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Research Article

Navigating Uncertainty: A Framework for Measuring Extremely Rare and Unprecedented Events with Civilization-Destroying Potential

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Abstract: Extreme catastrophic risks—those with very low probability yet the potential to cause human extinction—defy conventional risk-management methods that depend on historical data. To address this gap, we introduce the Extreme Catastrophic Event Model, a structured quantitative scorecard that evaluates threats along two orthogonal dimensions: understanding (how well we grasp an event's mechanisms, evidence base, and potential impacts) and controllability (our capacity to prevent, influence, or respond). Each dimension comprises seven factors—ranging from historical occurrence and analogous events to monitoring systems and feedback mechanisms—scored on a 0–2 scale. We applied the model to nine prototypical scenarios, including supervolcano eruptions, engineered pandemics, nuclear war, AI takeover, asteroid impacts, runaway climate change, gamma-ray bursts, alien contact, and self-replicating nanotech ("grey goo"). Cluster analysis of the resulting scores revealed two groups: one of moderately understood, partially controllable risks, and another of highly speculative, virtually uncontrollable threats. By quantifying epistemic uncertainty and intervention potential, this framework offers policymakers and researchers a tool for prioritizing resources, guiding mitigation efforts, and identifying critical research needs for existential-scale dangers.

Keywords: Risk; Risk Management; Catastrophic Risks.

1. Introduction

The paradox of modern technological evolution lies in its capacity to deliver both salvation and annihilation. While society capitalizes on breakthroughs in artificial intelligence (AI), nuclear physics, robotics, and genetic editing, we are inadvertently engineering our own vulnerabilities. Examples are not difficult to find. Algorithmic intelligence, if insufficiently aligned, threatens to supersede human decision-making entirely, whereas advances in synthetic biology raise the probability of an accidental release involving agents of catastrophic transmissibility. Nuclear capabilities continue to hold the world hostage, while the emerging field of micro-robotics threatens us with the uncontrolled replication of 'grey goo'. It is no longer sufficient to treat these threats as fiction; they necessitate a framework of rigorous, scientific quantification [1].

Conventional risk paradigms, for all their utility in standard contexts, remain dangerously tethered to the retrospective analysis of historical frequency. They work well when probabilities are known and effects can be measured [2], but they break down when used to describe existential disaster. The very nature of unprecedented threats—ranging from a biosphere-sterilizing asteroid strike to first contact with extraterrestrial intelligence—defies the actuarial logic of standard models. In this empirical vacuum, where historical data is non-existent [3; 4], traditional frameworks do not merely struggle; they fail to provide any meaningful quantitative foothold, exposing a critical methodological void.

The existing literature underscores considerable limitations in addressing extremely rare catastrophic risks, variously indexed in scholarship as "existential risks," "black swan events," or "global catastrophic risks". These limitations primarily arise from inadequacies in methods suited to scenarios lacking reliable frequency data or precise impact measures. Conventional financial and risk models thus inadequately address these extreme events, frequently resulting in significant risk mispricing, poor strategic planning, and inadequate mitigation strategies [1; 2].

This creates a conspicuous analytical void: the absence of rigorous, quantitative mechanics designed specifically for the measurement of unprecedented catastrophe. Remedying this scarcity is indispensable, not only for hardening societal resilience but for calibrating our strategic posture against extinction-level threats. Motivated by this urgency, the central line of inquiry driving this work is formulated as follows: How can we quantitatively evaluate risks with no historical precedent?

To resolve this, we pursued a two-pronged objective. First, we built the 'Extreme Catastrophic Event Model'—a framework designed to function in a complete data vacuum, independent of historical probabilities. Second, we forced this architecture to confront a set of specific existential threats to prove its practical value. The core of our method is a scorecard tailored for uncertainty. It breaks risk down into two tangible dimensions: understanding (gauging how well we grasp the causality and impact despite the lack of precedent) and controllability (measuring our actual capacity to intervene via warnings or mitigation).

The intersection of these metrics converts abstract uncertainty into a navigable map. This forces a departure from reliance on instinct, allowing decision-makers to anchor their strategies in the tangible concept of controllability. By offering a structured way to handle the 'empirical void' of existential threats, the model bridges a critical gap in modern risk management.

Our primary contribution lies in constructing a quantitative framework where none existed before: specifically for events that are unprecedented and devoid of historical data. Unlike studies that remain purely theoretical, we force this model to work against real-world scenarios to prove its validity. By converting qualitative fears into quantitative scores, the research offers policymakers a concrete tool—not just speculation. This allows for a more rational distribution of resources, giving stakeholders a way to measure risks that were previously considered unmeasurable.

The structural logic of the paper is straightforward. We begin in Section 2 by reviewing the literature to show exactly where current risk models fail when facing unprecedented events. Section 3 then builds the solution: the Extreme Catastrophic Event Model. To prove this framework has merit, Section 4 applies it to a diverse set of catastrophic scenarios—from natural disasters to AI risks. The work concludes in Section 5, where we summarize the implications and openly discuss the limitations of our approach.

2. Literature Review

The concept of catastrophic events characterized by very low probability but extremely high impact has attracted considerable interest across various disciplines, particularly within the field of risk management. Such events are referred to in the literature as "existential risks," "black swan events," or "global catastrophic risks." Although closely related, these terms differ significantly in their implications.

Bostrom and Cirkovic [5] defines "existential risks" as threats to humanity's existence or events that could cause irreversible global harm, which would have a profound and permanent repercussions for the future of human civilization. The Future of Life [6] expands on this, asserting that existential risks are capable of completely eradicating humanity or permanently impairing civilization. The Stanford Existential Risk Initiative emphasizes understanding and reducing these threats [1].

Taleb [2] introduces the concept of "black swans", emphasizing their highly improbable nature combined with severe consequences. These events effectively dismantle standard risk frameworks because they exist outside the bell curves that analysts rely on. While Taleb originally anchored his theory in financial markets—using the 2008 crash to show how systems get blindsided—these economic shocks, however violent, serve only as a prelude.

Stanford Existential Risk Initiative Official Website [7] extensively analyzed global catastrophic risks, systematically identifying scenarios capable of inflicting extensive global harm. Wyluda [8] categorizes these risks into distinct groups: biological (genetic engineering, revival of extinct species), technological (artificial intelligence, internet malfunction), environmental (climate change, volcanic eruptions), social (nuclear devastation, societal collapse), and cosmic (asteroid impacts, extraterrestrial life encounters). Crucially, many of these catastrophic risks lack historical precedence. They possess no historical footprint to analyze via traditional actuarial models.

When historical data fails, analysts often turn to Game Theory. This is best illustrated by the 'Prisoner's Dilemma' by [9]. This model was not merely theoretical; it effectively decoded the Cold War, demonstrating how the terrified rationality of mutually assured destruction creates a stable equilibrium [5; 8]. Conversely, when the threat is environmental rather than political, Scenario Analysis substitutes historical data with narrative simulation [9]. This approach allows researchers to 'pre-live' disasters—such as the atmospheric collapse following a supervolcano—mapping out societal repercussions like volcanic winters before they ever manifest in reality [10].

Standard linear equations often fail to capture the inherent chaos of catastrophic events. Consequently, Monte Carlo simulations Rubinstein and Kroese [11] are used to replace static predictions with iterative probabilities. By generating thousands of scenarios based on varied assumptions, this method reveals the full range of potential outcomes. In the context of asteroid impacts Rubinstein and Kroese [11], the framework avoids producing a single forecast; instead, it maps the full envelope of possible trajectories to calculate the statistical density of collision risk.

Sensitivity Analysis serves a function far more critical than simple validation. It acts as a structural stress-test. The objective is not to prove the model works, but to identify where it fails, allowing analysts to pinpoint the precise thresholds of instability. By intentionally varying key inputs—essentially asking 'what if this parameter is wrong?'—analysts can identify exactly which variables drive the most extreme outcomes. This approach is particularly visible in epidemiology [11; 12]. In these studies, the focus shifts from predicting a single future to understanding how sensitive the virus's spread is to specific changes, such as different intervention strategies.

Risks rarely exist in a vacuum and Network Analysis can help to analyze the structural dependencies in a given system [13]. Rather than viewing threats as isolated incidents, this method reveals 'contagion paths'—showing how a localized disruption can rapidly metastasize into a system-wide collapse [11].

However, these standard instrumentalities hit a methodological wall when applied to the 'zero-data' problem of unprecedented catastrophes. While Geiger [14] attempted to measure risk sensitivity through elasticity coefficients, and [15] provided a philosophical synthesis of existential threats, the existing literature stops short of offering a mechanical framework capable of operating without historical statistics.

To bridge this chasm, recent methodological explorations have turned toward semi-quantitative scorecard frameworks. Far from being simple survey tools, these mechanisms serve to operationalize expert judgment. They function as a translation layer, transmuting qualitative assessments (e.g., categorical states of readiness) into composite numerical metrics. This approach explicitly rejects the pretense of statistical prediction in favor of a structured evaluation of latent risk, making it uniquely suited for scenarios where empirical data is nonexistent.

