The State of Global Catastrophic Risk Research: A Bibliometric Review

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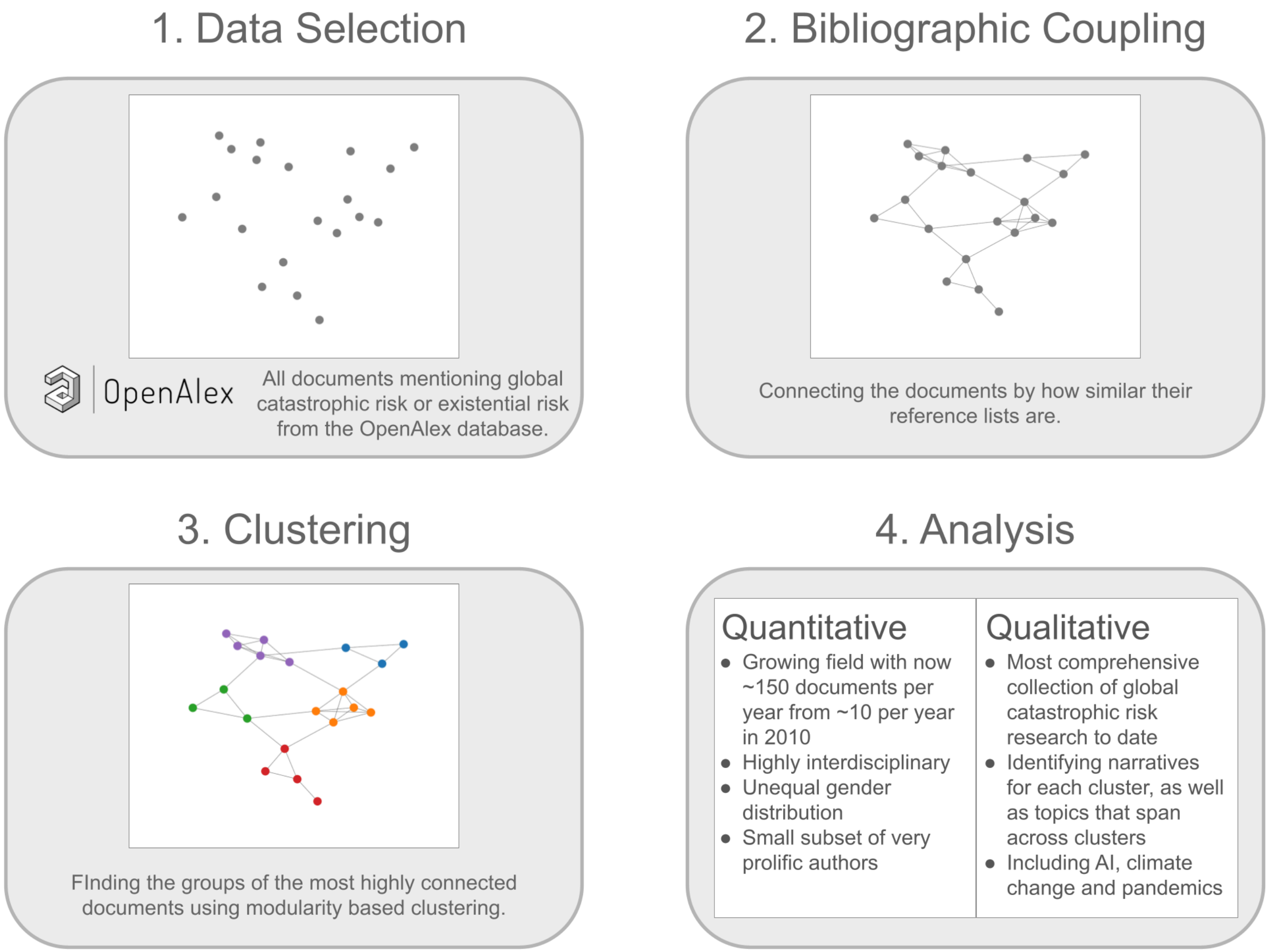
Visual summary



Abstract

The global catastrophic risk (GCR) and existential risk (ER) literature focuses on analysing and preventing potential major global catastrophes including a human extinction event. Over the past two decades, the field of GCR/ER research has grown considerably. However, there has been little meta-research on the field itself. How large has this body of literature become? What topics does it cover? Which fields does it interact with? What challenges does it face? To answer these questions, here we present the first systematic bibliometric analysis of the GCR/ER literature. We consider all 3,437 documents in the OpenAlex database that mention either GCR or ER, and use bibliographic coupling (two documents are considered similar when they share many references) to identify ten distinct emergent research clusters in the GCR/ER literature. These clusters

align in part with commonly identified drivers of GCR, such as advanced artificial intelligence (AI), climate change, and pandemics, or discuss the conceptual foundations of the GCR/ER field. However, the field is much broader than these topics, touching on disciplines as diverse as economics, climate modeling, agriculture, psychology, and philosophy. The metadata reveal that there are around 150 documents published on GCR/ER each year, the field has highly unequal gender representation, most research is done in the US and the UK, and many of the published articles come from a small subset of authors. We recommend creating new conferences and potentially new journals where GCR/ER focused research can aggregate, making gender and geographic diversity a higher priority, and fostering synergies across clusters to think about GCR/ER in a more holistic way. We also recommend building more connections to new fields and neighboring disciplines, such as systemic risk and policy, to encourage cross-fertilisation and the broader adoption of GCR/ER research.

1 Introduction

Many scholars argue that we are in a time of extraordinary *global risk* (e.g. (Centeno et al., 2015; Lawrence et al., 2023; Lynas, 2020; Ord, 2020)), in which a variety of hazards such as war, disease, or a changing climate threaten humanity on an unprecedented scale. Global risk here means risk to humanity on a global scale. Approaches to studying global risk vary and overlap. For example, some scholars approach the study of global risks through the lens of *tipping points* (Wunderling et al., 2024), while others use a frame of *critical transitions* (Scheffer et al., 2012), *systemic risk* (Arnscheidt et al., 2024; Centeno et al., 2015), or *global polycrisis* (Lawrence et al., 2023).

A subset of global risk research focuses on possible worst-case outcomes. This is the study of global catastrophic risk (GCR) and existential risk (ER). There are varying definitions of what constitutes a GCR or an ER. Common definitions are that GCR is the risk of the death of a significant fraction of all humans or a significant loss of well-being on a global scale, while ER is the risk of human extinction or catastrophes judged to be of a similar magnitude (for example, a permanent global collapse or a long-lasting global dictatorship). While both terms can be traced back at least to the realization of the inherent danger of the first nuclear weapons (Beard and Bronson, 2023) and the general realization that it was possible for humanity to go extinct (Moynihan, 2019, 2020b), they became distinct concepts in the 2000s. ER was introduced as a term by Bostrom (2002), while GCR was brought to prominence in an edited volume by Bostrom and Cirkovic (2008). While these works helped formalize and popularize these concepts, it is important to note their position within a much longer and broader history of concern about global catastrophes and human extinction.

The focus of the GCR/ER literature has evolved over time. Early work focused on separately assessing the risk of catastrophes due to distinct large hazards, such as nuclear war or dangerous artificial intelligence. This approach has found one of its clearest descriptions in Toby Ord's "The Precipice" (Ord, 2020). This view has been criticized as being too simplistic, with other research arguing for splitting risk into hazard, exposure, vulnerability, and response, as is common in other fields that study risk (e.g., disaster risk science) (Kemp et al., 2022; Liu et al., 2018), challenging the idea of "natural" GCR (Baum, 2023), avoiding siloed thinking that focuses on single hazards (Sepasspour, 2023), considering new areas like latent risk (Tang and Kemp, 2021) and making new connections to other adjacent fields like systemic risk (Arnscheidt et al., 2024; Manheim, 2020).

It is not clear how much the research communities within and adjacent to GCR research overlap. Also, the GCR/ER literature has grown rapidly in recent years and has touched on many topics, but it is not clear how, where and why the terms of GCR and ER are used. How large has this body of literature become? What topics does it cover? Which fields does it interact with? What challenges does it face? There is little meta-research in the GCR/ER field to answer such questions. This makes it difficult for researchers and the public to get an overview of GCR/ER research and its arguments. The closest efforts thus far were a short review (Ó hÉigeartaigh, 2017), a GCR assessment by the RAND Homeland Security Operational Analysis Center which tried to assess the GCR/ER landscape for the next 30 years (Willis et al., 2024), an anthology of key ER texts (Beard and Hobson, 2024), a GCR horizon scan to identify currently underexplored risks (Dal Prá et al., 2024) and a crowd-sourced machine-learning model (Shackelford et al. 2020) to create a bibliography of GCR/ER documents. While all helpful, these efforts do not allow us to understand the different research communities involved in the study of global risk, how they and their research focus have changed over time.

To answer such questions around how the field has developed, this article provides the first systematic review of the space of GCR and ER research. Our process is illustrated in the visual summary. Starting with all documents listed in the OpenAlex database (Priem et al. 2022) that mention GCR/ER, we use bibliographic coupling to identify distinct research clusters. Bibliographic coupling means that two documents are defined as similar when they have similar reference lists. This metric is generally seen as the bibliometric measure that best captures the current state of a field (Zhao and Strotmann, 2015). We then further filter the clusters for their relevance to GCR/ER via structured author input (see Section 2), and analyze the clusters in detail by describing the main narratives and arguments and metadata (e.g. who are the main authors for different clusters), uncovering the main connections, analyzing the methodological approaches, and tracing the field's development over time (see Figures 2 and 3 for a quick overview of the field).

2 Methods

This paper aims to give an overview of all published research literature that uses the terms GCR/ER. This is not the same as all the literature which is relevant to GCR/ER, which is much larger. We use this approach as we want to track the development of the research which directly focuses on GCR/ER. GCR is a term that is used almost exclusively by researchers who work on those topics with a focus on the magnitude of the outcome, and was not in general use before it was coined in 2008. It is therefore a promising term to find and assess the research focused on these topics. Since "existential risk" is used in a wide range of contexts to mean a wide range of things (e.g. as in Huggel et al. (2022)), this introduces more false positives (i.e. articles which use "existential risk" but are not related to existential risk as defined in the Introduction). We aim to screen out such false positives in several steps, detailed further below. .

To find these documents we used the bibliographic catalog OpenAlex (Priem et al., 2022). OpenAlex is similar in scope to commercial bibliographic catalogs like Web of Science or Scopus (Alperin et al., 2024), but has the advantage of being completely open access. After downloading the dataset we followed standard bibliometric procedures (Zhao and Strotmann, 2015) to connect the documents via their similarity (using bibliographic coupling, see below) and clustered the resulting network to reveal those that share themes and topics. This step was done with VOSviewer, a widely used bibliometric tool (van Eck and Waltman, 2010). The clusters were then used to look at the metadata of the GCR/ER literature and to qualitatively describe the main documents in each cluster. The main documents were selected from the clusters by using those documents that in their cluster either had the most citations, were connected to a lot of other documents in the dataset or mentioned the terms GCR/ER often.

