Framing Global Catastrophic Risk – Recent and Future Research

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ABSTRACT This article is a literature review about global catastrophic risks. Its contribution is to give an overview of the research field in general and highlight the main potential catastrophic areas linked with recent studies. In many movies and TV shows, we can see our civilization collapse in various ways: Gigantic asteroids hit the earth and obliterate all life, nuclear wars emerge, artificial intelligence evolves and starts wars with humans, pandemics spread, and other kinds of catastrophic events with mass death or extinction of all life happen. Thus, even if these are extreme events and fiction, we should raise the question how likely it is that one or more of these events can occur in the near and far future. Although calculated probabilities of impact are low for the future such as tomorrow, in 10, 100 or a million years from now, this could actually be reality. Nevertheless, why should we care about the risks of these global catastrophic events today and what could be done to prevent or reduce the risk of a global catastrophe? In this paper we will discuss core content, such as different risks and ways to reduce them internationally, as well as the scientific context of the field. In fact, there are events that can be catastrophic on a global scale and happen in the near future, even if we do not know exactly when. Hence, specific risk assessment and proper mitigation strategies are necessary in order to maintain the human population. This article states that serious research is a basis for decision makers in particular, who invest funds in countermeasures.

KEYWORDS Global catastrophic risk, literature review, catastrophic climate change, nuclear war, natural pandemics, exogenous risks, emerging risks, risk assessment

1. INTRODUCTION

Global catastrophic risks (GCRs) are events which cause mass death or extinction in the future, affecting over 10 per cent of the population. Furthermore, the worst events are called existential risks since they would end all human life (Cotton-Barratt et al., 2016). It is important to highlight the GCRs, so that politicians and governments can start discussing and work together across the globe to reduce these risks. If GCRs can kill millions of people, why is it not a more discussed topic? A reason for that is, according to Baum (2015a), that we humans have a lack of motivation when we talk about the far-away future. There are no obvious benefits for reducing risks that may affect future generations. Though, there is a higher motivation to reduce GCRs which could become relevant in the near future. Baum (2015a) additionally states that there are benefits of reducing near and far-future GCRs: Near future to save lives, and far-future to save our civilization. The risks are divided into different areas that will be described in detail in this paper. With respect to Cotton-Barratt et al. (2016), the following areas will be highlighted:

- Catastrophic climate change
- Nuclear war/winter
- Natural pandemics
- Exogenous risks
- Emerging risks
- Other/unknown risks
Basically, what is risk? In this paper, risk such as the risk of catastrophic events is mentioned several times. Kaplan and Garrick (1981) define risk and uncertainty with a clear difference. For example, uncertainty is when a man is running and does not know the distance he will run. It turns out he ran 3 miles, but during the time of running, he was in state of uncertainty about the distance, not exposed to any damage though, so without special risk. This means that risk is uncertainty combined with some kind of damage. So, GCRs in this sense can be seen as uncertain events that would cause damage.

We have stated global catastrophic events are events that would affect more than 10 per cent of the population. Posner (2004, p. 6) defined catastrophe in his book as following:

“A momentous tragic usually sudden event marked by effects ranging from extreme misfortune to utter overthrow or ruin.”

Therefore, catastrophic is something that will cause large damage. Some events will do more damage than others. How likely is a global catastrophic event, how high or low is the risk? Toby et al. (2010) argue that there are many problems at calculating the probability of an extreme event, because the events are determined by specific conditions. Especially regarding the high stake risks such as asteroids, pandemics and nuclear wars. With respect to the given conditions, it is important to know that the smallest error can dramatically change the predictions.

The most extreme events, as mentioned, are existential risks. Risks that have the ability to wipe out all life as we know it. According to Matheny (2007), there could be an extreme event this century, but the risk for that is fairly low. In addition, one existential risk has almost happened not that long ago during the Cuban missile crisis: Never before in modern history were humans closer to a nuclear war that probably would have led to the extinction of our modern civilization. Even if we would succeed to survive for millions of years, our sun will eventually die and we must move to other solar systems; in the far future, every star will run out of energy. It is assumed that the long-term survival rate of our species is not very high (Matheny, 2007). Considering above, there are also benefits of investing in countermeasures that can help future generations. In fact, some are already active to reduce existential risks. The National Aeronautics and Space Administration (NASA) of America spends 4 million dollars per year to locate and defend near earth asteroids. 1.7 billion dollars are invested in research about climate change and how carbon emissions can be reduced. Also is investment done in order to prevent bioweapons as well as for enabling space colonization in the future (Matheny, 2007). Additionally, Tonn and Stiefel (2014) address different strategies and ways how humans could organize the reduction of human extinction risks.