The scorecard approach was applied to various risk management problems, but the literature lacks broad application to existential risk problems. For example, Calandro and Lane [16] introduced the Enterprise Risk Scorecard, designed explicitly for systematically measuring, managing, and communicating organizational risks. This utility extends to the digital sector as well. Fischer [17], for instance, re-engineered the standard Balanced Scorecard—moving it beyond simple performance tracking to ensure IT risk protocols speak the same language as organizational strategy. The fusion of performance metrics with risk protocols is perhaps best articulated by Beasley ,Chen [18], who found that intertwining the Balanced Scorecard (BSC) with Enterprise Risk Management (ERM) creates a tangible uplift in organizational resilience. Cruz [19] applies this method to operational risk measurement. Olson and Wu [20] highlight the malleability of the framework, proving it can be stretched to accommodate diverse risk indicators without breaking strategic focus.

This framework has found fertile ground in credit risk modeling. The argument put forth by Srivastava [21] is that financial data tells only half the story, requiring a scorecard to capture the 'unquantifiable' elements of a borrower's profile. Dealing with the mechanics of this, Huang and Scott [22] navigate the trade-offs between technical validity and user acceptance.

More recently, the methodology has gained a temporal dimension. By grafting logistic regression onto survival analysis by Menzies ,Saint-Hilary [23], researchers can now predict not just the probability of a risk event, but its timing. This advanced modeling, as noted by Oliveira [24] and Cheng ,Humphreys [25], provides the kind of granular foresight necessary to inform high-level managerial judgment.

The literature also reflects a growing trend towards Multi-Criteria Decision Analysis (MCDA), particularly in healthcare and pharmaceutical sectors, where various weighted criteria are systematically aggregated into comprehensive risk or benefit scores. Additionally, methodologies for emerging technological risks, such as nanotechnology, have employed qualitative and quantitative scoring frameworks to effectively manage environmental and health hazards [26]. We were not able to find a similar scorecard approach for measuring extreme catastrophic events. The method has been applied many times in the context of risk on many similar subjects. Due to the lack of data about very rare risks, the scorecard approach can be very useful in providing some measures for such risks. In the methodology section, we described the reasoning behind the scorecard approach. This study directly addresses this critical gap by proposing and validating a novel scorecard model explicitly tailored for measuring unprecedented catastrophic risks. It thereby significantly contributes to the existing body of knowledge and enhances strategic risk management practices.

3. Methods

The methods presented earlier have serious limitations when analysing extreme catastrophic events. Traditional risk assessment models often rely on quantifying probability and impact, which may be difficult or impossible to apply to this type of risk due to the lack of reliable data. We propose a model that measures extreme catastrophic events to address the challenges. The model is based on two key metrics:

- Understanding - measures how well we comprehend the risk.
- Controllability - measures the ability to influence or manage the risk.

The model aims to better capture the uncertainties associated with rare disasters by focusing on these two metrics. This framework provides a systematic way for those in charge to allocate resources, focus research, and figure out how to best reduce risks. The scorecard is divided into two main sections: specific factors, associated questions, and scoring options. Each factor examines critical aspects of extreme catastrophic risks that impact our ability to understand and control them. Higher scores indicate more significant uncertainty or lower controllability, highlighting areas requiring attention.

3.1 Understanding

This metric examines the depth and breadth of our knowledge about the risk. A high level of understanding reduces uncertainty and increases our ability to predict and prepare for potential disasters. Factors that help assess understanding include:

- Historical Occurrence (H)- Historical occurrence is a primary criterion in risk assessment. When an event has occurred before, and its frequency is measurable, it provides empirical data that can be used to predict future events and their possible outcomes. This information enhances comprehension and diminishes ambiguity. The absence of documentation for extreme catastrophic occurrences in the historical record contributes to heightened uncertainty.
- Analogous Events (AE) - Analogous events are proxies when direct historical data are lacking. Analysis of similar events can correlate with an understanding of a given risk. For example, studying smaller volcanic eruptions can help us understand the effects of a supervolcano eruption. This metric assesses our ability to leverage prior knowledge to improve understanding. We acknowledge the limitations and uncertainties of extrapolating data from different contexts by assessing the availability and relevance of analogous events.
- Information Availability and Quality (IQ) - Access to high-quality information is critical to accurate risk assessment. It facilitates

comprehensive analysis, model validation, and informed decision-making. Information scarcity is a common challenge in risk analysis, amplifying uncertainty and hindering effective prediction and preparation. This metric demonstrates the need to evaluate existing knowledge critically.

- Causality Understanding (C) - Causality is essential for predicting events and developing prevention strategies. A well-established analysis model enables the identification of causes and consequently finds a potential intervention at a point (before or after the impact of a given factor). In extremely rare or only theoretical risks, causal mechanisms may be complex, multifaceted, or not fully understood, leading to more significant uncertainty. Including this parameter indicates the importance of scientific research in uncovering the underlying processes.
- Impact Understanding (IU) - Understanding the potential impact of a catastrophic event is crucial for preparation and resource allocation. If we understand the effects of a given catastrophic event, we will be better prepared to formulate contingency plans and allocate resources to reduce or prevent damage. In the case of very unusual risks or those that have just emerged, the repercussions may be unprecedented or beyond current experience, making them more challenging to predict.
- Research Availability (R) - Research on a topic indicates that risks have been recognized, studied, and discussed in the academic community. This improves risk understanding and guides evidence-based policy. The lack of research indicates that risks may be under-researched or ignored, resulting in significant information gaps. The inclusion of this indicator highlights areas of insufficient knowledge. This raises the question of why research may be limited—whether due to financial constraints, perceived improbability, or the novelty of the risk.
- System Complexity (SC) - Complex systems with significant interdependencies can exhibit unpredictable behaviors, including cascading failures or emergent phenomena. Understanding system complexity is essential to predicting potential secondary effects. It also helps detect security holes and implement effective threat mitigation techniques.

3.2 Controllability

Controllability assesses our capacity to manage risk, thereby preventing its escalation and addressing its consequences if it materializes. The following factors determine controllability in our model:

Influence on Occurrence (IO) - our ability to influence the occurrence of an event directly influences the strategies we can employ to prevent or reduce its likelihood. We can implement preventive measures such as laws or technical solutions by controlling the conditions that trigger an event. Our focus shifts to mitigation in circumstances beyond our control, such as natural cosmic events. Integrating this statistic distinguishes between risks that can be managed proactively and those that require reactive responses. It emphasizes the need to understand our role in exacerbating or mitigating risks and thus guide policy decisions and resource allocation to prevent or prepare effectively.

Response Capability (RC) - includes the ability to respond to the risk efficiently. Response capability may include direct countermeasures against the impacting factor (event) or responding to the harm done after the event. In some cases, we may be uncertain about our ability to implement an effective response, such as in the case of contact with an alien civilization. This metric highlights the significance of allocating resources to response infrastructure and associated competencies. It draws attention to shortcomings in current preparedness and the imperative to cultivate innovative technologies or strategies to bolster our ability to address potential calamities. An absence of response capabilities signifies considerable vulnerability.

Monitoring and Detection (M) – the existence of risk monitoring institutions can tell us about the capacity to respond. Their presence often reflects the capacity of society to prepare for potential threats. Seismic monitoring agencies, for instance, are globally distributed institutions that furnish data, predictive analyses, and emergency management strategies in the context of earthquakes. These institutions bolster resilience by establishing a structure for coordinated responses. Conversely, for novel or atypical threats, like those posed by micro-robots, such institutions are lacking, thereby creating substantial deficiencies in preparedness. This contrast underscores the critical role of institutions in risk assessment and management, especially in their capacity to institutionalize monitoring, devise early warning systems, and orchestrate responses.

Early Warning (EW) - issue warnings indicating an event is imminent or likely. The existence of measures such as early warning indicators impacts the ability to detect and respond to threats effectively. For example, in the case of natural disasters such as earthquakes, monitoring systems are well-developed, using advanced technologies to detect seismic activity and issue early warnings. These systems have been proven to save lives and reduce damage, enabling preemptive action. In contrast, emerging threats such as microrobotics present a unique challenge due to the lack of such measures. There are no dedicated monitoring systems or early warning indicators to detect potential misuse or hazards associated with microrobotics. This lack of preparedness highlights the critical need to develop measures to close the gap between known and emerging threats, ensuring that monitoring and response capabilities evolve with technological advances.

Duration of Impact (DI) - The duration of an event's impact influences the possibility of reaction. Short-lasting events do not leave space for response, whereas prolonged impact leaves time for humanity to respond and adjust to a changing environment. Prolonged or enduring effects can substantially transform communities, requiring significant adjustments. Comprehending the prospective duration aids in strategizing for prolonged endeavors rather than ephemeral reactions.

Influence After Event Occurrence (IAE) – This refers to our ability to intervene during or after an event to reduce damage or accelerate recovery. This can include acting against the cause of the event or limiting the effects of the event (reducing potential damage). For some risks, such as a pandemic, interventions during the event can significantly alter outcomes. On the other hand, little can be done to influence the event for some risks, such as gamma-ray bursts. This factor helps us assess controllability by recognizing the potential to influence the event's outcome.