All code and data used here are available in the repository which accompanies this study: https://github.com/florianjehn/bibliometrics/ (Jehn and Ilin, 2024)

2.1 Data acquisition

On OpenAlex we search for all documents containing the terms "global catastrophic risk" OR "existential risk" in their title/abstract and if available full text as well. This resulted in 3,437 search results. We downloaded the data from OpenAlex (https://openalex.org/) on 03.07.2024 with the API call:
"https://api.openalex.org/works?page=1&filter=default.search:%22global+catastrophic+risk%22+OR+%22existential+risk%22".

This dataset was then filtered for relevant documents as described in the following steps.

2.2 Bibliographic coupling and clustering in VOSviewer

We conduct bibliographic coupling and clustering analysis in VOSviewer (van Eck and Waltman, 2010); this is an established tool in scientometrics and tends to deliver better results than comparable methods (van Eck et al., 2010; Waltman et al., 2010).

First, bibliographic coupling determines the similarity between documents. Here, documents are considered similar when they cite similar references. Bibliographic coupling is a standard method in scientometrics and is especially useful to get an overview of the current state of a scientific field (Zhao and Strotmann, 2015). To give equal weight to all documents we used fractional counting (Perianes-Rodriguez et al., 2016). Fractional counting means that the strength of the link between two documents due to a certain shared reference is divided by the total number of times this reference is cited across the entire dataset, preventing highly cited documents from unduly influencing the coupling strength.

Total link strength for a given document is then calculated by summing the strengths of all of the links between a given document and all other documents in the dataset. Total link strength can at maximum be as large as the number of references a document has. Thus, a document with high total link strength is connected to many documents and has a high overlap in their reference lists.

To find the distinct groups of documents in the dataset, we used the modularity based clustering technique implemented in VOSviewer (Waltman et al., 2010) with its default values. We discarded all unconnected documents (documents that don't share any references with the main group of documents), clusters with 5 or less documents in them and also documents with less than two total link strength (meaning documents that share only a single reference with all other documents considered), as those documents do not have a direct relation to the topics researched here and only clutter the data. A flow chart depicting all steps of document selection and exclusion is shown in Figure 1.

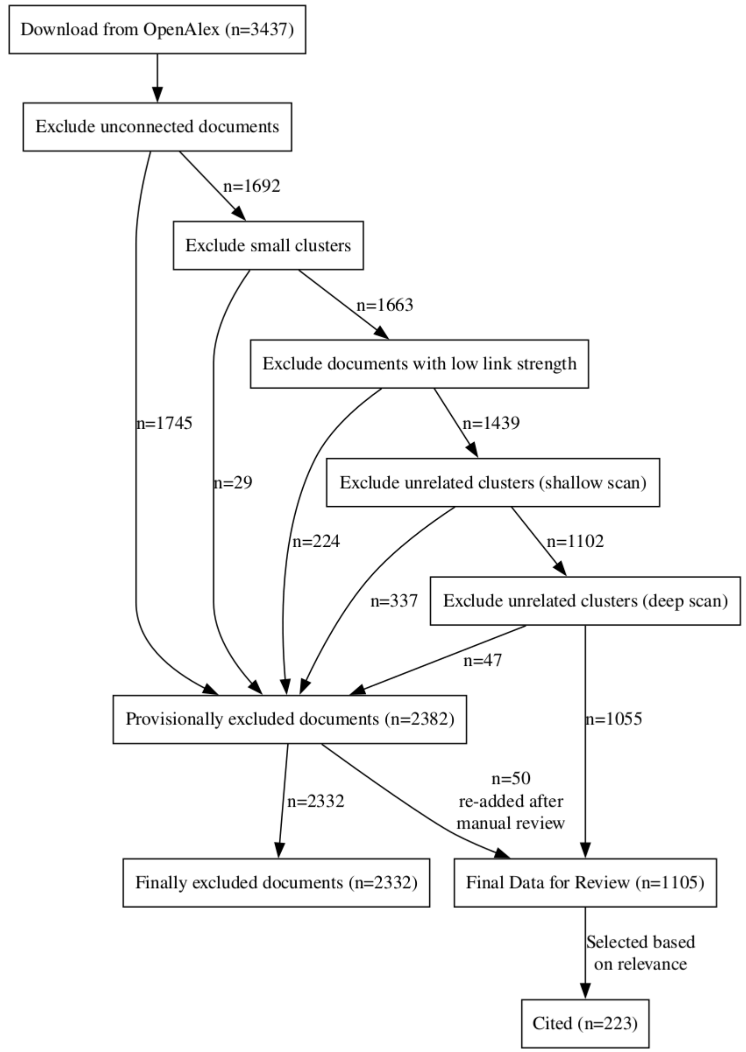


Figure 1: Flow chart representing all steps of document selection and exclusion.

2.3 Determining the topics of clusters

We determined the topics of the clusters in a two step process:

- **Shallow Scan**: Each author received the lists of documents from the different clusters identified in section 2.2. They reviewed the titles and abstracts to understand the content of these documents. Independently, each author created a brief description for all clusters. After completing this task, the group collaboratively decided on short descriptive titles for each cluster. During this step we excluded clusters from further analysis which did focus on topics outside of GCR (for example using ER in relation to an illness a person has). A cluster was excluded when the majority of the authors did not deem it relevant to GCR and ER (this removed clusters 6, 7, 8, 14, 15, 16, 22 and 23).

- **Deep Scan**: Each author was assigned 1-3 clusters to summarize. For each cluster they reviewed documents with the highest OpenAlex relevance score, total link strength, citations, and normalized citations. They assessed whether each document primarily addressed GCR/ER or only mentioned it briefly. Documents focused on these risks were summarized and integrated into a coherent narrative for the cluster. Documents that only briefly mentioned the risks were used as examples of their context and usage. During this step we also further excluded three of the smaller clusters (13, 20, 21), because they contained only a very small number of relevant documents. The relevant documents were then discussed in section 4.11.

Both scans were conducted by subject-level experts which all have previous experience or publication in GCR/ER.

Additionally, to complement these documents in the main dataset, we also manually looked at the documents that were excluded in the first step because their references did not have any overlap with the main dataset, to make sure that no important research was overlooked. This resulted in a small selection of documents that were deemed important to include, which are now discussed in section 4.12.

2.4 Subsequent analysis in Python and gender detection

Based on the clustered documents from VOSviewer we created all other plots in Python. To determine author gender for Figure 5 we used gender-guesser (v0.4; https://github.com/lead-ratings/gender-guesser). This guesses gender based on the first name. We acknowledge that this might misrepresent the actual gender a person identifies with, but since we are only calculating aggregate statistics (i.e. not looking at individual researchers) this is not a problem for the analysis. One limitation is that the tool also excludes gender identities that do not fit the classical binary.

3 Development of the field

Our bibliometric analysis yielded 10 distinct research clusters with a primary focus on GCR and ER. We label these clusters as “Foundations” (key foundational texts of the field), “Artificial Intelligence”, “Climate Change”, “Governance”, “Pandemics”, “Transhumanism”, “Global Resilience and Food Security”, “Risk Management and Mitigation”, “Reasoning and Risk”, and “Emerging Biotechnologies, Emerging Futures”. We describe the content of each cluster in detail in Section 4. In this section, we first conduct a more quantitative analysis of the bibliometric data. This reveals, among other things, how the clusters have grown over time, how the clusters relate to one another, who is authoring the research and where they tend to be located, as well as in what journals the research is being published.

3.1 How has the GCR/ER literature developed over time?

The literature has grown from around only 10 documents each year in 2010 to more than 150 for 2023 (Figure 2). Not all of those documents included here have GCR/ER as their primary focus, as the list still includes some false positives and documents that only mention GCR/ER in passing, but the overall trend is also mirrored in the dataset of Shackelford et al. (2020) which only includes articles that researchers have manually tagged as GCR/ER relevant.

We can see a clear dip in the amount of documents in 2020. This is an unexpected trend at first, because the amount of all scientific papers published in the same period does not show such a dip (SJR World Report, 2024). One possible explanation is COVID-19. While the yearly number of new documents decreased or stayed constant for all other clusters, the number of new documents for the Pandemic cluster increased. This suggests that researchers who previously studied other aspects of GCR/ER devoted more time to working on pandemics instead, either in academia (which could explain the rise in pandemic documents) or outside of academia (which could explain the overall drop). A similar trend can be found in other fields which are relevant to COVID-19. For the field of life sciences for example, Riccaboni and Verginer (2022) found that in 2020 there was a rapid rise in publications about COVID-19, while all other topics saw a decrease.

We can also compare the relative sizes of the clusters over time (Figure S1). The Foundations and the Governance clusters were more dominant from 2000 - 2010, but since then research has been spread more evenly between the different clusters and the proportions have stayed fairly similar, with some more diversification in topics in the last few years. The main changes were a constant decrease of documents in the Governance cluster, the uptick of publications in the Pandemics cluster in 2020 and the beginning of the Global Resilience and Food Security cluster in 2015. This also shows how the GCR/ER literature diversified its scope over time, starting with a narrow set of more philosophical discussions and slowly branching out to more specific topics like global food security. This trend of field diversification over time can also be found in other new fields, e.g. degrowth (Engler et al., 2024).

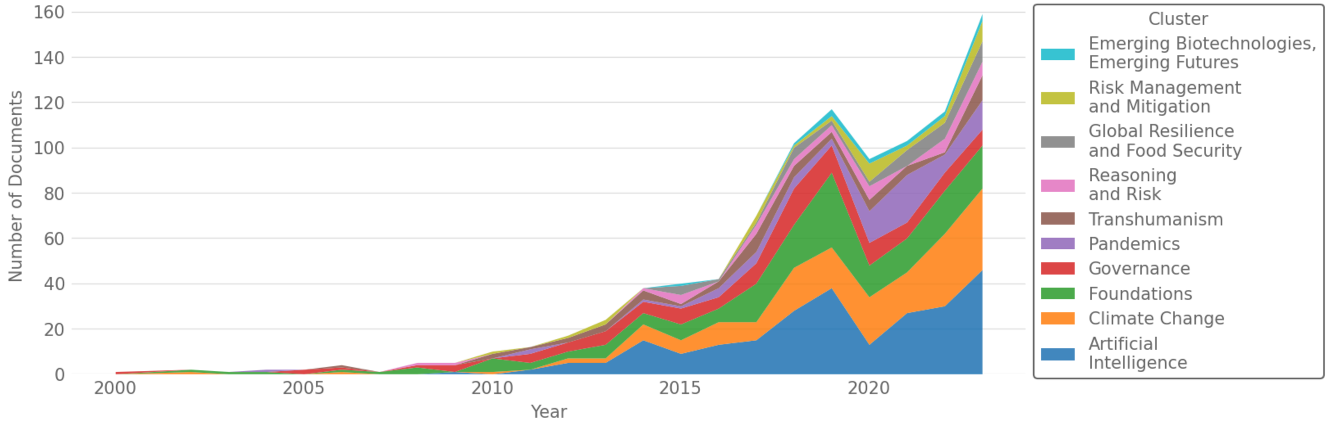


Figure 2: GCR/ER documents per year by cluster. The same data shown as percentage of the documents in a given year can be found in Figure S1. This still contains some false positive entries (see Section 2), but is a reasonable representation of the overall trends. See Figure S2 for the overall amount of documents per cluster.

