need to turn away from obsolete ideas about control and safety and embrace Earth system science. If researchers turn, will practitioners follow? This is very much for practitioners to decide: whether they choose to live in a fantasy world, one where safety is a product of humans interacting with man-made technology, or in the real world, where it is an outcome of man pushing and nature shoving back, harder.

---

[13] It also puts industry as a whole in a peculiar situation toward investors and shareholders.

[14] Emergency services' capacity to intervene will be limited by the stress put by environmental conditions on infrastructures (e.g., buckling rails, melting tar), vehicles (helicopters less able to lift up and fly in hotter air conditions) and personnel.

References

J. Abraham et al., The ocean response to climate change guides both adaptation and mitigation efforts. Atmos. Ocean. Sci. Lett. **15**(4), 100221 (2022)

A. Baraer, The impact of climate events on French industrial facilities between 2010 and 2019. Loss Prev. Bull. **277**, 19–22 (2021)

P. Caye, *Morale et chaos. Principe d'un agir sans fondement* (Editions du Cerf, 2008)

CIA, *Safeguarding Chemical Businesses in a Changing Climate*, 2nd edn. (Chemical Industries Association, 2021)

CSB, *Safety Digest: CSB Investigations of Incidents During Startups and Shutdowns* (US Chemical Safety and Hazard Investigation Board, 2021)

M.C. De Ruiter et al., Why we can no longer ignore consecutive disasters. Earth's Future **8**(3), e2019EF001425 (2020)

A. Dibley, T. Wetzer, C. Hepburn, National COVID debts: climate change imperils countries' ability to repay. Nature **592**, 184–187 (2021)

J. Downer, On ignorance and apocalypse: a brief introduction to 'epistemic accidents', in *Safety Science Research: Evolution, Challenges and New Direction*, ed. by J.-C. Le Coze, 1st edn. (CRC Press, 2019)

Environment Agency, *Climate Change: Risk Assessment and Adaptation Planning in Your Management System. Guidance* (Crown Publications, 2023)

IMechE, *Adapting Industry to Withstand Rising Temperatures and Future Heatwaves* (Institution of Mechanical Engineers Report, 2023)

International Law Association, *White Paper 02: Anthropocene* (ILA, Paris, 2023)

IPCC, Sections, in *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. by Core Writing Team, H. Lee, J. Romero (IPCC, Geneva, Switzerland, 2023), pp. 35–115

L. Kemp et al., Climate endgame: exploring catastrophic climate change scenarios. PNAS **119**(34), e2108146119 (2022)

Y.H. Kim et al., Observationally-constrained projections of an ice-free Arctic even under a low emission scenario. Nat. Commun. **14**(3139) (2023)

M. Landau, R.S. Stout Jr., To manage is not to control: or the folly of type II errors. Public Adm. Rev. **39**(2), 148–156 (1979)

B. Latour, *Down to Earth: Politics in the New Climatic Regime* (Polity Press, 2018)

T. Lenton, *Earth System Science: A Very Short Introduction* (Oxford University Press, 2016)

Q. Li et al., Abyssal ocean overturning slowdown and warning driven by Antarctic meltwater. Nature **615**, 841–847 (2023)

J. Lovelock, *Gaia* (Oxford University Press, 2016) (original edition 1979)

M.A. Martin et al., Ten new insights in climate science 2022. Glob. Sustain. **5** (2022)

D.I.A. McKay et al., Exceeding 1.5°C global warming could trigger multiple climate tipping points. Science **377**(6611) (2022)

A. Mesa-Gomez, J. Casal, F. Munoz, Risk analysis in Natech events: state of the art. J. Loss Prev. Process Ind. **64**, 104071 (2020)

C. Perrow, *Normal Accidents* (Princeton University Press, 1984)

L. Persson et al., Outside the safe operating space of the planetary boundary for novel entities. Environ. Sci. Technol. **56**(3), 1510–1521 (2022)

E. Piatyszek et al., Natech events triggered by floods: when floods cause technological accidents. Floods **1**, 73–87 (2017)

E. Pilone et al., Climate change and NaTech events: a step towards local-scale awareness and preparedness. Saf. Sci. **139**, 105264 (2021)

J. Pisani-Ferry, *Climate Policy Is Macroeconomic Policy, and the Implications Will Be Significant*. Policy Brief 21-20 (Peterson Institute for International Economics, 2021)

J. Rasmussen, Risk management in a dynamic society: a modelling problem. Saf. Sci. **27**(2–3), 183–213 (1997)

M. Rodell, B. Li, Changing intensity of hydroclimatic extreme events revealed by GRACE and GRACE-FO. Nat. Water **1**, 241–248 (2023)

S. Sagan, *The Limits of Safety* (Princeton University Press, 1993)

W. Steffen et al., The trajectory of the Anthropocene: the great acceleration. Anthr. Rev. **2**(1) (2015)

United Nations Office for Disaster Risk Reduction, *Global Assessment Report on Disaster Risk Reduction 2022: Our World at Risk: Transforming Governance for a Resilient Future* (Geneva, 2022)

K.E. Weick, Drop your tools: on reconfiguring management education. J. Manag. Educ. **31**(1), 5–16 (2007)

S.A. Zenios, The risks from climate change to sovereign debt. Clim. Change **172**(30) (2022)