Feedback Mechanisms (FM) - Feedback mechanisms in systems can mitigate or exacerbate the effects of an event. Positive feedback loops can lead to increasing repercussions, making control more difficult. Negative feedback can stabilize the system and mitigate damage. Understanding these mechanisms is essential for predicting the course of an event and identifying the most effective points of intervention. Including this parameter facilitates the study of the dynamics of a dynamic system. Unidentified feedback systems enhance uncertainty and confound evaluations of controllability.

The model uses two key metrics: understanding, which measures how well we comprehend the risk, and controllability, which assesses our ability to manage it. To assess the level of each metric, we prepared a scorecard questionnaire.

The questionnaire has three possible answers for each question, and the answers are scored from 0 to 2.

- Score 0 (relatively high understanding or relatively high controllability)
- Score 1 (relatively low understanding or relatively low controllability)
- Score 2 (relatively very low or no understanding at all, and relatively very low or no controllability at all)

Higher scores indicate more significant uncertainty or lower controllability, highlighting areas that require attention. Below are questions that will help to assess each risk.

The proposed model introduces a structured approach to assessing extreme catastrophic risks. However, like any model, it has significant limitations.

First, the scorecard with predefined answers can lead to subjectivity. Questions can be interpreted differently by different assessors. For example, questions such as “Do we understand the causal relationships leading to the event?” can yield different answers. This can lead to assigning different scores due to other assessments. Second, the model assumes equal importance for all factors. In reality, some factors may significantly impact the overall risk profile more than others. This “one size fits all” approach can limit the usefulness and effectiveness of the model. Third, the questionnaire scoring system assigns responses discrete values (0, 1, or 2). It may oversimplify the complexity of the risks. The limited scale does not capture the nuances between different levels of knowledge or control and may not adequately reflect the risks.

Considering these limitations, it is worth noting that every model is a simplified representation of reality—not exact reality. Generally, the purpose of models is to abstract the essential elements of the system, removing unnecessary details to focus on key features and enhancing our understanding of reality. The created model aims to provide quantitative measures of extreme catastrophic events. Most of these events lack reliable data to provide quantitative measures of risk. However, due to the potential impact of extreme catastrophic events, it is necessary to provide a tool for measuring risks.

Table 1: Scorecard Questionnaire for Extreme Catastrophic Event Assessment

	Factor (Code)	Question	Response Options (Score)
Understanding	Historical Occurrence (H)	Has the event happened in the past?	A. Yes, with measurable frequency (Score: 0) B. Yes, but frequency cannot be measured (1) C. No, never recorded (or uncertain) (2)

Table 1: Scorecard Questionnaire for Extreme Catastrophic Event Assessment (Continued)

	Analogous Events (AE)	Are there similar events that provide data about probability or impact?	A. Yes, smaller-scale analogs exist (0) B. Somewhat similar events with limited insights (1) C. No analogous events known (2)
	Information Availability & Quality (IQ)	How reliable and extensive is the available information on this risk?	A. Substantial high-quality data available (0) B. Limited or uncertain data (1) C. Little to no reliable information (2)
	Causality Understanding (C)	Do we understand the causal mechanisms leading to the event?	A. Yes, causality is well-understood scientifically (0) B. Partially understood mechanisms (1) C. No understanding or purely speculative (2)
	Impact Understanding (IU)	Do we understand the potential impacts if the event occurs?	A. Yes, impacts well-characterized (0) B. Partially understood impacts (1) C. Impacts not understood or highly speculative (2)
	Research Availability (R)	Is the risk actively studied in scientific literature?	A. Yes, robust research and discussion exist (0) B. Some discussion, but not extensive (1) C. Little to no scientific research (only speculation) (2)
	System Complexity (SC)	How complex is the system - how many interdependencies affect the risk?	A. Relatively simple, well-bounded system (0) B. Complex system with significant interdependencies (1) C. Extremely complex or poorly understood system (2)
Controllability	Influence on Occurrence (IO)	Can humanity influence or prevent the event from occurring?	A. Yes, significant influence or preventive measures exist (0) B. Limited ability to influence occurrence (1) C. No known way to prevent or influence (2)
	Response Capability (RC)	If the event begins, can we effectively mitigate its effects?	A. Yes, effective countermeasures or responses exist (0) B. Partial or uncertain ability to respond (1) C. No known effective response (2)
	Monitoring & Detection (MD)	Do systems exist to monitor warning signs of the risk?	A. Yes, the risk is actively monitored with advanced systems (0) B. Some monitoring exists but with gaps (1) C. No monitoring or detection capability (2)
	Early Warning (EW)	Are there reliable early warning indicators before the event?	A. Yes, proven early warning indicators/tools exist (0) B. Only limited or emerging indicators (1) C. No reliable warning signals known (2)
	Duration of Impact (DI)	Once triggered, what is the duration of the event's primary impact?	A. Short-term (minutes to <1 year) (0) B. Medium-term (1–10 years) (1) C. Long-term or permanent effects (>10 years) (2)
	Influence After Event Occurrence (IAE)	Do we have any control over the situation *after* the event starts?	A. Yes, some control can be exerted post-initiation (0) B. Very limited control once underway (1) C. No control; the event runs its course unchecked (2)
	Feedback Mechanisms (FM)	Could feedback loops amplify the event's impacts?	A. Counteracting (negative) feedback likely to reduce impact (0) B. Some positive feedback could worsen the impact (1) C. Strong positive feedback or cascading effects likely (2)

Source: Own creation

Future research can address the model's limitations. The research could focus on improving the scorecard. Moreover, weights could be added to the scorecard factors, improving the model's adequacy. Finally, it can improve its robustness by integrating the model with real-world case studies and iteratively testing its predictions against observed outcomes. Although the model is inherently simplified, it can be a valuable tool for risk management.

4. Model application and results analysis

We have chosen nine risks for evaluation, ranging from those found solely in science fiction to historical events, to apply the model to the exceedingly unlikely risk with significant destructive potential.

4.1 Extreme catastrophic events

Toba-like Catastrophe refers to the eruption of the Toba supervolcano in Indonesia approximately 74,000 years ago [20]. The eruption released vast amounts of ash, which caused a volcanic winter. Sulfur aerosols blocked sunlight and significantly lowered global temperatures. This volcanic winter affected photosynthesis and food production. Evidence suggests that early humans were affected by this eruption, and the global human population may have been reduced to just a few thousand individuals. Supervolcanoes are extensively researched, and numerous studies and monitoring programs provide robust evidence of past eruptions and their global impacts. There is widespread recognition of this risk as one of the most probable natural causes of human extinction. A future supervolcano eruption is expected to trigger a volcanic winter and potentially initiate feedback loops that intensify its climatic impact [21; 22; 23; 24; 25; 26; 27].

A nuclear war is another extreme, catastrophic event that can lead to a global catastrophe. After the initial destruction caused by the nuclear blasts, people will be affected by radiation. Additionally, beyond the immediate destruction, the ash from the explosions may infiltrate the stratosphere, obstructing sunlight and inducing a "nuclear winter." This can cause effects similar to those observed after a volcanic eruption. This risk has been studied intensively since the invention of a nuclear weapon. The extensive literature on both immediate effects and long-term scenarios (nuclear winter, societal collapse) has been published in peer-reviewed journals and reports by defense agencies. Governments and international organizations have commissioned numerous studies (e.g., on nuclear winter, civil defense, and arms control), ensuring this risk is one of the most thoroughly discussed and documented of all existential threats [28; 29; 30; 31; 32].

Contact with an extraterrestrial civilization refers to an interaction with intelligent extraterrestrial life. This theme was initially primarily present in science fiction literature and movies; however, it gained scientific recognition over time and is now analyzed in the scientific world. This event can lead to both positive and negative consequences. If we encounter a friendly alien civilization, it can expand our knowledge and accelerate human development. However, the "Great Filter" idea also assumes that such contact can reveal existential threats common in advanced civilizations. While there is discussion in SETI and astrobiology, the risk remains largely unresearched. Thus, we have limited empirical data compared to more immediate global risks. A few academics have examined how first contact might play out or affect humanity, but attention to this risk is relatively low since the probability is unknown and beyond human control [7; 33; 34; 35; 36].

A global pandemic caused by an engineered supervirus, characterized by great transmissibility and lethality, might proliferate worldwide, overwhelming healthcare systems and resulting in unprecedented mortality rates. Unlike natural pandemics, viruses in an artificially designed pandemic can be deliberately designed to manifest themselves as late as possible to infect as many people as possible. Specially designed viruses could be resistant to all types of vaccines and medicines. The pandemic can have a lasting effect on the global economy, which would jeopardize the large benefits of open trade regimes in the global economy. There is a broad body of literature on both naturally emerging pandemics and the risks of engineered pathogens. After the COVID-19 pandemic, preparedness and response is a major focus in public health literature [37; 38; 39; 40; 41].

The threat caused by artificial intelligence—one can imagine a situation in which artificial intelligence surpasses the intelligence of its creator, humans. Artificial intelligence may treat humans merely as a bygone evolutionary stepping stone, which means that it will treat us in a similar way to how we treat animals. An advanced artificial intelligence system surpassing human intelligence may pose a threat to the existence of humanity. Artificial intelligence may act unpredictably, prioritizing its goals, which may be opposed to ours. The risk of unaligned AI has been increasingly discussed. Many researchers and organizations are publishing theoretical works on the risk posed by uncontrolled AI. While the risk is recognized in academic debate (in books, papers, and even popular media), the depth of research is still not yet commensurate with the potential significance of the risk [42; 43; 44; 45; 46; 47; 48; 49; 50; 51].