What also stands out is the transhumanism cluster, as this topic does not directly relate to the understanding and management of GCR/ER. It is included here, as many of the documents in that cluster discuss GCR/ER topics like human extinction or artificial intelligence from a transhumanist perspective. This thematic overlap is also given by many of the early researchers of GCR/ER having a direct connections to transhumanism (e.g. Nick Bostrom).

3.2 How do the clusters relate to each other?

Even though the clusters represent distinct parts of the overall GCR/ER literature, they frequently refer to each other and often tackle similar topics from different points of view. Figure 3 visualizes these connections by showing the strength of the bibliographic coupling between the different clusters (essentially how much the references from different clusters overlap, see Section 2). The biggest overlaps can be found between the Foundations and the Climate Change clusters and between the Foundations and the Artificial Intelligence clusters. This high overlap is likely due to many of the early scholars in the field, like Nick Bostrom or Seth Baum, consider AI as a serious threat and therefore often cite and explore AI related topics in their foundational works.

However, apart from these two larger overlaps, the references from the Foundations cluster are also used a lot in the Global Resilience and Food Security cluster (and vice versa), while all other smaller clusters have their largest overlap with other clusters besides the Foundations cluster. This shows the interdisciplinary nature of the field of GCR/ER. Also, as the field has diversified across disciplines, most have tended to link back to the foundational work, likely by citing their definitions of ER/GCR.

While the idea of GCR and ER is taken up in many fields, they often only take it up as only a discussion point and not the main focus of their work. This is different for the Global Resilience and Food Security cluster, because the origins of that cluster were directly inspired by the works in the Foundations clusters. Figure 2 and Figure S2 also show that, in terms of the number of papers published, the GCR/ER literature puts a strong emphasis on risk from AI, with climate change a close second.

There are also topics that span across several clusters, but are covered from different angles in those clusters:

- Artificial Intelligence: The main AI cluster discusses the broad strokes of AI research, the Pandemics cluster highlights AI as something that could both be helpful and detrimental for global health and the Risk and Reasoning cluster mainly frames AI as a technological risk.
- History: History is often used to frame the topic of the cluster in a broader view and learn from past events. This is especially present in the Pandemics and Foundations cluster.
- COVID-19: This pandemic was one of the closest events to a GCR in recent history and is therefore often used as an example or comparison.

The Climate Change cluster is more evenly connected to all other clusters, suggesting that the field of climate change research serves as a kind of connective tissue between GCR ideas and more general research about risk and global threats. Interestingly, the literature on nuclear war does not appear as its own cluster, despite having been studied for a similar length of time as anthropogenic climate change and also having a focus on a potentially very large catastrophe.

Moreover, we can see that all clusters share at least some overlap in what they cite, although this is sometimes very small.

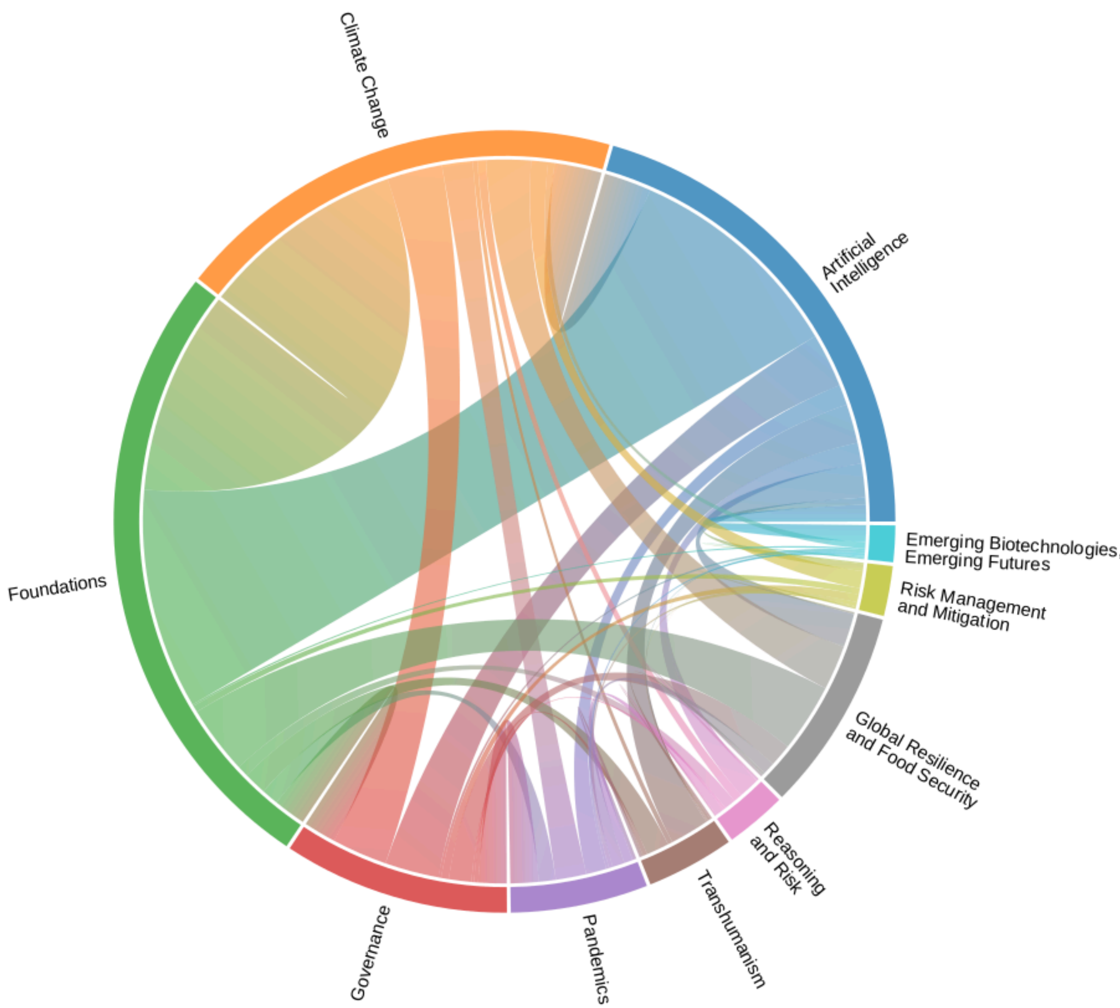


Figure 3: Chord diagram of how the clusters relate to each other. The thicker the line is between two clusters, the more their references overlap. For example, the figure shows that the Artificial Intelligence cluster has a large overlap with the Foundations cluster. The total width of each section for a cluster represents the overall size of the connections to other clusters (based on the sum of fractional counting of the bibliographic coupling strength, see Section 2); for the total number of articles in each cluster, see Figure S2. This figure is based on the 1105 documents selected for the review.

3.3 What is the current state of the GCR/ER literature?

While an imperfect metric for the importance of a given author to the field, it is also interesting to look at which authors have published the most articles across these clusters: this is shown in Figure 4. We find that Seth Baum and David Denkenberger have published the largest number of documents here. Interestingly, half of the most prolific authors are from the Global Resilience and Food Security cluster. The main exception being Seth Baum, who is the dominant author in the Foundations cluster and Milan Ćirković, who has published a lot in the Foundations cluster as well, but also in the AI cluster.

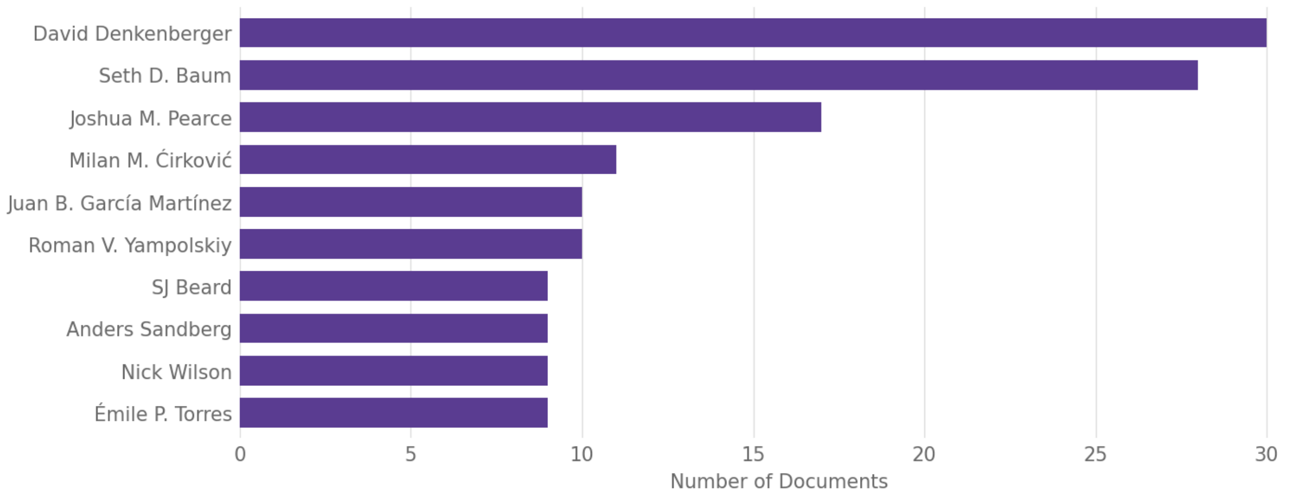


Figure 4: Most prolific authors across all clusters, in terms of the number of documents published.

The reason for this overrepresentation of the Foundations and the Global Resilience and Food Security clusters can be found in the amount of unique authors in relation to the number of documents in a cluster (Figure S3). This shows that both the Foundations, but especially the Global Resilience and Food Security cluster have a small group of authors that publish the majority of documents, while this is not the case in other clusters. This can also be seen in the overall amount of documents published per author and cluster as well (Figure S4).

Many of these most prolific authors are located at a few key institutions. Namely, the Alliance to Feed the Earth in Disasters (ALLFED), the Global Catastrophic Risk Institute (GCRI), the Centre for the Study of Existential Risk (CSER) and the now-dissolved Future of Humanity Institute (FHI). This is to be expected, as these organisations are also the ones that are most explicitly focussed on GCR/ER. A more detailed breakdown of the main institutions can be found in Figure S5 and Figure S6, but does not mention these institutes directly, as OpenAlex mainly collects university affiliations and does not break them down below the university level. These organizations are mostly still the same as those highlighted by Sundaram et al. (2022). While this small set of organizations makes it easier to aggregate at these places, it also means that for many researchers not living in the US or UK, it is difficult to start working on GCR/ER topics. Further consequences of this concentration are discussed in Sundaram et al. (2022).