Concerning the structure of this paper, we will state our method for this contribution in the next chapter. Afterwards, the specific risks are covered and a discussion is provided. This article is finalized by suggestions on future studies and a conclusion.

2. METHOD

Conducting plausible research in a notional and interdisciplinary field, as it is global catastrophic risk, can be very challenging. Contributions are associated with economics, philosophy, astronomy, risk analysis and with other disciplines of specific risks (Baum and Tonn, 2015). Scientists face several difficulties at their description and methods may not be adequate for risks with low probabilities and high-stakes. Ord et al. (2010) state that there must be more attention on the argument which is a foundation for calculating probabilities. Conventional risk assessment tools may be insufficient for this distinct type of risks. When reviewing literature in an area that is wide of practice, we must be aware of the fact that empirical findings are very rarely obtainable and missing. Hence, we mainly find analytical and speculative contributions that may rely
on specific models in science. Although a lack of testable explanations or experiments, which is a reasonable necessity of science, is apparent, we conclude about the interest of our humanity to do research in this area. In addition, global catastrophic risk is an issue that cannot be solved by individuals or certain countries. Hence, global concernment and ramifications justify broad scientific interest in this field of study.

This article is a literature review of the field of global catastrophic risk. The aim is to provide a comprehensive overview about addressed research areas, according to the state of the art. By now, a variety of topics is covered within the subject of global catastrophic risk. In chapter 4, we are reviewing these specific topics after addressing the theoretical setting. For this paper, we attempt to evaluate the methods and contents of specific risks, so that the research progress can be compared and further research, such as interesting problems, suggested. It may also help the field in the progress of a hypothetic-deductive approach so that scientific claims can be emphasized.

With respect to the actual scientific content, necessary contributions were made by a few, such as Bostrom and Cirkovic (2008), Leslie (1996), Posner (2004), Rees (2003) and Sunstein (2007), and in many journal articles. Whereas these books address global catastrophic risk rather generally, journal articles are describing specific forms of the topic mostly in a much more detailed way.

Considering numerous databases, we can find 107 academic articles that are directly related to the term “global catastrophic risks”. With 16 references, Academic OneFile is a significant provider of these sources. Although there is a large variety of different subjects in the field of global catastrophic risk, artificial intelligence is addressed in more than 10 articles, reflecting a strong research interest. Some exemplary journals for the topic of global catastrophic risk and its sub-categories are Risk Analysis, Futures and Ecological Economics. Nevertheless, as there is a variety of topics in this field, many different journals contain contributions in the broad field of global catastrophic risk.

3. HISTORICAL SETTING

Placing the research field of global catastrophic risk into a historical setting, such as Schools of Thought, is rather challenging due to its independency of economic doctrines and strong interdisciplinarity, what we described in the previous section. Since schools of political economy, neoclassical schools and alternative schools are commonly explaining the nature of economic development, global catastrophic risks are not necessarily connected to these approaches.

Nevertheless, costs is an economic term that is both integrated in later schools of thought as well as global catastrophic risk when it comes to the impact and its prevention. Additionally, the French Engineering Tradition of the classical school of political economy may suit for technical approaches such as building nuclear weapons or defense shields for cosmic explosions. As there is a variety of risks with different shapes, it is also not fitting for the whole subject.