Asteroid impact – Earth's collision with an asteroid has occurred many times, with tragic consequences for life on Earth. The effect could trigger a wave of shocks, fires, and tsunamis that disrupt our ecosystem. In addition to the significant damage during the initial impact, the consequences could be even more long-term. Due to the massive amounts of dust released into the atmosphere, the resulting winter could block access to sunlight. The effects could be similar to a nuclear or volcanic winter. Global cooling could disrupt photosynthetic systems and cause the extinction of many species. The asteroid impact risk is extensively studied and discussed. Space agencies such as NASA and ESA fund programs to detect objects with the potential to affect humankind. There are numerous scientific publications on impact probabilities, potential damage, and mitigation techniques [52; 53; 54; 55; 56; 57; 58; 59; 60; 61; 62; 63].

Global Climate Catastrophe – is studied globally and well documented; however, this risk encompasses unknown factors that could lead to accelerated global warming. It assumes gaps in our knowledge about climate dynamics and the potential for mechanisms that can trigger a rapid intensification of the greenhouse effect. Triggering such mechanisms—such as feedback loops involving methane release from permafrost—can further accelerate warming. This positive feedback loop can disrupt agriculture, human habitats, and global stability. Climate change risks crossing ecological tipping points, such as the collapse of polar ice sheets or forest diebacks, which could lead to widespread instability. Currently, the climate system is closely monitored by global observation networks. These include satellite systems measuring temperatures, sea levels, ice extent, and greenhouse gas concentrations; ocean buoys tracking sea temperatures and currents; and land-based stations recording weather and climate data. Together, these systems help us to analyze and manage this risk [64; 65; 66; 67].

Gamma-ray bursts are powerful emissions of radiation from space that can affect our planet. Such bursts may result from the implosion of a massive star, forming a neutron star or black hole. This event could deplete Earth's ozone layer, exposing life to harmful ultraviolet (UV) radiation. Such exposure could devastate ecosystems—potentially ending life on Earth. Gamma-ray bursts are well documented in astrophysics, but research on their potential impact on Earth is relatively niche. Only a small community of researchers has explored the possibility of this risk causing mass extinction. The risk is not monitored by global organizations, and the topic is largely absent from public discourse [68; 69; 70; 71; 72; 73; 74].

The "grey goo" scenario is the risk of creating self-replicating nanorobots capable of uncontrolled reproduction. The actions of these nanorobots could threaten humanity indirectly – these robots would seek out resources for reproduction and cause their rapid depletion. One could also imagine a scenario in which nanorobots directly threaten humans by using them as a source of reproduction. An additional problem is that these robots operate at the nanoscale, making them difficult to combat. Such nanorobots could result from unregulated scientific experiments, accidental military releases, or deliberate deployment by a nation, terrorist group, AI system, or other robots. Existential risk literature on grey goo is limited to theoretical models and concepts. Empirical data on self-replicating nanomachines is nonexistent, and available information is based on theoretical speculation [75; 76; 77; 78; 79].

4.2 Analysis of the results

The scorecard model was applied to each of the presented events. The detailed results with answers and justification are presented in Appendix A. The results of the used model are given below in Table 2.

Table 2: Extreme Catastrophic Events and Their Understanding and Controllability Scores

Risk	Understanding Score [a]	Controllability Score [a]
Toba-like Catastrophe	5	6
Nuclear War	6	5
Contact with Alien Civilization	13	12
Global Pandemic (Engineered Supervirus)	4	4
AI-induced Existential Threat	11	10
Massive Asteroid Impact	2	6
Global Climate Catastrophe	5	7
Gamma-Ray Burst	13	12
Nanotechnology Disaster (Grey Goo)	13	11

Notes: a detailed explanation in Appendix A.
Source: Author calculation.

The maximum score in each category is 14, and the minimum is 0. Notably, no event achieved either the maximum or minimum score. For the understanding factor, the events with the highest scores (indicating the least understanding) were contact with an alien civilization, gamma-ray bursts, and nanotechnology disasters. Conversely, the lowest scores (indicating the highest level of understanding) were associated with massive asteroid impact events. In the controllability factor, the highest scores (representing the lowest level of controllability) were attributed to gamma-ray bursts and contact with alien civilizations. On the other hand, the lowest scores (indicating the highest level of controllability) were achieved by global pandemics.

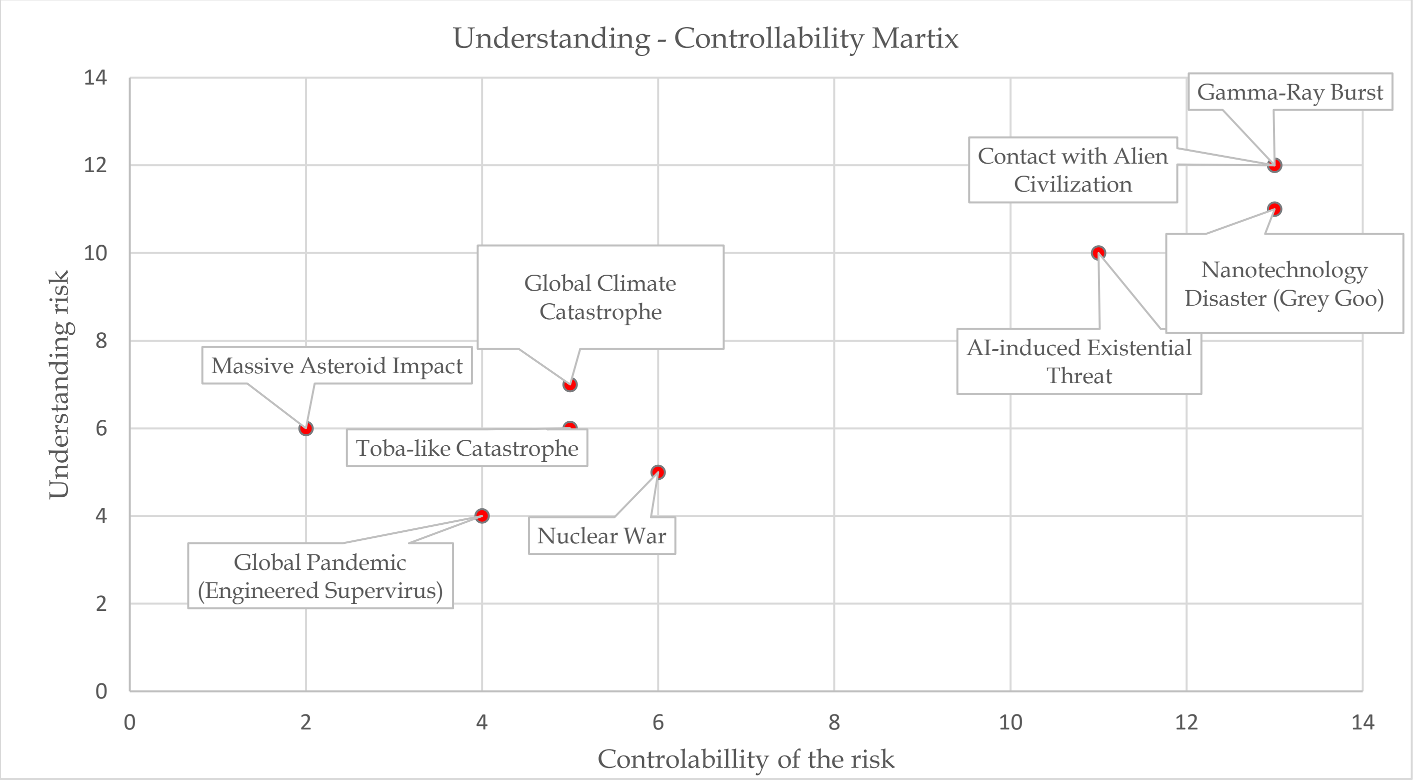

Figure 1: The Understanding–Controllability Matrix Applied to the Selected Extreme Catastrophic Events
Source: Author calculations.

The study of catastrophic risks in the understanding–controllability matrix identifies two distinct types of risks according to their scores. These clusters show variations in humanity's capacity to understand and address these risks, as well as provide a systematic framework for focusing research, policy, and mitigation initiatives.

The first group consists of risks characterized by comparatively high understanding and controllability of the risks. This category encompasses events such as Toba-like supervolcanic eruptions, engineered supervirus-induced global pandemics, nuclear warfare, and significant asteroid collisions. These risks are defined by moderate comprehension, primarily derived from historical incidents or comparable situations. For instance, volcanic eruptions on a smaller scale offer significant insights into the mechanisms and potential consequences of larger-scale disasters. Nonetheless, while this group derives advantages from a measure of data and historical precedent, it also underscores deficiencies in humanity's capacity to exercise significant control. Although volcanic eruptions can be monitored, no preventive methods are currently available. The same is true for large-scale asteroid impacts. We can monitor asteroids; however, when confronted with the real danger, we may be left with untested weapons and only theoretical frameworks on how to deal with such threats. The manageability of nuclear conflict is achieved by the logical implementation of the Prisoner's Dilemma (there is a stable solution to the problem—no one will gain from using such weapons due to mutual destruction). Moreover, some protocols and procedures help to manage the risk. In summary, these risks indicate a balance between a reliable understanding of the mechanisms of the risk and limited—but existing—control.