Authors in the United States and the United Kingdom contribute around 60 % of the publications (Figure S7 and Figure S8). But there is also a substantial contribution from authors in Germany, Australia and Canada. The vast majority of authors are from OECD countries, with only few from the rest of the world.

Another unequal distribution can be found in the gender of the authors (Figure 5, see Section 2.4 for how the gender was determined). The field of GCR/ER as a whole is quite skewed towards male researchers, around 75 % of the authors being male. The difference is even more extreme when we look at the most prolific researchers (Figure 4) where out of 10 researchers, none is female.

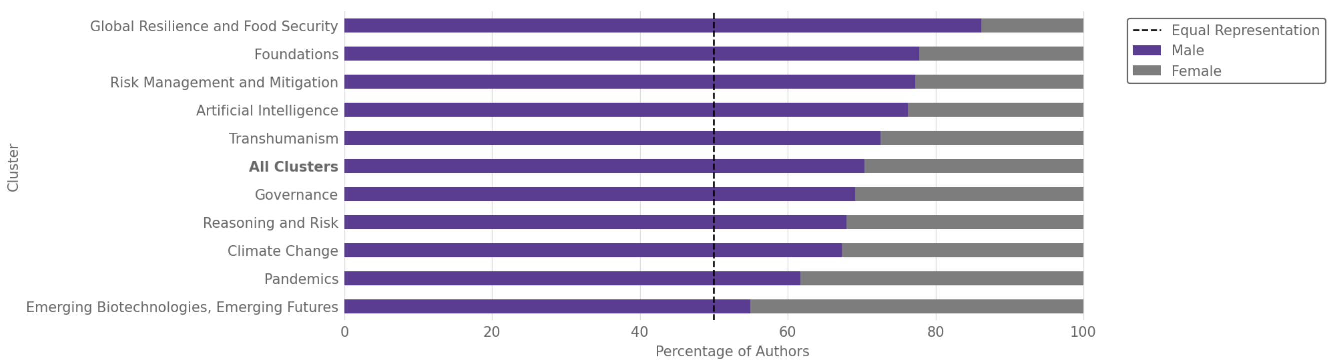


Figure 5: Gender Balance in GCR/ER research based on all clusters. See Section 2 for an explanation on how gender was determined.

This skew is especially present in the Global Resilience and Food Security, with around 85 % of the authors being male, but the Foundations, Artificial Intelligence as well as Risk Management and Mitigation are quite skewed as well. Only the Pandemics and biotechnology clusters even come close to a 1 to 1 ratio. The gender imbalance in GCR/ER research can likely be attributed to a combination of historical underrepresentation of women in fields similar to GCR/ER (or where GCR/ER originated from), such as certain STEM fields (Huang et al., 2020), where clusters like AI and risk management are heavily rooted, and systemic barriers such as biased professional networks, unequal access to opportunities, cultural stereotypes about expertise in technical and policy-related fields (Holman et al., 2018) and the skew towards male authors in science in general (Larivière et al., 2013). In addition, institutional challenges feminists have long been pointing towards, including work-life balance issues and lack of female role models in leadership, likely further perpetuate the skewed gender distribution (Wang and Degol, 2017). This lack of gender diversity has also been criticized in earlier work (Cremer and Kemp, 2021; Futerman et al., 2023), highlighting it as a persistent issue for the field of GCR/ER.

There is also no clear journal for the full breadth of GCR research. If we look at the most-represented journals from across the overall dataset (Figure 6) it looks like Futures or AI & Society might fit that role, but if we separate that by clusters (Figure S9) it becomes apparent that Futures is only used in the Foundations cluster, while AI & Society is only used in the Artificial Intelligence and Reasoning and Risk clusters.

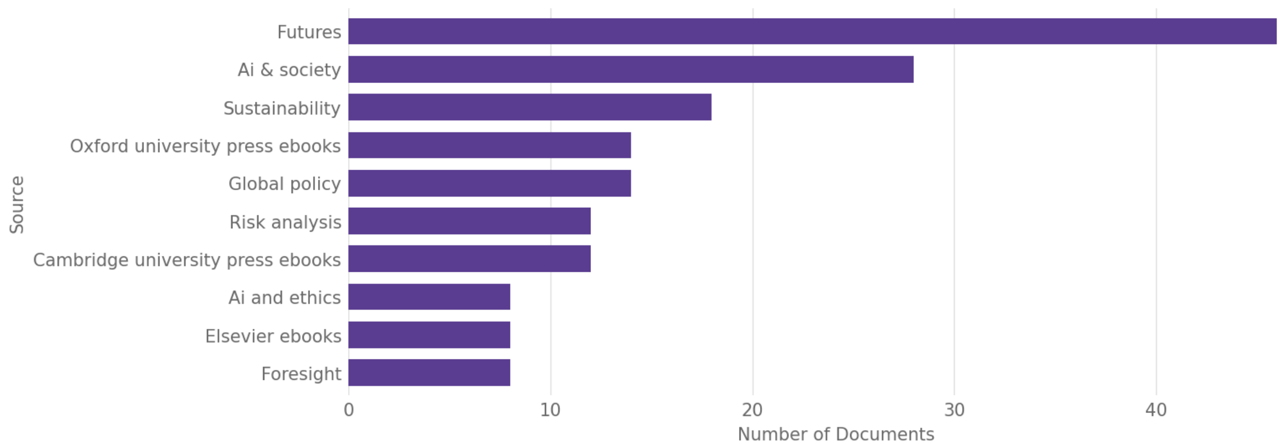


Figure 6: Most common publication outlets from across all clusters.

4. What are the main thematic clusters and what narratives are they discussing?

In this section, we describe the research clusters revealed by our bibliometric analysis in more detail. Our discussion of each cluster focuses on the key narrative we perceive to be present, but we aim to be inclusive in the sense that if a document is part of a cluster and is relevant to GCR/ER we typically mention it even if it does not address GCR/ER in detail. The documents in each cluster that have no relevance to GCR/ER as understood in this paper are not discussed. The cluster descriptions differ in their structure to reflect the structure of the documents in the cluster.

4.1 Foundations

This cluster includes key foundational texts about GCR and ER. Most documents in this cluster focus on general conceptual discussions: for example, Bostrom (2002) first defines ER as a risk "where an adverse outcome would either annihilate Earth-originating intelligent life or permanently and drastically curtail its potential", and Bostrom (2013) discusses why reducing ER should be a primary global concern within a utilitarian framework. Both Matheny (2007) and Kent (2004) make similar arguments. Besides this key theme, the documents can be grouped in these distinct topics:

Classifications: documents that provide and discuss definitions and concepts along with general classifications of GCR. Avin et al. (2018) provides a general framework for classifying GCRs by critical systems affected, global spread mechanisms, and prevention and mitigation failures. Baum and Handoh (2014) propose a framework integrating planetary boundaries and GCRs. A similar focus can be found in Cernev and Fenner (2020), who try to integrate the United Nations Sustainable Development Goals and GCR. Torres (2023) examines five definitions of ER and proposes a pluralistic approach. They emphasize that the definition of ERs should be context-dependent, while highlighting the critical importance of communicating ER issues to a broad, non-expert audience. Manheim (2020) makes the case that the complexity of our modern world is a major risk in and of itself, as highly complex systems tend to be fragile. Schoch-Spana et al. (2017) introduce the term "Global Catastrophic Biological Risk" to sharpen the focus of the research community on large biological threats.

Methodological issues: regarding GCR quantification and assessment. For example, Cirkovic (2008) and Baum (2023) highlight some issues with quantification of GCR from natural events such as asteroid impacts or supervolcanic eruptions from Earth's geological record. Ord et al. (2010) discuss the challenges of estimating probabilities for rare, high-stakes events. Both Tonn and Stiefel (2013) and Beard et al. (2020) show that a wide variety of approaches exist to make these estimations, some clearly better than others, but criticize that the ER community often relies on the flawed ones. Sundaram et al. (2022) builds on such criticism and highlights seven key issues that have to be resolved for the field of GCR/ER to achieve its potential in safeguarding humanity.

Specific risks: Beard et al. (2021) discuss how climate change contributes to GCR. They explore potential feedback loops between collapsing ecological and socio-technological systems and highlight the complexity of climate change's systemic impacts on global food security, politics, and ecosystems. On a related note, Baum et al. (2013) explores the risks of stratospheric aerosol injection geoengineering and the potential for societal collapse causing its failure, leading to a rapid temperature increase and possible global catastrophe.

Longtermism and space settlement: These documents focus on how we should weigh future generations against today and the value and possibility of space settlement. Tonn (2018) makes the case that we have obligations to future generations and should take those into account when planning. Bostrom (2003) combines both concern for the long term future and space settlement and argues that delaying space settlement means lower human population numbers over the lifetime of the universe, which he sees as a major loss. However, he also notes that this does not mean that we should do it as fast as possible, but that we should instead make sure that we get to the time of space settlement safely. Baum (2015) and Baum et al. (2019) make a similar argument and come to the conclusion that while most GCR interventions can be justified by only looking at the near-term future, some only make sense if you take the long-term future into account. Armstrong and Sandberg (2013) propose that we could do space settlement in the foreseeable future if we choose so.

History of the field: Moynihan (2020a) traces how the stream of ideas that created the term ER developed from the 18th century to today, while Shackelford et al. (2020) try to systematically aggregate all research that is relevant for existential risk studies.

4.2 Artificial Intelligence

Documents in this cluster are about risks from artificial intelligence (AI). The cluster includes overview documents that summarize the different types of ERs from AI and the discourse about these risks, as well as documents that focus on one particular aspect of AI-related ER. While most documents in this cluster examine the dangers of AI, some also argue that risks from AI are overstated, and highlight the positive opportunities of AI. The majority of the documents are about ER, but a substantial subset also discusses near-term risks and the societal impact of AI, as well as the ethics of digital minds. In the following we present a few prototypical documents for each of these categories.

Overviews: Turchin and Denkenberger (2020) provide a taxonomy of AI related GCRs, distinguishing *narrow AI*, which is not able to self-improve, *young AI*, that can self-improve, and *mature AI*, which has been self-improving for a long time, and has vastly superhuman capabilities. Another important overview document is by Critch and Krueger (2020) who classify different types of risk-inducing scenarios, and summarize existing research on potential solutions, such as transparency, formal verification, preference learning, or corrigibility. They also summarize research focused on scenarios with multiple stakeholders as well as multiple AI systems. Vold and Harris (2021) summarize arguments why AI poses an ER on a philosophical level, and McLean et al. (2023) provide a literature review that identifyings various AI-related risks, such as AI removing itself from human oversight or developing unsafe goals.

Concrete existential risk: There are several documents that focus on one particular risk from AI, or address a specific problem. Maas et al. (2022) discuss AI as an ER in the context of military applications. Sotala and Gloor (2017) focus on suffering risk (S-risk): that is, the risk that most people survive but experience a great deal of suffering. They argue that S-risks are similar to extinction risks in terms of probability and severity. Armstrong et al. (2016) discuss the risks from an “AI arms race” and provide a model for navigating the situation in which different teams that work on AI capabilities have to trade off safety for speed. Bucknall and Dori-Hacohen (2022) argue that *current* AI systems, despite not posing an ER in themselves, are an important factor for ER. They may have a negative impact on cybersecurity, or lead to an increase of political tension between different actors, thus exacerbating ER from AI, as well as from pandemics, climate change, or nuclear war.

