A safety-critical systems approach to analysing, managing and explaining climate change and other complex socio-ecological problems

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Abstract

Massive socio-ecological problems like climate change are difficult to model because they involve multiple interacting systems with complex, non-linear dynamics. The resulting scientific uncertainty is used by sceptics to confuse public discourse and delay mitigation. We urgently need both better models and clearer ways of explaining the global environmental emergency.

Many diverse arenas (e.g. medicine, energy, aerospace and defence) have developed systems-based methodologies for assessing risks and managing critical, complex projects ranging from emergency surgery to space stations.

For example, aerospace design starts with establishing critical parameters for safe operation. The "Safety Case" determines design requirements. "Mission Assurance" methodologies are then used to build, operate and maintain vehicles to standards that ensure that essential human and mechanical systems always function within wide safety margins. Similar proactive risk management methods can be applied to critical socio-ecological problems.

The first step is to define the critical biophysical and social parameters of a sustainable global system. We can then assess major environmental, economic and social trends in terms of whether they support or threaten systemic viability. This will indicate if essential parameters will be breached and determine the likely timelines and impacts of these tipping points. Multiple trends and their relative strengths can then be modelled using a combination of causal-loop diagrams and force-field analyses. This will allow us to understand the implications of cross-sectoral interactions, including the probability and impacts of disruptive, non-linear events.

This approach reframes climate change as a security issue. It focuses attention on managing dangerous risks and ensuring a safe future. While it will not eliminate all uncertainties, it will help clarify risks, timelines, costs and options, and assist policy-makers in understanding and explaining both dangers and opportunities.

Keywords: safety, critical, risk, complex systems, non-linear, timelines, parameters, climate change, tipping points, sustainable, socio-ecological, proactive design, reframe.

The need for a new approach

The problem

UN Secretary-General Ban-Ki Moon warns about “the gathering threat of climate change”:

> Scientists have long sounded the alarm. Top-ranking military commanders and security experts have now joined the chorus. Yet the political class seems far behind.
>
> You all know the potential consequences. A downward global spiral of extreme weather and disaster…. Fragile states tipping into chaos.
>
> Yet greenhouse emissions are rising faster than ever…. If we continue along the current path, we are close to a 6 degree increase.
>
> Too many leaders seem content to keep climate change at arm’s length, and in its policy silo. Too few grasp the need to bring the threat to the centre of global security, economic and financial management (Moon 2013).

Adaptation, although necessary, will not prevent dangerous climate change (Ackerman & Stanton 2013). We risk passing irreversible tipping points, such as the loss of Arctic sea-ice (Livina & Lenton 2012), the release of methane from permafrost (Schuur & Abbott 2011) and ocean acidification (Hönisch 2012).

Mitigation options are rapidly shrinking (Stocker 2013). The International Energy Agency states: “If action to reduce CO2 emissions is not taken before 2017, all the allowable CO2 emissions would be locked-in by energy infrastructure existing at that time” (IEA 2012).

International intervention is urgently needed. However, because most decision-makers fail to understand the gravity of the global emergency, the political will to act is missing.

Systemic resistance

Efforts to regulate greenhouse gases have been unable to replicate the success of the 1989 Montreal Protocol on Substances that Deplete the Ozone Layer. Despite many high-profile international conferences and the warnings of peak international organizations (Richardson 2012), concern about environmental issues is lower than 20 years ago (GlobeScan 2013).

Why?

Doug Miller, chairman of GlobeScan, says "Evidence of environmental damage is stronger than ever, but our data shows that economic crisis and a lack of political leadership mean that the public are starting to tune out" (Masters 2013). Climate change is increasingly viewed as a conflict between economic and environmental interests (McKibben 2012). As a consequence more and more politicians are avoiding the issue as politically divisive (Pielke 2012). For example it was not mentioned in the 2012 US presidential debates (Elver 2012).

The need to aim for a safe climate

Many studies have been done on the economic, institutional and cultural factors blocking constructive intervention (e.g. Figueres & Ivanova 2002, Jinnah et al. 2009, CRED 2009, Goldenberg 2013). But is systemic resistance enough to explain why decades of work by thousands of scientists have failed to alter the current trajectory of climate change? Kevin Anderson and Alice Bows suggest that although the dangers are well known, most policy-makers are not advancing realistic solutions:

> [W]hile the rhetoric of policy is to reduce emissions in line with avoiding dangerous climate change, most policy advice is to accept a high probability of extremely dangerous climate change rather than propose radical and immediate emission reductions (Anderson & Bows 2011, p. 40).