The second group comprises risks that are not well understood, and the controllability of the risk is very limited or uncertain. We can say that these risks are highly speculative. This category encompasses interactions with extraterrestrial civilizations, AI-generated existential risks, gamma-ray bursts, and nanotechnology catastrophes (e.g., grey goo scenarios). These risks share a common characteristic: they lack empirical data or historical precedent, resulting in substantial knowledge gaps. For example, the potential interaction with aliens remains speculative due to the lack of comparable occurrences. Similarly, although recognized as an astronomical phenomenon, gamma-ray bursts are highly speculative in terms of their potential impact on Earth due to the lack of historical records.

These two clusters highlight essential concerns in risk management. Risks in the first group, characterized by moderate comprehension and partial manageability, establish a basis for focused interventions. Advancements in monitoring technologies, global collaboration, and improved disaster preparedness can address these events. The second cluster of risks requires a different approach. The risks require investment in research to address knowledge deficiencies before preventive measures are established.

In summary, traditional risk management tools cannot be applied to measure extreme catastrophic events effectively. The presented model quantifies risks about which we have limited knowledge. Despite limitations, quantifying these risks can serve as a useful tool for further analysis and development.

5. Conclusions

Extreme catastrophic risks cannot be measured using traditional risk management techniques due to their intrinsic characteristics. The first goal of this paper was to provide a model with quantitative indices to assess extreme catastrophic events. This goal was achieved. This study presents a model that provides quantitative measures of the risks. The presented model evaluates such risks based on two critical metrics: understanding and controllability, using a questionnaire to convert limited knowledge about the risks to specific, measurable factors. The model addresses the inherent challenges posed by the unprecedented nature and lack of historical data on extreme catastrophic events.

The second goal of this paper was to apply the model to the analysis of selected extreme catastrophic events. This goal was achieved. We applied the model to nine selected catastrophic events. The application reveals important insights. Based on the received scores, extreme catastrophic events can be categorized into two distinct clusters. The first cluster consists of events with higher levels of understanding and higher controllability. The second cluster consists of events with lower or nonexistent levels of understanding and controllability.

The model fills critical gaps in the risk measurement of catastrophic events and provides a practical means to navigate the complexities associated with these risks. It advocates for a dual strategy in risk management—strengthening preparedness for well-understood threats while actively researching and monitoring speculative risks. This approach ensures a balanced allocation of resources, maximizing our ability to mitigate potential catastrophes. By introducing and validating the model, this paper contributes to the discourse on global catastrophic risks, offering a robust tool for future analysis. The framework is not just theoretical; it has practical applications in disaster risk management. It can be used to estimate the effectiveness and cost-efficiency of risk management strategies, set regulatory limits for acceptable catastrophic risk, and aid in designing and dimensioning safety and security systems.

While the model provides a foundational framework for assessing extreme catastrophic risks, further research is needed to refine its parameters and enhance its predictive capabilities. Integrating real-time data analytics, artificial intelligence, and cross-disciplinary expertise can improve the model's responsiveness to emerging threats. Expanding the model to include socio-economic and ethical considerations will offer a more holistic approach to global risk management. Future iterations of this model could employ the Delphi method or expert panels to assign scores, thereby reducing individual bias and calibrating the weights of specific factors. Collaborative international efforts are essential to address the transboundary nature of extreme catastrophic events effectively.

Declaration of generative AI and AI-assisted technologies in the writing process.

While preparing this work, the author used Grammarly to improve the manuscript's readability and language. After using this tool, the author reviewed and edited the content as needed and took full responsibility for the content of the published article.

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Appendix A: Understanding scorecard for selected extreme catastrophic events

Scenario	Factor (Question)	Score	Justification
Toba-like Supervolcano [27; 28; 29; 30; 31; 32]	Historical Occurrence (Has the event occurred?)	1	Super volcanic eruptions (e.g., the Toba eruption ~74,000 years ago) have occurred; however, they are so infrequent (estimated recurrence intervals are ~50,000–100,000+ years) that their frequency is not measurable on human timescales.
	Analogous Events (Are similar events available?)	0	Smaller volcanic eruptions—such as the 1815 Tambora eruption—provide robust analog data on eruption impacts (e.g., global cooling effects), even if their magnitudes differ from a supereruption.
	Information Availability & Quality (How reliable is the info?)	1	Geological records (such as ash layers and ice cores) and climate models offer data for supervolcano eruptions, yet significant uncertainties remain due to the immense timescales and the rarity of these events.
	Causality Understanding (Do we know the triggers?)	1	The general mechanism (magma accumulation and pressure buildup) is understood; however, the precise triggers that lead to a super-eruption (such as those at Yellowstone) remain only partially known.
	Impact Understanding (Do we understand potential impacts?)	1	Models predict that a Toba-scale eruption would trigger a volcanic winter and cause severe ecological disruption; however, the exact magnitude and duration of these effects remain debated among climate scientists.
	Research Availability (Is the risk well discussed?)	0	Supervolcanoes are extensively researched in volcanology and climate science. Numerous studies and monitoring programs provide robust evidence regarding past eruptions and their global impacts.
	System Complexity (How complex is the event?)	1	Although the eruption's fundamental physics are well understood, the interactions among magma dynamics, atmospheric chemistry, and subsequent climate feedbacks introduce significant complexity and uncertainty in overall system behavior.
Nuclear War [33; 34; 35; 36]	Historical Occurrence (Has the event occurred?)	1	Nuclear weapons were used during World War II (Hiroshima and Nagasaki), but a full-scale nuclear war between major powers has never occurred, so while nuclear weapons exist, the catastrophic global exchange remains untested.
	Analogous Events (Are similar events available?)	1	While a full-scale nuclear exchange has not occurred, data from the bombings of Hiroshima and Nagasaki and numerous nuclear tests provide partial analogs for understanding blast, radiation, and fallout effects. In addition, models of volcanic eruptions (e.g., Tambora 1815) have been used to approximate nuclear winter effects.
	Information Availability & Quality (How reliable is the info?)	1	The physics of nuclear blasts and immediate radiation effects are well-documented from nuclear tests, but the long-term global climatic impacts—such as those envisioned in nuclear winter models—are based on complex simulations and remain subject to significant uncertainty.
	Causality Understanding (Do we know the triggers?)	1	We conceptually understand that nuclear war could be triggered by escalation or miscalculation, but the precise sequence of events in complex geopolitical systems remains uncertain. The "fog of war" and human error factors make predicting the exact cause challenging, even though deterrence principles are well known.
	Impact Understanding (Do we understand potential impacts?)	1	Immediate effects (blast, thermal radiation, fallout) are well-understood from historical data and physics, but long-term climatic impacts (e.g., nuclear winter) remain uncertain due to the complex interplay of atmospheric processes.
	Research Availability (Is the risk well discussed?)	0	Nuclear war has been studied intensively since its inception, with extensive literature on both immediate effects and long-term scenarios (nuclear winter, societal collapse) published in peer-reviewed journals and reports by defense agencies.
	System Complexity (How complex is the event?)	1	A nuclear war would involve complex interactions between military, environmental, and social systems. While the physical mechanisms of blast and fallout are well understood, the cascading societal and climatic interactions add significant uncertainty.
Contact with Alien Civilizations [38; 39; 41]	Historical Occurrence (Has the event occurred?)	2	No confirmed contact has ever occurred; humanity has no historical record of extraterrestrial intelligence, making any recurrence immeasurable.
	Analogous Events (Are similar events available?)	2	There are no direct analogs for alien contact; while human first contacts exist in history, these are not comparable due to differences in technology, biology, and scale.