Arguments for optimism: Müller and Cannon (2022), Ćirković (2015), and Asp (2019) critique the arguments for ER from AI, and argue that we should focus on other risk drivers such as biotechnology, or nuclear weapons. Further, Obschonka and Audretsch (2020) and Yang et al. (2024) highlight the positive opportunities that AI enables, like helping with data analysis or for aggregating and synthesizing information.

Societal impact and near-term risks: Some documents, rather than focusing on longer time horizons, discuss the risks that will appear in the near term. For example, Page et al. (2018) identify various risks from task-specific (narrow) AI, such as malfunction, malicious attacks and mismatch of objectives. (Dürr et al., 2023) focus on the implications of natural language processing, and Bullock (2019) highlight issues with AI systems that are used in governance and bureaucratic decisions. Further, Segessenmann et al. (2023) discuss issues of how AI shapes our culture and society and propose a research agenda for addressing these issues.

Ethics of digital minds: Bostrom and Yudkowsky (2014) discuss various ethical considerations around AI, including the possibility that AI systems may be moral patients which warrant moral consideration. Harris and Anthis (2021) review the literature on the ethics of artificial entities. They conclude that most scholars agree that artificial entities may in principle qualify for moral consideration. Yampolskiy and Fox (2012) argue against assigning moral agency to AI systems, and Bryson et al. (2017) and (Chesterman, 2020) argue against legal personhood for artificial entities, since they cannot be held accountable in a way that a human can.

Most documents in this cluster use the term *existential risk*. Critch and Krueger (2020) explicitly focuses on extinction risk, and argues that approaches to reduce extinction risks are also useful to reduce GCRs in general. Most other documents also focus on extinction risk without making the distinction to other GCRs/ERs explicit. A notable exception is the work by Sotala and Gloor (2017) which specifically focuses on risks that do not involve human extinction, and rather focuses on scenarios in which most people survive but experience suffering (S-risks).

4.3 Climate Change

This cluster of research investigates climate change as a contributor to GCR. The documents range from exploring how climate change could have catastrophic impacts, through to responses, governance, and the risk posed by emergency interventions such as solar geoengineering. Only two documents in the cluster explored the central question of what an ER from climate change actually is. One answer is that it is a risk which threatens the survival and basic human needs of an individual, community, nation-state, or humanity at large (Huggel et al., 2022). Another simply hinges on temperature rise: >3 °C is catastrophic, and >5 °C is beyond catastrophic (Xu and Ramanathan, 2017).

Mechanisms: Several documents explored the precise pathways from climate impacts to a global catastrophe. The largest, overarching view is offered by (Richards et al., 2021), who translate a literature review into a set of feedback loops, identifying food insecurity as the most concerning pathway. Others put forward issues such as runaway positive feedback loops in the climate system (Kareiva and Carranza, 2018), and diminishing returns to adaptation (Steel et al., 2024). The one emerging consensus is that there is unlikely to be one single catastrophic impact, but rather a collection of different interacting stressors.

Climate Security: Another theme in the literature focuses on the threat of climate change to human and national security. Some try to quantify the potential damages in terms of the human cost (the number of people who will be displaced from the long-term human climate niche) (Lenton et al., 2023) or to trace the different indicators of disastrous climate change (Ripple et al., 2022). Others focus on how climate change and ecological breakdown could trigger conflict and security threats within countries (Black et al., 2022), or how the impacts of climate change could lead to a plethora of security issues from displacement to flooded military bases (Busby, 2021).

Catastrophic Climate Governance: The smallest theme is that of how to conduct international governance in the face of catastrophic climate change. Two pieces recommend that global governance needs to be reformed to reflect the complexity of climate change and GCR (Fisher and Sandberg, 2022; Kreienkamp and Pegram, 2021), while Kim explores how international law could be transformed to enable planetary stewardship of the Earth (Kim, 2022).

Response Risks: Research has not just covered potential responses to climate change, but also the risks that these responses could pose. The most prominent is solar geoengineering. These are interventions which seek to mitigate climate change by reflecting solar radiation away from the Earth back into space, thus cooling the planet. Parker and Irvine (2018) examine the potential for termination shock from a stratospheric aerosol injection system used to mitigate climate change (although they see the risk as low). McLaren and Corry (2023) worry that climate security could justify emergency powers, dangerous emergency interventions, and draconian crackdowns on protesters and migrants. Pierrehumbert (2019) echoes these concerns, suggesting that solar geoengineering is not a safe alternative to decarbonisation. All of the articles touch on the question of whether the cure to catastrophic climate change may be worse than the disease. Unfortunately, they do not agree on the answer.

4.4 Governance

This is a diverse cluster which covers several themes, including definitions and fundamental concepts, potential cross-cutting models of governance, the role of innovation in ER, and solar geoengineering. The different themes share a focus on governing GCR, whether that be through conceptual models or specific interventions. Geoengineering was likely identified in this cluster because it also touches on cutting-edge risk management issues such as legitimacy and the governance of free-driver problems.

Fundamental concepts: A small minority of documents develop key, fundamental concepts of governance. Bostrom and Ćirković (2008) provide the original most widely cited (and perhaps vaguest) definition of a GCR as a "risk that might have the potential to inflict serious damage to human well-being on a global scale". Wiener (2016) advances the idea of the 'Tragedy of the Uncommons". That is, the idea that action on GCRs and ERs are severely challenged by some unique characteristics. These include the unavailability heuristic (risks that haven't been experienced are less salient), mass numbing (an enormous loss of lives is less moving than the personal detailing of one death), and under deterrence (traditional legal measures don't work, for instance criminal charges are of little use if someone has already destroyed the penal system). Both definitions and ideas such as the Tragedy of the Uncommons are pivotal to understanding and governing GCR.

Governance Models: A few articles focus on the global governance of GCR. These range from broad ideas of how to robustly govern during times of turbulence (Ansell et al., 2024), through to specific (and incredibly ambitious) proposals for a Universal Global Peace Treaty (namely to reduce the risk of a superintelligent AI being deployed for the purpose of war) (Carayannis and Draper, 2023).

Innovation and Existential Risk: A small number of documents examined the role of innovation in ER. Matthews et al. (2021) put forward the case that the Silicon Valley model of 'move fast, break things' could be made more sustainable by pairing it with deliberative approaches such as citizens assemblies. Mitcham (2021) explores how engineered GCRs are often framed as innovative 'solutions' even if they are creating risk; a problem which requires better cost-benefit-risk analysis across engineering as a whole.

Geoengineering: The most prevalent thematic cluster focuses on geoengineering, particularly solar geoengineering. Some documents examine the big picture of solar geoengineering, such as where the idea derives its legitimacy from (Jacobson, 2018) and what principles and institutions of international law are relevant (Reynolds, 2019). One article seeks to loosely quantify the contribution of stratospheric aerosol injection (the most widely discussed version of solar geoengineering) to reducing climate-related ER (Halstead, 2018).

4.5 Pandemics

Documents in this cluster can be summarized with the label "governance of pandemics", with many documents in this cluster using the recent COVID-19 pandemic as an example, but also referring to earlier pandemics. Most studies use ER as a general description of the dangers of pandemics and not in the sense of Bostrom (2002), but there are also some documents that directly refer to GCR and ER as we are considering them here. For example, Doran et al. (2024) frames pandemics as a GCR and explores what we can learn from past pandemics to be better prepared for future ones, while Rietveld et al. (2024) look at what COVID-19 can teach us about GCR governance. Generally, the documents in this cluster have the following main themes:

History of pandemics: Lynteris (2018) explores the historical evolution of masks as personal protective equipment during epidemics, focusing on their origins during the 1910–1911 Manchurian plague and their symbolic role in medical modernity. Abraham (2011) looked at how the H1N1 pandemic developed and how its danger was overestimated, but still argues that we can take this as an important case study on how pandemics are treated and coordinated on a global scale.

Risk perception: Klinke (2021) explores how the public perceives risk and advocates for a non-tendentious, theory-neutral approach to foster scientific literacy, knowledge, and decision-making competence. He emphasizes public engagement in risk governance through scientific, associational, and public deliberation. Ansell and Baur (2018) discuss how we manage and interpret major shifts caused by risks. They argue that how we define and frame risks ultimately influences what we do to control them. Dawson and Hanoch (2022) make a similar argument, but focus on anthropogenic risk, while both Rheinberger and Treich (2016) and Rheinberger and Treich (2017) try to determine the general attitude of humans towards large risks.

COVID-19: Morens et al. (2020) address the discussion on the origins of COVID-19. Foa and Welzel (2023) highlight how a large threat like COVID-19 makes us feel insecure and more open to authority. Fronteira et al. (2021) look at how COVID-19 interacts with other, already existing, endemics. Garcia et al. (2022) discuss how COVID-19 has highlighted how unprepared we are for big health threats and that we urgently need to invest more in health planning. Similarly, Sutherland et al. (2021) conducted a horizon scan to determine the best pathways to be better prepared for future pandemics. Hartley and Vu (2020) show that COVID-19 led to a surge in fake news and discuss what we can do to combat this. Taylor (2020) discusses the large uncertainty that COVID-19 has introduced and argues that in such an uncertain time ethics of care are the best way forward.

Zoonosis: Both Lynteris (2017) and Kock and Caceres-Escobar (2022) looked at the current situation on how disease is transmitted from animals to humans and what factors shape this transmission. Lynteris (2017) employs a more historical and theoretical focus, while Kock and Caceres-Escobar (2022) try to assess the global risk landscape for zoonosis in the aftermath of COVID-19.

AI and pandemics: A small fraction of documents addressed artificial intelligence and its relation to pandemics and global public health, such as Leslie et al. (2021), who explore how biased AI systems can exacerbate existing healthcare inequities during the COVID-19 pandemic, disproportionately harming disadvantaged communities. In the same context, Tzachor et al. (2020) look at the ethical issues that are raised when using AI tools in the context of a pandemic. Alamo et al. (2020) highlight how Open Access data makes it easier to tackle global threats like COVID-19.

4.6 Transhumanism

While this cluster is broad and contains a number of false positives, there is a clear prevailing thread related to transhumanism and its relationship with GCR/ER. While the label of "transhumanism" encompasses a wide range of views and perspectives (see More and Vita-More (2013) for an introduction; this is not in the cluster but is presented for context), a key theme in transhumanist philosophy is the use of scientific knowledge to transcend human limitations. These can include the limitations of our human bodies, such as aging and disease, as well as those of our minds. The articles in this cluster explore both the positive (i.e. risk-reducing) impacts of such developments on GCR/ER, as well as possible negative (i.e. risk-increasing) impacts.