The consequence of avoiding realistic emission targets is clear. The International Energy Agency warns: "If we don't change direction soon, we'll end up where we're heading" (International Energy Agency 2011). It should be equally obvious that we will never achieve a safe climate unless we aim for one. To do this we must make safe, viable outcomes our goal and priority.

If current methods are ineffective, then new methods are required. With time running out, we now need to challenge not only 'business as usual' in governments and industry, but also the 'business as usual' mental models and methods of scientists.

Using a safety-critical approach

Managing risk

Climate change is not only humanity's "greatest market failure" (Benjamin 2007), but also our greatest failure in risk management. Although sophisticated tools for evaluating and managing risk are used in many arenas (e.g. aviation, insurance, finance, health, project development), we are not applying the same methods and standards to humanity's biggest risks—the potentially catastrophic threats posed by climate change (FAO 2011) and other major socio-ecological problems (such as the loss of biodiversity and growing resource shortages).

Large global problems are frequently viewed as too complex to allow risk to be accurately evaluated, let alone managed. However, Nick Mabey and his colleagues argue:

> Public policy decisions (ranging from military procurement, to interest rates, to financial system regulation) are taken under higher levels of uncertainty than exists over climate change science, impacts or policy choices. In fact the range of uncertainty in climate change is generally smaller than that common in long-term security analysis (Mabey et al, 2011).

The enormous cost of mitigation is also seen to be a barrier to managing climate change risk. This view is countered by Frank Ackerman and Elizabeth Stanton:

> Protection against threats of incalculable magnitude – such as military defense of a nation's borders, or airport screening to keep terrorists off of planes – is rarely described as "too expensive." The conclusion that climate policy is too expensive thus implies that it is an option we can do without, rather than a response to an existential threat to our way of life. (Ackerman & Stanton 2013)

Political priorities can rapidly shift when leaders believe that there is a threat to national security. Whole economies can be mobilised to meet emergencies, as occurred in the Second World War, when many nations allocated 40%-75% of their GDP to military production. Following the '911' attack on the United States, and the global financial crisis of 2008, politicians quickly overcame normal budgetary constraints, allowing trillions of dollars of new funds to be accessed.

Most decision-makers are unlikely to take urgent action on climate change unless it is framed as a security threat (i.e. reframed from being a primarily environmental issue). They—and the public—

need to understand that dangerous climate change is not only the greatest threat to the long-term survival of their societies but also a short- and medium- term threat to economic and social stability.

To frame climate change (and other interacting complex socio-ecological problems) as a security emergency, policy advisors will have to focus on risk assessment and management: identifying both dangerous threats and the requirements for safe outcomes.

Fortunately, proven tools for managing risk and ensuring safe, viable outcomes already exist.

Ensuring safe outcomes

Fields such as aerospace, medicine, business, energy and defence have sophisticated, proven methods for analysing complex problems, managing risk and ensuring safe outcomes (e.g. Bowen & Stavridou 1993, Fowler 2004, U.S. Department of Defence 1993). Many of these "best practices" can be usefully applied to managing complex socio-ecological issues where safe, viable outcomes are essential.

For example, when designing or modifying an airplane or space vehicle, aerospace engineers begin by establishing the critical parameters for its safe operation – the "Safety Case". The Safety Case determines the design requirements. "Mission Assurance" methodologies are then used to build, operate and maintain the vehicle to standards that ensure that essential human and mechanical systems always function within wide safety margins (Alberts & Dorofee 2005).

We should take a similar safety-critical approach to designing a safe future for humanity. We need to start with a complex systems approach that establishes the critical biophysical and social parameters of a sustainable global system; then use this Safety Case to determine its design requirements; and then use Mission Assurance methods to strengthen systemic resilience (Evans & Steven 2009) and ensure that every critical element always functions within wide safety margins (Smith 2006).