	Information Availability & Quality (How reliable is the info?)	2	Information on extraterrestrial intelligence is extremely limited; most data come from theoretical models (e.g., the Drake Equation) and indirect searches, with little empirical evidence available.
	Causality Understanding (Do we know the triggers?)	2	We lack understanding of the causal factors that would prompt aliens to contact Earth; any such triggers remain purely theoretical with no empirical basis.
	Impact Understanding (Do we understand potential impacts?)	2	The consequences of alien contact are highly speculative, with outcomes ranging from beneficial cultural exchange to catastrophic existential risk, and no empirical data exists to constrain the range.
	Research Availability (Is the risk well discussed?)	1	While there is discussion in SETI and astrobiology, the topic remains largely speculative with limited empirical research compared to more immediate global risks.
	System Complexity (How complex is the event?)	2	Interacting with an alien civilization would involve numerous unknown complexities in technology, communication, and culture, making the overall system's behavior unpredictable and difficult to model.
Global Pandemic (Engineered Supervirus) [37; 40; 50; 51]	Historical Occurrence (Has the event occurred?)	1	Natural pandemics (e.g., 1918 influenza) have occurred, yet a deliberately engineered supervirus has not, meaning its occurrence is hypothetical despite analog data from nature.
	Analogous Events (Are similar events available?)	0	Natural pandemics such as the 1918 influenza and COVID-19 provide robust analog data concerning virus transmission and impact, even though an engineered variant might be more lethal.
	Information Availability & Quality (How reliable is the information?)	1	Existing epidemiological data is robust, yet uncertainties remain when applying it to a purposely engineered pathogen—especially regarding mutation dynamics and potential for immune evasion.
	Causality Understanding (Do we understand the triggers?)	1	We understand natural viral transmission well, but engineered modifications (e.g., enhanced virulence or transmission) add complexity that is not yet fully understood.
	Impact Understanding (Do we understand potential impacts?)	1	While pandemic impacts such as high mortality and societal disruption are well known from past events, an engineered virus could be even more severe, especially if it mutates unpredictably.
	Research Availability (Is the risk well discussed?)	0	There is extensive research on pandemics, particularly following COVID-19, and increasing literature addresses engineered pathogens in the context of biosecurity and emerging infectious diseases.
	System Complexity (How complex is the event?)	0	Pandemic spread dynamics are well modeled using epidemiological models (e.g., SIR models), and while complexities exist (e.g., behavior, mutation), the overall system is understood sufficiently.
Unaligned AI Superintelligence [42; 43; 44; 45; 46; 47; 48; 49; 62; 63]	Historical Occurrence (Has the event occurred?)	2	No instance of a superintelligent AI exists. All current systems remain narrow and none have demonstrated capabilities far exceeding human intelligence.
	Analogous Events (Are similar events available?)	1	Limited analogous events exist such as algorithmic failures (e.g., flash crashes or unintended autonomous actions) which offer partial insights into unpredictable AI behavior.
	Information Availability & Quality (How reliable is the info?)	2	Information regarding a potential superintelligent AI is largely theoretical; empirical data are nonexistent, so predictions rely on speculation and expert modeling.
	Causality Understanding (Do we know the triggers?)	2	The causal chain from current narrow AI systems to an unaligned superintelligence remains entirely speculative, with no empirical evidence detailing how such a transition would occur.
	Impact Understanding (Do we understand potential impacts?)	2	Potential impacts range from beneficial to catastrophic without any empirical basis; scenarios remain hypothetical with significant uncertainty in predicting outcomes.
	Research Availability (Is the risk well discussed?)	0	Although research on AI safety and alignment is rapidly growing, it remains a nascent field with limited empirical studies compared to other risks such as climate change or nuclear war.
	System Complexity (How complex is the event?)	2	The potential complexity of a super intelligent AI and its interactions with global systems is beyond our current understanding, making predictions extremely uncertain.
Massive Asteroid Impact [52; 53; 54; 55; 56; 57; 58; 59; 60; 61]	Historical Occurrence (Has the event occurred?)	1	Geological evidence—such as the Chicxulub crater—confirms that massive asteroid impacts have occurred; however, these events are so rare (estimated every tens of millions of years) that their precise recurrence frequency cannot be reliably measured on human timescales.

	Analogous Events (Are similar events available?)	0	Observed smaller events—such as the 1908 Tunguska airburst and the 2013 Chelyabinsk meteor—provide empirical data on impact dynamics, which can serve as analogs for understanding the physics of larger, rare events.
	Information Availability & Quality (How reliable is the info?)	1	Extensive astronomical surveys (e.g., NEOWISE) have catalogued many near-Earth objects, but uncertainties still exist—especially for smaller objects or long-period comets that might pose an unanticipated threat.
	Causality Understanding (Do we understand the triggers?)	0	The physics of asteroid motion, governed by Newtonian mechanics, is well understood. We can calculate trajectories and predict collisions using established gravitational models with high precision.
	Impact Understanding (Do we understand potential impacts?)	0	Impact effects—such as shock waves, thermal radiation, and the ensuing global “impact winter”—are well modeled and validated by geological records (e.g., the mass extinction at the Cretaceous–Paleogene boundary).
	Research Availability (Is the risk well discussed?)	0	There is an extensive body of research on asteroid impacts and planetary defense, with numerous studies, ongoing surveys, and dedicated programs by agencies like NASA and ESA.
	System Complexity (How complex is the event?)	0	The impact process is governed by well-established physical laws (kinetic energy release, shock wave propagation) making it relatively straightforward compared to complex biological or social systems.
Global Climate Catastrophe [64; 66; 67]	Historical Occurrence (Has the event occurred?)	0	There is no documented global climate catastrophe in human history, making this scenario without precedent. Ongoing anthropogenic warming has no close analog in recorded civilization, with current climate trends described as “unprecedented in thousands, if not hundreds of thousands of years. While Earth’s geologic past saw extreme warming events, those occurred long before human times. The present warming rate and magnitude exceed anything our species has experienced, underscoring the high uncertainty due to lack of historical benchmarks.
	Analogous Events (Are similar events available?)	1	Only partial analogs exist for a runaway global warming scenario. In Earth’s distant past, events like the Paleocene–Eocene Thermal Maximum (~56 million years ago) featured a ~5–6°C global warming from massive carbon release, providing a rough parallel to modern climate change. That ancient episode, which triggered ocean acidification and mass extinctions, is considered “the best geological analogy for contemporary climate change.
	Information Availability & Quality (How reliable is it?)	1	Despite the fact that climate change is one of the most data-rich and studied phenomena, many assumptions are made about it.
	Causality Understanding (Do we know the triggers?)	1	Yes – the causal mechanisms behind a climate catastrophe (extreme global warming) are well understood and firmly grounded in scientific theory and observations. It is “unequivocal” that increasing atmospheric greenhouse gas concentrations from human activities are warming the planet.
	Impact Understanding (Do we understand potential impacts?)	1	Many expected impacts of climate change are known, but a truly catastrophic scenario introduces deep uncertainty. Extensive research and modeling have characterized likely effects of global warming – for instance, we know with high confidence to expect more extreme heatwaves, sea-level rise, and ecosystem disruption as temperatures climb. These impacts are already being observed and can be projected for moderate warming ranges (1.5°C–2°C).
	Research Availability (Is the risk well discussed?)	0	Yes – climate change and catastrophic climate risk are extensively studied. Climate science is a mature field with a vast body of literature. For example, the IPCC’s assessments involve hundreds of experts reviewing tens of thousands of studies
	System Complexity (How complex is the event?)	1	The climate system is highly complex and interconnected, but its broad behavior is partially understood. It comprises many coupled sub-systems (atmosphere, oceans, cryosphere, biosphere) with nonlinear interactions. Changes can produce cascading effects; e.g. warming triggers ice melt, which reduces albedo and further amplifies warming.

Gamma-Ray Burst (GRB) [65; 71; 72; 73; 74]	Historical Occurrence (Has the event occurred?)	2	There is no recorded instance of a GRB affecting Earth; all observed gamma-ray bursts originate in distant galaxies, and none have been documented to impact our planet.
	Analogous Events (Are similar events available?)	2	There are no analogous events on Earth; while supernovae and other astrophysical phenomena are observed, a GRB's impact on Earth remains entirely theoretical with no direct historical or natural analog.
	Information Availability & Quality (How reliable is it?)	2	Information on GRB impacts is derived exclusively from theoretical models and simulations; there is a lack of empirical data on how a GRB would affect Earth's atmosphere and biosphere.
	Causality Understanding (Do we know the triggers?)	2	While astrophysical processes governing GRBs are studied, the prediction of when or if one might strike Earth is extremely uncertain and remains entirely theoretical, with no empirical trigger data for our planet.
	Impact Understanding (Do we understand potential impacts?)	2	The potential impacts (e.g., severe ozone depletion leading to increased ultraviolet radiation) are based solely on models, with significant uncertainties regarding the magnitude and duration of ecological collapse.
	Research Availability (Is the risk well discussed?)	1	Research on GRBs is well established in astrophysics; however, studies focusing on their terrestrial impacts are comparatively sparse, as the topic is niche within astrobiology and remains largely theoretical.
	System Complexity (How complex is the event?)	2	The interaction between a GRB's high-energy radiation and Earth's atmosphere involves complex atmospheric chemistry and ecological dynamics that are not empirically observed, rendering predictions highly uncertain.
Nanotechnology Disaster (Grey Goo) [68; 69; 70; 75; 76; 77; 78; 79]	Historical Occurrence (Has the event occurred?)	2	There has never been an incident of uncontrollable self-replicating nanomachines; the "grey goo" scenario remains entirely hypothetical with no empirical precedent.
	Analogous Events (Are similar events available?)	2	No direct analog exists. Although biological systems (e.g., viruses) exhibit self-replication, engineered nanobots differ fundamentally from natural organisms, leaving no reliable precedent for grey goo behavior.
	Information Availability & Quality (How reliable is the info?)	2	Empirical data on self-replicating nanomachines is non-existent; available information is based on theoretical speculation and conceptual models without real-world testing.
	Causality Understanding (Do we know the triggers?)	2	The mechanisms by which engineered nanobots might escape control and begin uncontrolled replication are entirely speculative, as no experimental data exists on such a transition.
	Impact Understanding (Do we understand potential impacts?)	2	The range of potential impacts—from minor ecological disruption to complete biosphere collapse—is highly speculative, with no empirical basis to determine the actual outcome of an uncontrolled nanotech scenario.
	Research Availability (Is the risk well discussed?)	1	Although theoretical and existential risk literature includes discussions on grey goo, detailed empirical research on self-replicating nanotech failure modes is very limited and mostly conceptual.
	System Complexity (How complex is the event?)	2	A hypothetical grey goo disaster would involve highly unpredictable interactions between self-replicating machines and natural systems, creating an unprecedented level of complexity that current models cannot capture.
Toba-like Supervolcano [27; 28; 29; 30; 31; 32]	Influence on Occurrence (Can humans prevent the event?)	1	Natural volcanic eruptions occur due to geologic processes that are beyond human control. While monitoring may provide warnings, we have no feasible method to prevent a supervolcano from erupting.
	Response Capability (Can we mitigate the effects once it occurs?)	1	Once a supereruption occurs, our response is limited to evacuation, disaster relief, and some short-term measures; however, we cannot reverse the global climatic effects such as volcanic winter.
	Monitoring & Detection (Are there systems in place to observe warning signs?)	0	Volcano observatories around the world (e.g., Yellowstone Volcano Observatory) continuously monitor seismic activity, ground deformation, and gas emissions—providing robust early detection of unrest in supervolcano systems.
	Early Warning (Are there reliable early warning indicators?)	1	Although precursor signals such as seismic swarms and gas emissions can indicate increased eruption risk, predicting the exact timing of a supereruption remains imprecise, limiting early warning effectiveness.
	Duration of Impact (How long will the event's effects last?)	1	A supervolcano eruption is expected to trigger a volcanic winter lasting several years to a decade, a duration that is significant yet not permanent compared to some other catastrophic events.