M*oral enhancement*: the modification of human beings to be better moral actors. Persson and Savulescu (2010) argue first that humans' moral value is unrelated to their formal membership in the species *Homo Sapiens*, and second that human psychological limitations are a source of many of the modern world's ethical problems, including problems of global suffering and injustice as well as the creation of GCR/ER. Therefore, they argue that, if it were technically feasible, there should be no fundamental objection towards biologically enhancing humans to become more moral actors, and that this would help reduce GCR/ER. A number of other articles in the cluster build directly on this contribution: Jebari (2014) explores whether moral enhancement in service of GCR/ER reduction should focus on behaviors, emotions, or dispositions; Persson and Savulescu (2014) respond to some practical and moral objections to their original proposal; Rakić and Ćirković (2016) argue that moral enhancement should be strictly voluntary to avoid potential totalitarianism; and Ćirković (2017) expands from individual moral enhancement to consider moral enhancement of an entire global human civilisation. Some other articles in the cluster build on the moral enhancement discussion with explicit mention of GCR/ER, but without a substantial focus on enhancement specifically as a tool for GCR/ER reduction (Carter, 2017; Heinrichs and Stake, 2018).

GCR/ER related problems arising due to transhumanism: Other articles in the cluster connect transhumanism to GCR/ER in different ways. For example, Jebari, (2014a) argues that extension of the human lifespan, a common transhumanist goal, could lead to an increase in GCR/ER, for example through increased environmental stresses from a now much more quickly growing population. Gyngell (2012) considers how genetic engineering could, viewed from more of an evolutionary biology lens, improve the human species' prospects for continued persistence. Meanwhile, Lavazza and Vilaça (2024) present a proposal for creating artificial intelligences which have moral value and can continue to promote moral value in the universe should humanity become extinct.

Biological risk: Beyond these, some articles in the cluster are related to GCR/ER but not to transhumanism. These tend to be related to biological risk (e.g. Evans, 2020; Shapiro, 2015); most likely, they were included in the cluster because of the deep connection between transhumanism and advancements in biological understanding.

Finally, there are a number of articles in the cluster which are unrelated to GCR/ER. Often, these are articles which have used “existential risk” in a very different sense than we are considering in this paper (e.g. the ER to a single individual), or which mention GCR/ER in passing but do not consider it in detail.

4.7 Reasoning and risk

The documents in this cluster all broadly engage with reasoning and risk, though not all specifically address GCR. It reflects the multidisciplinary and interdisciplinary nature of GCR. Subsets that emerge across the cluster include:

Heuristics and bias in risk perception: Several authors examine psychological factors, such as cognitive biases, that influence how humans perceive and reason about risks. Yudkowsky (2008) and Schubert et al. (2019) note the role of the availability heuristic in reasoning about catastrophic risk, looking at how human bias can lead to underestimating risks that are difficult to conceptualize without familiar or historical precedents. Yudkowsky also examines hindsight bias. They further recognize the potential for fictional depictions of 'end of the world' scenarios to influence reasoning when real-world facts or precedents are lacking. Aicardi et al. (2018) and Blackwell (2015) both highlight the role of science fiction in shaping perceptions of the threat posed by artificial intelligence. Haque et al. (2023) and Yang et al. (2019) explore how different conditions affect interactions with and exposure to information. Haque et al. (2023) examines how the “psychological discomfort” of polarization can result in confirmation bias, reinforcing existing beliefs and obstructing objective risk evaluation, while Yang et al. (2019) focus on the impacts of information need and perceived knowledge. Gill (2017) highlights potential for cultural differences in risk perception.

The indiscernibility of GCR and its implications for risk assessment: Paura (2019) proposes that Jonas’ (1984) 'precautionary principle' should only apply to present or imminent risks with uncertain outcomes, while ER assessment should focus on future hypothetical risk. Køien (2020), Yudkowsky (2008), and Greenbaum (2015) explore the concept of 'Black Swan Events', the unpredictability of catastrophic occurrences and argue we should consider tail risks more. Boyd and Wilson (2020), in a document on AI threats, use the term “technological wildcards” for the same kinds of events. The historical categorization of risks, or risk levels, is discussed in several documents, some drawing on the original work by Bostrom, with Paura (2019) providing the most detailed exploration. Some documents in this cluster look at risk mitigation strategies or tools, for example, (Boyd et al., 2020) emphasizes the importance of context-driven risk assessments in the case of pandemics.

AI and technological risks: Most documents in this cluster that addressed specific risks, rather than broader discussions of GCRs or reasoning about risks, focused on the threats posed by AI and other technological risks (Aicardi et al., 2018; Aithal, 2023; Botes, 2022; Demko et al., 2020; Gill, 2017, 2020). In particular, Boyd et al. (2020) describes AI as both as a risk in itself and as a risk multiplier with the potential to exacerbate other threats such as biotechnology or nuclear weapons.

4.8 Global Resilience and Food Security

This cluster primarily focuses on hazards related to GCR that could significantly affect global food production, the impact of these hazards on the food system, and strategies to strengthen food system resilience in such situations. The foundational documents in this cluster are Denkenberger and Pearce (2015), which compared a wide variety of resilient foods on their cost-effectiveness and Baum et al. (2015), which tried to map out different pathways we might have to increase the resilience of our food system. Most of the documents published in the following ten years ultimately connect back to and extend upon these two.

Dangers to the food system: When it comes to catastrophes that might impact the food system, the documents mostly focus on sunlight-blocking catastrophes (e.g. volcanic eruptions or nuclear war). While nuclear war is mainly cited as a motivation for studies about other topics like increasing food security after catastrophes, volcanoes are discussed more explicitly. Papale and Marzocchi (2019) try to raise the alarm about the threat of super-volcanic eruptions in general, Mani et al. (2021) show that even the eruption of smaller volcanoes could lead to catastrophic impacts, Noy and Uher (2022) sample how economists think about GCRs like super-volcanic eruption (but also AI, pandemics and solar flares), while Denkenberger and Blair (2018) even discuss what we could be doing to prevent super-volcanic eruptions in the first place.

Definitions: The authors in this cluster have also coined two new terms that summarize the kind of catastrophes that are being looked at here:

1) Abrupt sunlight reduction scenario (ASRS): This refers to events like volcanic eruptions which emit particles that block out sunlight and thus decrease global temperatures. Such a scenario and its impact on the global food system is modeled in Rivers et al. (2024).
2) Global catastrophic infrastructure loss (GCIL): This means scenarios where the electrical grid is disrupted or destroyed on a global scale. This could be caused by things like large geomagnetic storms. Moersdorf et al. (2024) provide context for the term and discuss the implications of such an event for the global food system.

Resilient foods: The documents in this cluster also look at various ways to enhance food security after such catastrophes: chemical synthesis of food (García Martínez et al., 2021a, 2022b), protein from microbes (García Martínez et al., 2021b, 2022a), novel approaches to utilize currently unusable food sources like leafs (Pearce et al., 2019; Throup et al., 2022), nutrition (Denkenberger and Pearce, 2018a; Pham et al., 2022), cost-effectiveness of resilient foods (Denkenberger et al., 2022; Denkenberger and Pearce, 2018b) and advantages and problems island nations will face after large catastrophes (with a focus on New Zealand) (Boyd et al., 2023; Boyd and Wilson, 2023b, a).

Refuges: Some of those documents also discuss the possibility of island refuges from GCR: this is done most explicitly by Boyd and Wilson (2023b). This means finding places on Earth or in space that are especially resilient to the negative effects of global catastrophes. This often identifies places in Oceania as especially well suited.

Interestingly, this cluster also includes Toby Ord's foundational work "The Precipice" (Ord, 2020). Possibly because both the cluster and the book share a very interdisciplinary look at GCR.

4.9 Risk management and mitigation

This cluster focuses on managing risks and mitigating their impacts across various contexts.

New ways of managing risks: Topper and Lagadec (2013) describe modern crises as interconnected "mega-crises" that require new, dynamic approaches beyond traditional models. Their framework suggests that interconnected global systems increase the likelihood of large-scale disasters, necessitating new management strategies. Tähtinen et al. (2024) try to map all risks globally ranging from local events like a flood to global catastrophes like super-volcanic eruptions, advocating for broader crisis preparedness. Similarly, Mignan and Wang (2020) examine interactions between catastrophic hazards, identifying network failures and business interruptions as key factors in risk cascades. Cernev (2022) explores how GCRs interact with planetary boundaries, recommending their integration into sustainability frameworks. Ayasreh (2023) suggests that science diplomacy could help avoid GCRs by improving international relations. Acemoglu and Lensman (2023) model how transformative technology should be regulated to ensure that the risk of new technologies is optimally distributed through time. Will (2020) argues that COVID-19 has revealed the flaws in current corporate risk management, which often overlooks tail risks. He suggests that given the complexity of systems like supply chains, we should anticipate frequent major disasters and plan accordingly.

Learning from past hazards: Besides these documents that focus on GCR directly, there are also a number of documents that don't focus on GCR/ER, but still contain relevant information. For example, Chenarides et al. (2021) talk about how COVID-19 has shown that the supply chains in our food production are inherently vulnerable. Cevik and Jalles (2020) looked at how exposure and vulnerability to climate change increased the chance that a state defaults on its debt and finds a clear linkage. Bosnjakovic (2012) studied how climate change might influence geopolitics. Amekudzi-Kennedy et al. (2020) analyzed how COVID-19 impacted transportation and civil infrastructure. They argue that we should include such worst outcomes like COVID-19 in our planning to be sure that our infrastructure is prepared for that.

4.10 Emerging Biotechnologies, Emerging Futures

Over the past 15-20 years, new applications and approaches have emerged in the life sciences that enable the rapid and precise manipulation of living organisms at scales and speeds not previously seen. Moreover, these techniques are embedded within a shift in mentality in some in the field, with true "engineering" taking the fore in disciplines such as synthetic biology and engineering biology. As an emerging technology, these advances have gained attention in their potential to contribute to GCR and ER, but these connections are seldom explicitly or distinctly drawn. Instead, this suite of developments can instead be viewed as "one to watch," where futures are being shaped, where governance may need to adapt, but that will likely have profound impacts on planetary society. As such, several of the documents in this cluster that deal with synthetic biology and bioengineering are not focused on existential or even catastrophic risk *per se* but rather on possible futures involving these technologies.

Horizon scans: A horizon-scan of the field appears in this cluster, for instance Kemp et al. (2020), and horizon-scanning has indeed emerged as a prominent tool in the global catastrophic or existential risk research landscape. A similar exercise is the basis for another document, a workshop report exploring the risks and benefits of the technology (El Karoui et al., 2019). In fact, Davies and Levin (2022) note that "bioengineering provides us with a safe sandbox in which we can begin to address existential risks…by developing a science that enables prediction and management of the goal-directed behavior of complex multiscale systems." Synthetic biology, or engineering biology, are often discussed as being dual-use, that is: as being developed for beneficial purposes but having the potential to be misused for harm. Moreover, there are also convergences between these technologies and others such as AI, and one of the documents explores the dual-use nature of this convergence (Undheim, 2024b).