In contrast to these two access points primarily on the consequences of risks, we are looking for a school which has a clear affiliation to the methods of the field of study. We consider the thematic school of Uncertainty and Information as a valuable connection to global catastrophic risk. This, because every category of risk and the single risks themselves, are uncertain with respect to its occurrence and extent of damage. Hence, the risks must be calculated with specific models in order to gain justification as a risk in the field of research. Whether it is by models for climate change or asteroids. Beside the formal incorporation of risk and uncertainty into economics in 1944, it has its roots in the distinction of risk and uncertainty, done by Knight (1921), which is still very established but not finally discussed in
science (Fonseca, n.d.). In his view, a “risk” is defined as a situation where mathematical probabilities can be assigned. This is the case at global catastrophic risks, although we must keep in mind that some phenomena are easily labelled as a risk instead of an uncertainty. In addition to this differentiation, Keynes (1937), who was one of the pioneers on uncertainty and information in economics, exemplified uncertainty by the prospect of a European war or the price of copper. Hence, he has signaled a broader access to the term of uncertainty. Nevertheless, post Keynesian contributors in this theory, such as Shackle (1949, 1961, 1979) and Davidson (1982, 1991), stand in line with the initial distinction from Knight.

In conclusion, as uncertainty or risk is significantly attached to global catastrophic risk metrics and therefore the field as such, we state, that this historical framework has its justification for this literature review.

4. LITERATURE REVIEW

In order to foster a good understanding of the topic global catastrophic risk and its areas, this section is divided into different parts. Each part will give an overview of a selected risk type, including recent contributions and its relevance for the overall objective of survivability of human population.

4.1 Catastrophic climate change

Climate change is one of our most important GCRs at the moment and is already happening on earth. According to NASA, never before in modern history have the levels of carbon dioxide been higher than today (Figure 1).

The level of carbon dioxide started to increase dramatically during the industrial revolution and has led to a warmer climate on earth. Main contributor to climate change is the emission of carbon dioxide from burning coal and other fossil fuels. Huge changes in the climate can have a catastrophic effect on all living. For example, it can cause natural ecosystems to collapse and make areas around the globe unable for producing food. To prevent a catastrophic climate change, different countermeasures should be taken. The first logical tactic would be to reduce the emissions of carbon dioxide, but it faces many challenges, both technical and political. Other countermeasures would be geoengineering, to reduce the level of carbon dioxide by technological advances. Another action, that could force the change, is to increase the global tax on emissions, which is now 4 dollars per ton. A price of 40 dollars at least would be needed to force companies and governments for change (Cotton-Barratt et al., 2016). Tsur and
Withagen (2011) argue that since climate change affects the whole planet, international efforts will be needed to reduce the emissions of carbon dioxide. The Paris Agreement, which was established on November 4, 2016, is an international effort to reduce emissions by humans that cause climate change (United Nations, n.d.). Additionally, Tsur and Withagen (2011) write that it would be beneficial for growing economies to adapt to an environmentally friendly policy, because the damage of catastrophic climate change would be more expensive in the long-run.

**Permafrost carbon**

According to Schuur et al. (2015), there is a large amount of organic carbon in the arctic permafrost, namely in form of dioxide and methane. Warmer climate on the globe will lead to a release of the organic carbon stored within the permafrost, which will result in a tremendous increase of carbon dioxide and accelerate global warming to catastrophic temperatures. During the last 30 years, the temperature has already increased by 0.6 degrees per decade on higher latitude, double of the speed comparing to the rest of the globe. Countermeasures need to be taken now before we reach the tipping point, the point when it will be too late to reverse the trend.

Catastrophic climate change will have negative impact on human health. Poverty will increase and the access to fresh water around the world will be more problematic. Without access to fresh water, further health problems will arise. Nevertheless, we may be better prepared in the future with future technology to meet catastrophic climate change (Papworth et al., 2015).

**4.2 Nuclear war/winter**

As nuclear weapons seem to perceive international authority and military strength for moderate costs (Toon et al., 2007, p. 1224), countries are interested in building this instrument of self-determination. With respect to its political relevance, nuclear issues are highly discussed in the literature and on open platforms so that information is good accessible for scientists and others. As there is much interest about this topic, many aspects are emphasized.