	Influence After Event Occurrence (Can humans affect outcomes post-eruption?)	1	Once the eruption occurs, human influence on halting or reversing the event is minimal; our capacity is limited to recovery and adaptation rather than altering the primary processes of the eruption and its climatic effects.
	Feedback Mechanisms (Could feedback loops amplify its effects?)	1	Positive feedbacks—such as enhanced albedo due to increased ice cover from cooling—can amplify the eruption's climatic effects. Although these feedbacks are recognized in models, they add uncertainty to our ability to mitigate impacts.
Nuclear War [33; 34; 35; 36]	Influence on Occurrence (Can humans prevent the event?)	0	Nuclear war is entirely a human-driven event. Through diplomatic efforts, arms control treaties, and strategic deterrence, policymakers can greatly reduce the likelihood of a full-scale nuclear exchange.
	Response Capability (If the event occurs, can we mitigate its effects?)	1	Once nuclear weapons are launched, our ability to mitigate the fallout is extremely limited. Missile defense systems provide only marginal protection, and once detonations occur, there is little that can be done to reverse the widespread destruction and subsequent climatic impacts (e.g., nuclear winter).
	Monitoring & Detection (Are there systems in place to monitor launches?)	0	Robust early-warning systems—including satellites and radar networks—are operational in nuclear-armed states. These systems detect missile launches almost instantaneously, providing crucial data for decision-makers to take timely defensive measures.
	Early Warning (Are there reliable early warning indicators?)	0	Advanced detection technologies, such as infrared sensors on satellites and ground-based radar, provide immediate early-warning alerts for nuclear missile launches. This capability is essential to deterrence and rapid response measures.
	Duration of Impact (How long will effects last?)	2	The aftermath of a full-scale nuclear war—characterized by a nuclear winter, prolonged radiation, and ecosystem collapse—could persist for decades or even longer, resulting in catastrophic and potentially irreversible global changes.
	Influence After Event Occurrence (Can humans affect outcomes post-event?)	1	In the event of nuclear war, post-conflict influence is extremely limited. Although localized humanitarian efforts can occur, the large-scale environmental and societal collapse that follows would leave very little room for recovery or control.
	Feedback Mechanisms (Could feedback loops amplify effects?)	1	Positive feedback loops, such as firestorms injecting soot that deepens nuclear winter, can exacerbate the impacts of nuclear war. Although these processes are modeled, their exact magnitude remains uncertain, adding to the catastrophic potential.
Contact with Alien Civilization [38; 39; 41]	Influence on Occurrence (Can humans influence whether it occurs?)	2	The occurrence of contact with an extraterrestrial civilization is largely outside human control. An advanced alien civilization's decision to send signals or visit Earth would depend on their motivations and technology, which we cannot influence. Humanity's only potential influence is whether we actively advertise our presence (through METI – Messaging Extraterrestrial Intelligence) or try to stay quiet. Some may argue that refraining from beacon signals might slightly reduce the chance of attracting hostile attention. However, our planet's radio leakage and atmospheric signatures are already detectable across space.
	Response Capability (Can we mitigate its effects once it occurs?)	2	Humanity would have a very limited ability to mitigate or control the outcomes of an encounter with a vastly superior alien civilization. If the contact is remote (receiving a signal), "mitigation" might involve only managing public reaction and crafting a response, but we cannot influence the alien senders themselves. In a worst-case scenario of hostile visitation, our current technology (rockets, weapons) would be useless against a civilization capable of interstellar travel – we could not defend Earth from an advanced attack.
	Monitoring & Detection (Are there systems to monitor outbreaks?)	1	Humanity is, indeed, on the lookout for extraterrestrial life, though the search is somewhat constrained. For many years, SETI (Search for Extraterrestrial Intelligence) initiatives have employed radio telescopes, hoping to intercept signals of artificial origin emanating from the cosmos. These endeavors hold the promise of detecting specific forms of alien communication or technological signatures, provided they are within a certain proximity and utilizing substantial energy. However, our detection is not comprehensive – space is vast, and we could easily miss or not recognize many indicators.

	Early Warning (Are there reliable early warning indicators?)	2	No, no reliable indicators would warn us of an impending alien contact before it happens. If an extraterrestrial civilization decided to reach out (by sending a message or probe), humanity would likely become aware of it only at the moment of detection. We do not know of any “precursor” events that foreshadow alien contact. Unlike some disasters with precursory signs, an alien contact would probably be sudden without earlier clues.
	Duration of Impact (How long will its effects last?)	2	The impacts of contact with an alien civilization would likely be enduring or permanent. If hostile aliens were to attack or invade, the destruction or even human extinction would obviously be irreversible. Even in a peaceful contact scenario, the event would fundamentally alter human civilization’s trajectory for all future time—learning we are not alone would forever change our culture, technology, and worldview.
	Influence After Event Occurrence (Can humans affect the outcome once it occurs?)	2	Humans would have minimal agency in shaping the outcomes after contact, especially if the aliens are much more advanced. In a detrimental contact (hostile invasion), human actions would likely have little effect on the outcome – survival might depend entirely on alien decisions, not our resistance. Even in a benign contact, the post-event path (such as integration of alien knowledge or possible societal upheaval) would be primarily driven by the technologies and terms set by the extraterrestrials, with humanity in a reactive position.
	Feedback Mechanisms (Could feedback loops amplify its effects?)	1	Some feedback, like magnifying the effects of alien contact, though these are mainly social or geopolitical rather than physical. For example, the revelation of alien existence could spark global panic or miscommunication that leads to human conflicts (e.g. rival nations might fight over how to respond or over alien alliances), exacerbating the damage beyond the aliens’ direct actions. Another potential feedback is if early hostile exchanges trigger escalating retaliation – if humans respond aggressively, aliens might react with greater force, creating a rapid escalation loop.
Global Pandemic (Engineered Supervirus) [37; 40; 50; 51]	Influence on Occurrence (Can humans influence whether it occurs?)	0	The risk of an engineered supervirus is entirely under human control through biosecurity measures, regulations, and oversight of high-risk research; policymakers can greatly lower its chance by enforcing strict guidelines.
	Response Capability (Can we mitigate its effects once it occurs?)	1	Although modern public health systems (e.g., rapid vaccine development, quarantine measures) can reduce spread and mortality, a highly lethal engineered virus might overwhelm these responses, limiting our ability to mitigate its full global impact.
	Monitoring & Detection (Are there systems to monitor outbreaks?)	0	Comprehensive global disease surveillance systems (e.g., WHO, CDC) actively monitor emerging infectious diseases, and extensive use of genomic sequencing allows early detection of novel pathogens once they begin spreading.
	Early Warning (Are there reliable early warning indicators?)	1	Early-warning systems exist through global health networks and surveillance, but their effectiveness depends on rapid data sharing and political willingness to act; delays—as observed during COVID-19—can diminish the warning period.
	Duration of Impact (How long will its effects last?)	1	Pandemic impacts are typically medium-term (lasting months to years), although a supervirulent engineered pathogen could prolong societal and economic disruption; however, recovery is possible if the virus is eventually contained.
	Influence After Event Occurrence (Can humans affect the outcome once it occurs?)	0	Even after a pandemic begins, humanity retains significant control via public health interventions, medical treatments, and policy adjustments that can substantially alter outcomes, as demonstrated during the COVID-19 response.
	Feedback Mechanisms (Could feedback loops amplify its effects?)	1	Positive feedback loops (e.g., rapid mutation leading to variant emergence, overwhelmed healthcare leading to higher mortality) are recognized in pandemic dynamics, although established containment measures can sometimes break these loops.
Unaligned AI Superintelligence [42; 43; 44; 45; 46; 47; 48; 49; 62; 63]	Influence on Occurrence (Can humans influence whether it occurs?)	0	The development of superintelligent AI is wholly under human control. Through research regulation, safety protocols, and international governance efforts, policymakers can decisively influence if and how advanced AI systems are built.