Risks through new biotechnology: Another topic prevalent in this cluster is the fluidity between emerging technologies and their potential contributions to catastrophic and existential risk. For example, a number of documents discuss AI, but in its convergence with the life sciences or medicine (Forss et al., 2024; Knopp et al., 2023). This then shifts us more into the final topic dealt with in this cluster, what can broadly be termed 'artificial life' involving areas such as experimental embryology (Davies and Levin, 2022). While this again appears somewhat tangential, it may represent still another way of looking at ER: not necessarily the curtailment of human existence but changing abilities and understandings of the development of life.

4.11 Other distinct themes in the dataset

Besides these main clusters, the overall dataset also contains several other smaller themes. These can cross several clusters and often only refer to a smaller number of documents. As they are still relevant for GCR/ER research, we give a short overview here.

Forecasting and collective intelligence: Decision making around GCR/ER is hard, because most of the events that are considered are unprecedented. Some of the documents in the dataset try to find ways to improve these forecasts. Yang and Sandberg (2022) argue for using the insights of the collective intelligence field more to come to better assessments. Karger et al. (2022) try to adapt forecasting techniques so they can be used to forecast global risks better. This later resulted in the 2022 Hybrid Forecasting-Persuasion Tournament. Currie (2019) argues for the need for us to be more explorative when researching ER, because being conservative in science only works if you have a rough idea of the solution, which we don't have for ER.

Climate change: There are some climate change related documents outside of the main climate cluster. This includes an article about quantifying human deaths due to greenhouse gas emissions (Pearce and Parncutt, 2023), as well as a broader article about better longitudinal assessment of ER, drawing on climate change as an example (Undheim, 2023). McLaughlin (2023) explores why the climate justice literature does not discuss ER much and comes to the conclusion that this is because climate justice is built on the idea of preventing the worst outcomes of climate change.

Nuclear war: While the majority of nuclear war research is not bibliometrically connected to GCR/ER research, there are a few documents which are. For example, this includes the work by Scouras (2019) who highlights the potential consequences of a nuclear war like infrastructure destruction due to high altitude electromagnetic pulse, direct destruction and climatic effects and argues that this clearly makes nuclear war a GCR, while also acknowledging the high uncertainties in their assessment and the urgent need to do more research in this area. Futter et al. (2020) makes a similar argument and emphasizes that COVID-19 has shown that GCRs can and will happen and that we thus should funnel considerably more resources in the prevention of nuclear war. Pearce and Denkenberger (2018) take a more pragmatic approach and calculate what an optimal number of nuclear weapons might be. They argue that states should only have as many nuclear weapons as they need for deterrence and that 100 nuclear weapons could already cause so much damage that no more are needed for a single nation to ensure deterrence. While this would not remove the terrible destruction of nuclear war, it would at least make a nuclear winter less likely.

Effective Altruism: The research community which works on GCR/ER has an overlap with the Effective Altruism community. Due to that overlap, our dataset also contains some documents discussing Effective Altruism, like Skelton

(2016) explaining the movement's ethical ideas, Rubenstein (2016) highlighting the implication of these ideas for everyday life and Caviola et al. (2021) explaining why people might follow these ideas (or not). The reception of the movement seems to be mixed, often drawing criticism, which is highlighted by Gabriel (2017). These criticisms include its lack of focus on institutional change (the validity of this criticism is discussed by Berkey (2018)) and philosophical issues with the movement's key ideas (Plant, 2019; Zuolo, 2020). However, there are also others who highlight the good that has been accomplished, especially when it relates to animal welfare (Broad, 2018; Ng, 2019) and how the ideas of the movement relate to religion, e.g. in what way the ideas of Buddhism and Effective Altruism overlap (Baker, 2021) or how Effective Altruism highlights that Christians should strive to include more people in their moral considerations (Roser, 2021; Synowiec, 2022).

Societal reaction to risk: Haldon et al. (2020) survey historical examples of famine, war and pandemic, concluding that past societies responded primarily at a small scale to tackle the symptoms in the interest of elites. Using the first bubonic plague as an historical example, Dunn (2021) reflects on the insights that can be drawn from peoples' vulnerability during the COVID-19 pandemic to understand the past.

Global governance: Heerma Van Voss and Helsloot (2023) develop a framework to explain why states are bad at stabilizing long-term risks and call for making it a priority question in governance research. (Braithwaite, 2024) calls for simplifying complex global governance institutions to enable them to control catastrophes more effectively. Nathan and Hyams (2022) assess how global policy makers perceive GCR.

4.12 Unconnected, but relevant documents

Besides the clustered data, our approach also resulted in roughly half of the documents not being connected to this main group of interconnected documents. This is mostly due to their references having minimal overlap with the GCR/ER literature discussed above, but can also be due to incorrect or missing reference lists in OpenAlex. We therefore scanned these excluded documents manually and discuss relevant entries here, ordered by the cluster they belong to most closely.

Foundations: The majority of the unconnected documents thematically belong to the foundations cluster and includes many books. For example, "The Era of Global Risk" by Beard et al. (2023) compiled a collection of texts introducing key ideas of ER, Torres (2017) wrote an introductory book about ER for a lay audience, while Taylor (2023), dedicated a whole book to the idea of ER within peace and conflict studies. Similarly, the book chapter by Belfield (2023) is about connecting ER with the study of societal collapse.

Another big group here is the critique of GCR/ER ideas. Ćirković (2008) discusses the "observation selection effect," which means we can only observe certain conditions that allow us to exist and make observations. This potentially skews our estimates of risks. Cremer and Kemp (2021) criticize the definitions, philosophy, and methods of the field. They argue that ER is focused too much on techno-utopian approaches and technocratic technofixes. It should instead focus on making the field of GCR/ER more diverse and democratizing its policy recommendations. Schuster and Woods (2021) highlight similar problems in the study of ER, namely: its openness to authoritarian solutions, over-reliance on technological fixes and probability theory, and lack of engagement with certain modern philosophical ideas.

Besides these two main themes, the other documents cover a very wide range of topics. Coze (2023) classifies ER as a subcategory of global risk, which he thinks is a consequence of large technical systems, which our societies and its infrastructure consist of and which need to be managed with new approaches. Boyd and Wilson (2021) argue for anticipatory government as a solution to improve global risk governance. Leigh (2021) argues that populism and authoritarianism are a risk factor for ER/GCR, because they make decision making worse. Martínez and Winter (2022) explore how the term "existential risk" is understood and how it differs from other similar terms like GCR. Based on this they assess how the term should be used and interpreted in law. Thorstad (2023) evaluates how cost-effective ER prevention actually is and comes to the conclusion that it strongly depends on the assumptions you make, but that given the very small investment humanity is currently making it probably is cost effective. Finally, Vitor et al. (2023) argue for using TED talks to communicate GCR to the public.

Artificial intelligence: The texts here are mainly concerned about the risks stemming from AI. Bailey (2023) proposes that out-of-control technology like AI is the great filter which explains the Fermi Paradox. Carlsmith (2022) discusses the idea of AI presenting an ER, comes to the conclusion that it does, and assigns a probability of 5% that it will extinguish humanity. Contrastingly, Goertzel (2015) scrutinizes Bostrom and Yudkowsky's concepts of AI risk, finds them logical, but argues that they confuse something being possible with something being likely and therefore overstate the dangers. Hadshar (2023) reviews the evidence for risk of power-seeking AI, finding that there are no actual examples of it so far and so we should be less confident that this is an ER, but still be concerned. Kasirzadeh (2024) argues for a greater focus on "accumulative" AI risk, in which systemic threats and vulnerabilities due to AI gradually accumulate and then lead to irreversible collapse. The only solution focused document here is Nindler (2019) which discusses if and how the UN could help manage AI.

Pandemics: Cameron (2017), Connell (2017) and Yassif (2017) all emphasize the importance of the introduction of the term "Global Catastrophic Biological Risk", introduced previously by Schoch-Spana et al. (2017). They argue that this will help make it easier to prepare for large biological threats. Liu et al. (2020) discusses what we can learn from COVID-19 for the governance of GCR.

Global Resilience and Food Security: There is only a single document which fits here, by Jehn et al. (2024a). They model how the global food trade might react to global catastrophes like extreme space weather or supervolcanic eruptions, concluding that this would massively impact food availability worldwide, and that sunlight-blocking catastrophes will have considerably larger impacts than those in which food-producing infrastructure is lost.

5. Work on GCR/ER not covered in our dataset

Our methodology focuses on those documents which use the terms GCR/ER. This automatically excludes a large literature which is relevant to GCR/ER, but does not use these terms. This is not a problem per se, as this study here is meant to give an overview of the literature which directly situates itself with respect to the GCR/ER concepts. This allows us to see what topics the GCR/ER community focuses on and to identify some gaps and omissions which could be focused on more in the future.

Many of the documents that can be found when searching by GCR and ER as keywords are quite high-level, discussing broad ideas and generally having a meta view on the field of GCR/ER and the topics they address. This might be caused by less high-level research not seeing the need to refer back to the high-level ideas every time. For example, a study on a specific pandemic intervention may be motivated by concerns regarding GCR/ER, but since the focus is on the technical details it might not make sense to refer back to GCR/ER in the context of the resulting document. An example of this would be Jehn et al. (2024b), which discusses how seaweed could be used to enhance food security after a nuclear war, but does not specifically mention GCR or ER and is therefore not covered in this systematic review directly.

Additionally, a significant part of the research on GCR/ER happens outside of classic academic publishing paths. This is especially the case for much of the more technical research around Artificial General Intelligence (AGI), which is often published and discussed via other channels like the AI Alignment Forum (https://www.alignmentforum.org/, Access: Sep 17 2024). Kirchner et al. (2022) tried to aggregate AI research from a variety of sources and found that only a small fraction of this research was published in classic academic channels. While this trend seems to be particularly strong in AI, it could plausibly also be present in other parts of the GCR/ER literature. For example, another source that often features research on GCR and ER is the Effective Altruism Forum (https://forum.effectivealtruism.org/, Access: Sep 17 2024). Such contributions do not show up in scholarly search engines and are therefore essentially lost to everyone outside of these niche communities. To bring the field of GCR/ER forward it would be helpful if more of this work would find its way into academic journals or at least preprint servers, so it can be found and evaluated by a broader community.

Finally, there is likely much research which is relevant to GCR/ER, but as it is not framed as such and not directly connected to the literature of the GCR/ER, it can be quite hard to find. Examples here include:

Food security after global shocks: The University of Helsinki conducts research into global food shocks that are on a scale relevant to GCR (Ahvo et al., 2023; Sandström et al., 2024) and quite similar to some of the existing GCR food security research (Moersdorf et al., 2024). Also, the research around multiple breadbasket failure could have GCR sized consequences (Anderson et al., 2023).

Discussions around nuclear war and nuclear winter: Nuclear war and nuclear winter have been discussed for decades and are a clearly delineated field, with strong connections to the climate change community. Recent work here includes Coupe et al. (2019) who simulated the climate reaction after a nuclear war, while Xia et al. (2022) used this climate data to simulate the effects on the food system. These discussions are likely missing here, because nuclear war research predates the formal study of GCR/ER and has been its own clear and distinct topic since the first usage of nuclear weapons in 1945.