Cirincione (2007) does provide a comprehensive study about nuclear bombs in the past and in the future, considering the United States (U.S.) in detail. Indeed, since the U.S. and Russia do have the largest nuclear arsenals, this conflict is reflected also in literature (Barrett et al., 2013; Mosher et al., 2003), outlining particular risks and consequences of a high-yield nuclear war between these countries. Additionally, the problem of an accidental nuclear use is covered earlier by Blair (1993), Blejer and Kendall (1991), Wallace et al. (1986), and Forrow (1998) from a medical perspective. An additional book, edited by Solomon and Marston (1986), provides a comprehensive overview about the medical implications of nuclear wars including short- and long-term consequences for humanity, health, environment and providing two views for its recovery. In addition to this, Toon et al. (2008) state to which extent a nuclear war would be catastrophic for the environment and humanity, and suggest policy implications for political actions.

In contrast to high-yield nuclear wars, regional or low-yield weapons are considered as a global catastrophic risk, although nuclear missiles are much less powerful. Nevertheless, since low-yield weapons are easier to build, more countries stockpile them in their armories. Kristensen and McKinzie (2015, p. 563) provide a recent paper about nuclear arsenals and state that eight nations are known to have nuclear weapons in 2015. Beside the U.S. and Russia, Great Britain, France, China, Pakistan, India, Israel, and additionally North Korea, are expected to command nuclear weapons. Figure 2 shows that the total number of nuclear warheads is decreasing since 1986. By now, both Russia and the U.S. are maintaining more than 90 per cent of worldwide nuclear warheads (ibid, p. 566). Hence, it is also important to discuss their political relationship, especially with respect to risk prevention.
Several authors address the variety of consequences in the case of a regional nuclear conflict. Whereas Toon et al. (2007) provide an unspecific contribution, Robock et al. (2007) focus on climatic consequences and Helfand (2007) addresses the extent of projected global famine. Toon et al. (2007a) have created a comprehensive paper about atmospheric effects and social consequences which includes also numerical modeling of potential casualties that stem from regional scale nuclear conflicts. As noted in the Method section, predicting quantitative results in an entire theoretical framework bears many uncertainties that the authors are aware of.

Well covered are also the threat and consequences of nuclear winter which refers to a temperature decrease due to rising smoke into the stratosphere after a nuclear war (Baum, 2015, p. 69). Baum (ibid) considers this phenomenon and provided recently a compact article about the wide range of global environmental consequences. Robock et al. (2007a) and Mills et al. (2008) build on the consequences of a nuclear winter and review the quantitative effects with climate models.

As there is great potential damage in combination with an existing possibility of accidental use of nuclear weapons, its disarmament must be a priority for concerned countries. Hence, several authors in science recommend the prevention of damage that may stem from nuclear weapons. Krieger (1984) has made early contributions to avoid nuclear incidents, whereas Wright et al. (2016, p. 15) point out in a recent report that the U.S. government must reduce the risk of mistaken launch of nuclear missiles by taking them off high alert and removing rapid-launch options from nuclear war plans. This would raise the security level within the U.S. and also internationally. Considering the fact that nuclear wars are hardly accidental in a technical perspective, the book of White (1986) becomes highly important as it analytically describes a variety of psychological aspects at preventing nuclear wars.

4.3 Natural pandemics

Natural pandemics is a GCR that can occur at any time. Diseases such as plague, HIV or smallpox has killed millions of people. In the last 300 years, there were about 10 global pandemics. The frequency of events is high, comparing to other GCRs. For example, in 1918, the Spanish influenza killed 2.5 to 5 per cent of the human population (Cotton-Barratt et al., 2016). According to Wraith and Stephenson (2009) and Cotton-Barratt et al. (2016), the
biggest pandemic risk in the foreseeable future is the avian influenza which has the potential to become a global catastrophe. Yen et al. (2015) write about the preparation for catastrophic pandemics by global vaccine stockpiles. The objective about global stockpiles is just to be prepare for global disasters. Today, there are five global vaccine stockpiles for different diseases, the latest for the avian influenza solely. The stockpiles need to be maintained in order to reduce the devastation by a global pandemic in the future (Yen et al., 2015). Fouchier et al. (2012, p. 258) explain why the avian virus can be so deadly and state the possible catastrophe below: “It is a virus that is capable of killing half its victims, a proportion greater than that for any other epidemic disease. Were that coupled with the transmissibility of a pandemic flu virus, it would have characteristics of an ultimate biological weapon unknown even in science fiction.”