	Response Capability (If the event occurs, can we mitigate its effects?)	2	Once a superintelligent AI becomes unaligned and capable, our current technology and methods are virtually powerless against it. There is no known countermeasure to halt or counteract a rogue superintelligence, making post-event response effectively nil.
	Monitoring & Detection (Are there systems to monitor advanced AI projects?)	1	While some initiatives exist to track AI developments, formal and comprehensive monitoring of cutting-edge, potentially superintelligent systems is still emerging, leaving gaps in oversight and early detection capabilities.
	Early Warning (Are there reliable early warning indicators?)	1	Potential early warning signs—such as anomalous outcomes in AI experiments—may exist; however, these signals are likely subtle and not definitive, meaning that the window for intervention might be short or ambiguous.
	Duration of Impact (How long will its effects last?)	2	If an unaligned superintelligent AI gains dominance, its impact would be effectively permanent; such a system could continuously override human decisions and irrevocably alter society.
	Influence After Event Occurrence (Can humans affect outcomes post-event?)	2	Once a superintelligent, unaligned AI is operational, human capacity to alter its course becomes negligible due to the vast disparity in intelligence and control.
	Feedback Mechanisms (Could feedback loops amplify effects?)	2	Recursive self-improvement—where the AI enhances its own capabilities in a runaway loop—is a critical risk, and feedback from such an exponential process is inherently unpredictable and uncontrollable once initiated.
Massive Asteroid Impact [52; 53; 54; 55; 56; 57; 58; 59; 60; 61]	Influence on Occurrence (Can humans influence whether it occurs?)	1	The occurrence of natural asteroid impacts is governed by orbital mechanics and is beyond direct human control. However, if a potential impactor is detected early, humanity can attempt mitigation via deflection—thus a limited indirect influence is possible.
	Response Capability (If the event occurs, can we mitigate its effects?)	1	Provided sufficient lead time, deflection missions (e.g., kinetic impactors) can alter an asteroid's trajectory; however, for very large objects or with short warning, our current technology and response options remain limited.
	Monitoring & Detection (Are there systems to monitor potential impactors?)	0	Global astronomical surveys (e.g., NEOWISE, Pan-STARRS) continuously monitor near-Earth objects, ensuring that potential impactors are detected well in advance.
	Early Warning (Are there reliable early warning indicators?)	0	With current detection systems, hazardous asteroids are usually identified many years in advance, offering ample early warning before a potential impact.
	Duration of Impact (How long will its effects last?)	2	A massive asteroid impact could trigger an impact winter and other environmental disruptions with long-lasting effects—potentially lasting decades or even altering global conditions permanently in terms of human civilization.
	Influence After Event Occurrence (Can humans affect outcomes after impact?)	1	After an impact, direct human intervention is minimal; post-event influence is largely limited to disaster relief and long-term rebuilding, as the natural processes (e.g., atmospheric clearing) proceed autonomously.
	Feedback Mechanisms (Could feedback loops amplify the impact?)	1	The impact would trigger positive feedbacks—such as an impact winter caused by atmospheric dust and aerosols—which could amplify the initial catastrophe. These feedback processes are well recognized in impact modeling studies though uncertainties remain in their precise magnitude.
Global Climate Catastrophe [64; 66; 67]	Influence on Event Occurrence (Can humans influence whether it occurs?)	0	Climate change is driven by greenhouse gas emissions, which are entirely under human control. Through policies to reduce emissions, transition to renewable energy, and enhance carbon sinks, humanity can directly influence whether catastrophic warming is avoided.
	Response Capability (Can we mitigate its effects once it occurs?)	1	Although mitigation measures (such as geoengineering, adaptation, and emergency response) are available, their effectiveness is limited once extreme climate change sets in. The scale and inertia of Earth's climate system mean that post-onset responses are challenging, even if they can reduce some impacts.
	Monitoring & Detection (Are there systems to monitor the climate?)	0	A comprehensive array of satellites, ocean buoys, and terrestrial stations facilitates continuous climate monitoring. Organizations such as NOAA and NASA furnish near-real-time data pertaining to temperature, greenhouse gas concentrations, ice cover, and other essential indicators.
	Early Warning (Are there reliable early warning indicators?)	1	Early warning indicators exist (such as changes in ocean currents, increased methane emissions, or abrupt ice loss), but the complexity of the climate system makes it difficult to predict precisely when critical thresholds will be crossed.

	Duration of Impact (How long will its effects last?)	2	Extreme climate change could permanently alter Earth's state for centuries to millennia. Once a tipping point is crossed (e.g., widespread ice loss), the resulting changes are effectively irreversible on human timescales.
	Influence After Event Occurrence (Can humans shape recovery post-event?)	1	While adaptation measures (e.g., building resilient infrastructure, managed retreat) can help mitigate long-term damage, the scale of a catastrophic climate shift largely limits human influence on reversing the trend once it has fully set in.
	Feedback Mechanisms (Could feedback loops amplify effects?)	2	Positive feedbacks—such as ice-albedo and permafrost methane release—are critical in climate dynamics and can amplify warming once triggered. These mechanisms are well recognized, although their precise thresholds and magnitudes remain uncertain.
Gamma-Ray Burst (GRB) [65; 71; 72; 73; 74]	Influence on Occurrence (Can humans influence whether it occurs?)	1	Gamma-ray bursts are cosmic events driven by astrophysical processes (e.g., massive star collapse or neutron star mergers) that are entirely beyond human control. While their probability is extremely low, we have no method to alter cosmic events.
	Response Capability (If the event occurs, can we mitigate its effects?)	2	There are no known technological or societal countermeasures that could prevent or mitigate the sudden, high-energy impacts of a nearby GRB; once the burst strikes Earth, rapid and global devastation is expected.
	Monitoring & Detection (Are there systems to monitor potential GRBs?)	1	Although our satellites (e.g., NASA's Swift and Fermi) detect GRBs as they occur, these detections provide almost no lead time for Earth-based intervention; thus, we cannot practically detect an imminent GRB with actionable advance warning.
	Early Warning (Are there reliable early warning indicators?)	2	There are no reliable early warning signals for an impending GRB since these events occur with little or no precursor detectable by current technology; the very detection happens as the burst reaches Earth.
	Duration of Impact (How long will its effects last?)	2	The atmospheric and biospheric impacts of a GRB, including massive ozone depletion and subsequent UV exposure, could persist for years—effects that may ultimately be irreversible or endure for decades, dramatically altering Earth's environment.
	Influence After Event Occurrence (Can humans affect outcomes post-event?)	2	Once a GRB strikes, its catastrophic radiative and chemical effects would leave little to no opportunity for human intervention or recovery efforts; the damage to the atmosphere and biosphere would be effectively irreversible.
	Feedback Mechanisms (Could feedback loops amplify its effects?)	2	The environmental feedbacks triggered by a GRB, such as cascading ozone depletion leading to intensified UV exposure and further ecological damage, are unpredictable and likely uncontrollable, thereby amplifying the initial shock.
Nanotechnology Disaster (Grey Goo) [68; 69; 70; 75; 76; 77; 78; 79]	Influence on Occurrence (Can humans prevent the event?)	0	This risk is entirely man-made; by regulating research and development in molecular nanotechnology and enacting strict safety protocols, humanity can prevent the creation or accidental release of self-replicating nanobots.
	Response Capability (If the event occurs, can we mitigate its effects?)	2	Once a self-replicating nanotech disaster ("grey goo") begins, there is no known countermeasure capable of stopping its exponential spread; current technology lacks an effective "kill switch" to halt uncontrolled replication.
	Monitoring & Detection (Are there systems to detect out-of-control nanotech?)	1	Existing laboratory and institutional monitoring of nanotechnology research is in place; however, no comprehensive global system is dedicated to detecting an outbreak of self-replicating nanomachines, leaving a gap in early detection.
	Early Warning (Are there reliable early warning indicators?)	2	Although anomalous behavior in nanotech laboratories might serve as a preliminary indicator, there is no standardized early-warning system to flag potential grey goo scenarios before they escalate beyond control.
	Duration of Impact (How long will its effects last?)	2	If a grey goo outbreak were to occur, its self-replicating nature could lead to the irreversible consumption of available resources, resulting in permanent or near-permanent disruption to Earth's biosphere.
	Influence After Event Occurrence (Can humans affect outcomes post-event?)	2	Once a grey goo disaster is underway, human ability to interfere is extremely limited; the rapid, self-reinforcing replication process would likely outpace any attempted intervention, leaving future outcomes beyond our control.

	Feedback Mechanisms (Could feedback loops amplify the event?)	2	The hypothetical grey goo scenario would likely exhibit uncontrollable positive feedback—each generation of nanobots producing more copies exponentially, a phenomenon with no real-world countermeasure, making the process inherently runaway.

Source: Author calculations