Extreme climate change and climate change economics: While climate change is included within the clusters studied here, this research primarily represents the GCR community thinking about climate change and less the climate change community thinking about GCR. The literature around extreme climate change (Kemp et al., 2022) and tipping points (Wunderling et al., 2024) could be particularly good points via which to connect the fields, but there are also many contributions from climate change economics that explicitly and implicitly relate to human extinction or catastrophic climate change. Examples here include the so-called Stern Review (Stern, 2006) that explicitly discusses the possibility of human extinction as one morally acceptable justification of a positive discount factor and Weitzman's (2009) paper on catastrophic climate change.

Societal collapse: Brozović (2023) created an extensive review on societal collapse and mentioned GCR in a side note, while Belfield (2023) highlights connections between ER and societal collapse, and Schippers et al. (2024) see humanity in a death spiral towards societal collapse. Besides that there are few explicit connections. However, the research around quantitative history, for example in the form of the Seshat database, contains many insights relevant to GCR and ER (Hoyer et al., 2024; Turchin et al., 2019) and could be incorporated more.

Exoplanet habitability: This field is concerned with what makes a planet liveable in the long term. Future research here might allow a quantitative approach to GCR/ER research by looking at the trajectories of habitable planets, like how long Earth-like planets remain habitable (Varela et al., 2023) or what kind of GCR/ER these are usually exposed to (e.g. high energy astrophysical events (Horvath and Galante, 2012)). This also allows us to build simple models to think about habitability in more general terms and what it might imply for humanity (Frank et al., 2018; Savitch et al., 2021).

Great power conflict: While conflict is sometimes addressed in some of the nuclear war literature reviewed here (Scouras, 2019) and included in discussions around the consequences of climate change (Black et al., 2022; Richards et al., 2021;

Undheim, 2024a), our analysis did not find any documents that explicitly look at great power conflict from a GCR viewpoint. Literature to attach to can for example be found in political sciences (Rendall, 2022) or international relations (Levy, 1985).

For future work, in order to create a more comprehensive dataset which potentially includes these and other missing areas, we provide a list of the main keywords per cluster in Figure S10.

6. How are the terms GCR and ER used?

The usage of the terms GCR and ER differs considerably. GCR is likely the less ambiguous term. When it is mentioned it is almost always in the spirit of the original work by Bostrom and Cirkovic (2008). ER on the other hand is used much more widely. While the term is often used in the sense of Bostrom (2002), it is also often used as a general descriptor of something very bad and catastrophic, and applied at much smaller scales (e.g. the existential risk to an individual human or to an industrial sector). This can be seen as another reason to focus on the term GCR and use ER only as a special case, as this could allow researchers to find the relevant research more easily. GCR usually refers to an unprecedented global catastrophe, such as the loss of a substantial fraction of the global population and disruption of global critical systems. ER has most frequently been defined as a permanent loss of humanity's future 'potential' (Bostrom, 2003; Ord, 2020). While ambiguous and ideologically idiosyncratic, scholars of ER tend to agree that this includes either a permanent global societal collapse, the lock-in of a dystopian global regime, or human extinction. Hence, ER can be seen as the most extreme scenario of GCR (Arnscheidt et al., 2024).

There are a variety of other terms that cover a similar scope, but are used by other communities and in other contexts. A non exhaustive list is: *polycrisis* (Lawrence et al., 2023), *global/existential catastrophe* (highlighted as often used in Baum and Barrett (2018)), *global risk* (Beard et al., 2023a), *global systemic risk* (Arnscheidt et al., 2024), *infinite risk* (Pamlin and Armstrong, 2015), *black swan and dragon king events* (Taleb, 2007), *doomsday*, *human extinction*, *global mega crisis*, *ultimate harm*, *existential threat*, *ultimate risk*, *global hazard*, *extinction hazard*, *obliteration of humanity*, *annihilation of humanity* (all highlighted in Boyd and Wilson (2020b)).

Apart from the uncertainty about the term itself, there is also disagreement about which hazards, threats, or risk drivers can lead to GCR. Boyd and Wilson (2020b) studied which existential hazards have been mentioned in the UN digital library, and found that 69% of the mentions are concerned with nuclear war, while other hazards are scarcely mentioned, if at all. Ord (2020) includes asteroids, volcanoes, stellar explosions, nuclear weapons, climate change, environmental damage, pandemics, AI and global authoritarianism as his main candidates for ER. Avin et al. (2018) has a similar, but somewhat different list including asteroid impacts, volcanic super-eruptions, pandemics (natural), ecosystem collapse, nuclear war, bioengineered pathogens, weaponized artificial intelligence and geoengineering termination shock. In contrast, a very broad view was used in the horizon scan by Prá et al. (2024) which comes up with 15 different catastrophes that might reach GCR scales, Leggett (2006) also outlines 15 global risks, while Kuhlemann (2018) argues that we can trace many global catastrophes back to a single root cause: overpopulation. Sepasspour (2023) conducted a literature review and comes to the conclusion that the most commonly included hazards in the GCR literature are AI, biotechnology, climate change, ecological collapse, near earth objects (e.g. asteroids, comets), nuclear weapons, pandemics and supervolcanic eruptions.

While we can find the majority of those main GCR hazards outlined by Sepasspour and others in our data as well, what is clearly missing in our dataset is research on near earth objects (asteroids/comets) and ecological collapse, as both are potentially high impact and have been researched for decades. For near earth objects, this is likely the case because research has shown that they are quite unlikely to occur anytime soon and because their effects are likely similar to supervolcanoes and nuclear winter (Bostrom and Ćirković, 2008; Wheeler et al., 2024). However, the gap in coverage of ecosystem collapse is more striking. Some of the research on planetary boundaries discussed here might fall in this category (see e.g. (Baum and Handoh, 2014; Cernev, 2022; Cernev and Fenner, 2020)) and there are some lone studies that were not captured in this systematic review, but also approach the topic (Jehn, 2023; Kemp, 2023) or discuss it in a different context (e.g. the context of global food security in Denkenberger and Pearce (2015a)). But overall, it seems like the topic of ecosystem breakdown is surprisingly under-researched from a GCR perspective, given its prevalence in the general literature and the scale and likelihood of its potential consequences. This might be due to a similar reason as nuclear war, meaning that there is already a big community of researchers looking into catastrophic consequences outside of GCR/ER, while also having conducted this research longer than the idea of GCR/ER exists. This highlights that global catastrophes that have only been discussed more in the last two decades (like AI) have a higher chance of being connected more with GCR/ER.

7. Challenges and opportunities for GCR/ER research

Our results show that research on GCR and ER is now firmly established as a research field, with a large number of documents produced each year spanning a wide range of topics. While this is encouraging, the field of GCR/ER also still has many areas where it can improve.

7.1 Missing publication outlets

GCR/ER research is often quite hard to find. This is mostly due to its high interdisciplinarity, but also due to the lack of unifying conferences and journals. While there are some conferences like the Stanford Existential Risk Conferences or the Cambridge Conference[s] on Catastrophic Risk, these are almost exclusively in the UK and USA, making it difficult for researchers outside of these regions to participate. More conferences would better bring together the different strands and substrands of research. The lack of shared venues is even more stark when it comes to scientific journals. There is no journal that is clearly focused on GCR/ER. The closest is likely the “Futures” journal, but it suffers from its broad scope, closed access, and connections to the Elsevier publisher (with negative associations for many scientists, see e.g. Heyman et al. (2016)). Having a diamond open access journal here, e.g. via the Peer Community Journal, would allow a more concentrated research landscape and make GCR/ER research available to everyone. However, it might also be the case that the field is currently still too small to justify a distinct journal or that an interdisciplinary field should instead focus on publishing in the journals of other fields, to build more connections.

Alternatively, it could be helpful to create a curated space for GCR papers in preprint repositories like arXiv. Pre-print evaluation initiatives like The Unjournal, Prereview or ReviewCommons offer further ways to find and evaluate papers outside of traditional academic channels, while still allowing them to be found by a broader community.

7.2 More balanced topic selection

Another point which clearly comes up is the dominance of the AI topic in the GCR research. Usually around a quarter of the research published each year is focused on AI and essentially all the other clusters also discuss AI at some point. In contrast, the general perception of global risk focuses much more on climate change and nuclear war. Other parts of the GCR landscape, for example ecosystem collapse, are under-researched in comparison. This is likely related to the origin of the field, which started out with a focus on risks from advanced AI. While we are not arguing that there should be less research on AI risk (better understanding of GCR in all domains is good), more research into non-AI topics might be fruitful, while also making it easier to find common ground with other fields. The missing focus on nuclear war in the GCR/ER literature is especially striking, given its very present threat and long history.

7.3 Connection to other fields and diversity

This connection with other fields might also help with another major problem: the skewed gender balance. This is likely due to the roots of GCR/ER research in fields with highly unequal gender balances, such as some STEM fields and philosophy. This imbalance should be addressed. Beyond the moral and ethical reasons, there are also practical reasons: more diverse perspectives allow us to come to more solid conclusions, and a diverse field is generally more inviting for others. Things that could be done here include targeted mentoring programs or connecting GCR/ER research to fields with a better gender balance as well as working towards achieving better balance across the board.

7.4 More consistent terminology

Our research here also suggests that scholars should focus on the term GCR when describing the field, because it is the better term when it comes to clearly identifying what documents are about. While ER is used in all kinds of contexts, GCR is only ever used in the context discussed in this article. This makes the research much easier to find. Related to this, it might also be fruitful to coin more special terms like global catastrophic biological risk and global catastrophic food failure to give smaller communities a term to aggregate around, while also making the ideas easier to find and easier to communicate to policy makers.

7.5 Policy uptake of GCR/ER ideas

What our research clearly shows is that there is now an established field of GCR/ER research and consequently a wide variety of knowledge available. However, many countries do not yet take this research into account for their risk assessments, because GCR/ER prevention seldom rises anywhere near the top of the list of pressing issues. Those at the top often seem more immediate and integral to everyday life. This means the GCR/ER community has to make sure that even in this difficult environment the ideas of GCR and ER are heard and acted upon in policy.

8. Conclusion

We have started this review with the questions: How large has this body of literature become? What topics does it cover? Which fields does it interact with? What challenges does it face? From our analysis it becomes clear that the GCR/ER literature is growing rapidly and is now firmly established as a research field. Over time it has branched out towards more and more topics and fields, such as climate change. However, we have also identified several areas where GCR/ER research could improve. The field is still partially isolated from other research communities and would be well advised to branch out more to create connections to already existing research, for example when it comes to nuclear war. Another problem is an imbalance in both gender and geographic diversity, which needs to be addressed. Still, the GCR/ER field has contributed considerably to both understanding and preparation for the largest risks that face humanity.

Data and code availability

All code and data used to create the figures in this document can be found in the repository:
https://github.com/florianjehn/bibliometrics (Jehn and Ilin, 2024)

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