Managing crises—the Apollo 13 example

The story of the 1970 Apollo 13 moon mission demonstrates how a safety-critical approach can be used to manage an emergency. After an oxygen tank exploded, the spacecraft's life-support systems began to fail. NASA's challenge was to devise a way to keep the astronauts alive and return them safely to Earth. Their successful crisis management approach can be summarised as:

- First determine the essential requirements for mission viability;

- Then determine critical timelines;
- Then determine available resources;
- Then design a solution that restructures available resources within the required timeframe to meet critical mission requirements.

The current global emergency is similar in nature to the Apollo 13 crisis. Spaceship Earth's life-support systems are failing and we also need to rapidly reconfigure existing resources in order to re-establish a safe, livable environment.

Unfortunately, unlike Apollo 13, Spaceship Earth does not have a proactive management team that is united around the goal of ensuring safe outcomes. Reactive, piecemeal methods based on obsolete mental models prevent us from recognizing the severity and immanence of the global emergency, let alone manage it (Taylor & Taylor 2007, Evans & Steven 2009).

Modeling for risk management

Because humanity has no experience of likely future climates, risk management must be forward-looking and proactive. Ian Dunlop warns: "It should not rely on backward-looking historical analysis as a guide to action, as we are currently doing, otherwise it will be too late to prevent irreversible catastrophic outcomes." (Dunlop 2013)

More holistic models are needed that have the ability to better integrate and analyse environmental, economic and social interactions (UNEP 2012). We also need to improve our ability to forecast and evaluate both slow onset, long-term events (FAO, 2011), and non-linear developments and tipping points.

A whole-systems approach does not involve modeling everything (Sterman 2000), but rather developing a comprehensive model of (only) the environmental, economic and social factors critical to the understanding and management of dangerous climate change.

The first step is to define the critical biophysical and social parameters of a sustainable global system (Folke 2013, Raworth 2012). We can then use evidenced-based probabilistic methods to assess whether major trends support or threaten systemic viability. This will indicate if essential parameters will be breached and determine the likely timelines and impacts of these tipping points. Multiple trends and their relative strengths can be integrated into a general model with causal-loop diagrams (Maani & Cavana 2004) and force-field analyses.[1] This will help clarify the implications of cross-sectoral interactions, including the probability and impacts of disruptive, non-linear events.

Understanding likely trends, timelines, tipping points and consequences will allow us to evaluate possible policy options and their costs and benefits; and from this determine optimal leverage points, intervention strategies and policies (Marten 2008). This approach focuses attention on strategic threats and what must be done to ensure a safe future. It will not eliminate all uncertainties, but it will highlight major dangers and opportunities and clarify risks. [My methodology applies diagnostic principles used in emergency medicine (e.g. Bosker et al, 1996) to the analysis of critical, complex socio-ecological issues.]

After the critical requirements for sustainable socio-ecological outcomes have been determined, backcasting can be used to design structures and processes capable of meeting these requirements. [This approach applies standard outcomes-based architectural and engineering design methods (e.g. Smith 2006, Birkeland 2008) to the proactive management of socio-ecological problems.]

These new methods can be integrated with proven business, industrial and defence approaches—e.g. scenario simulation (Gilad 2008, Herman & Frost 2008, Schwarz 2009) to help decision makers better understand complex socio-ecological problems and design sustainable solutions.

The need for a transformational narrative

Climate mitigation requires a paradigm shift in the way we produce and consume energy and other resources—the cultural, economic and technological transformation of our consumer society to a conserver society (Taylor 2008). This will not happen until people are convinced that change is both necessary and beneficial.

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[1] Methods such as 'story and simulation' and cross-impact balance analysis (Kosow 2011) can also be used to help combine quantitative and qualitative metrics and create consistent scenarios.

In particular climate change must be reframed in terms of superordinate goals (common needs and values) capable of bridging the current environmental/economic divide. To reduce their resistance to change, vested interests also need to be provided with constructive alternatives (Taylor 2013).

Conclusions

This approach is proactive rather than reactive. It recognizes that current methods and structures are failing to solve 'wicked' environmental and social problems. It starts by examining what is necessary to prevent potentially catastrophic risks rather than what is presently possible. Climate change is reframed as humanity's greatest security threat. Proven safety and mission critical methods are used to manage critical socio-ecological problems and ensure safe, viable outcomes (Sheard & Mostashari 2008, Sage & Rouse 2009).

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