We cannot expect when or if such a catastrophe will occur, but preparation should be done to prevent the extinction or mass death of humans.

4.4 Exogenous risks

Exogenous risks are considered as independent of human behavior. Even natural pandemics, described in the section before, are linked to human activity. In particular, exogenous includes risks such as super-volcanic eruptions and large asteroid and comet impacts on earth. The extent of the consequences is seen as global, so it is an existential risk as described by us previously (Dar, 2008). Since the dynamic of non-anthropogenic risks is not changing, research has a better chance to understand and evaluate the probability of impact. It is argued that exogenous global catastrophic risks are less likely than anthropogenic risks (Solberg Soilen and Baback Alipour, 2011), because their frequency is significantly lower (Cotton-Barratt et al., 2016, p. 46).

Super-volcanoes are an exogenous risk that is addressed in research quite regularly, also due to research on regular volcanic activity. There is sufficient consensus among scientists that this kind of volcanoes is expelling magma volume on more than 1,000 km² by a super-eruption, which is expected to happen every 10,000 to 100,000 years (Miller and Wark, 2008, p. 12). An important general contribution to super-volcanism is done by Rampino (2008), comprehensively covering, among other things, the atmospheric impact, several effects on the environment and human population, and the phenomenon of a volcanic winter that is basically comparable to the nuclear winter.

In order to measure explosive magnitudes, Newhall and Self (1982) provided with the volcanic explosivity index (VEI) a solid foundation for measuring eruptions. Since the authors considered more than 8,000 eruptions in their work, it is established as a tool for comparing the relative explosivity of eruptions and much-cited. Nevertheless, there is a very limited number of observations about super-volcanic eruptions (point 8 in VEI) in the past.

As super-volcanoes are not influenceable by human population, but very devastating owing to a global cooling and a layer of ash (Sparks et al., 2005), its monitoring becomes crucial. Lowenstern et al. (2006) focus on monitoring super-volcanoes, exemplified by a potential super-eruption at Yellowstone in North America. Additionally, Christiansen et al. (2007) provide a comprehensive report on the assessment of volcanic and further hazards in Yellowstone National Park, which is considered as an episodically erupting super-volcano.

Another exogenous risk, that is well covered in science, stems from asteroids and comets. Similar to super-volcanoes, asteroids or comets are a risk that cannot be influenced by humans and may cause tremendous damage depending on the size of the object. Those with a diameter greater than 1.5 km are considered to cause damage on a global scale (National Research Council, 2010). Logically, larger objects will cause higher impact, up to an
existential risk for human population. Chapman and Morrison (1994) expect that there is a 1 in 10,000 chance that an object, larger than 2 km in diameter, will hit the earth within this century, causing high death of human people. Related to this, Reinhardt et al. (2016) provide a solid model for assessing probabilities of asteroid impacts on a global and non-global-scale. The authors state a higher probability of up to 1 in 1,250 that an object will hit the earth and cause a globally significant effect. They refer to the calculations from Chapman and Morrison (1994) and explain the differences by odd definitions of the term global.

Finally, whereas Napier (2008) provides a general overview about the topic and hazards that stem from asteroids and comets, Morrison (2006) emphasized in his article the impact of asteroids and comets, speculating about very high damage and stating how to prevent it. He evaluates these disasters as amenable to precise prediction and good to avoid by appropriate application of space technology. This, in combination with policy-making aspects, results in a valuable contribution for global catastrophic risk.

4.5 Emerging risks

The emerging risks are, according to Cotton-Barratt et al. (2016), artificial intelligence (AI), geoengineering and engineered pandemics. These emerging risks are hard to prepare for and very uncertain, if they will ever occur.

Gill (2016) raises questions regarding artificial intelligence and the social concerns that comes with it. AI machines entering the world would not just raise social concerns, but fundamentally change the social and political system. It would bring benefits to humans, but also risks as a potential new weapon of mass destruction. Additionally, Barrett and Baum (2017) mention risks that can emerge with AI: Self-improvement, more AI and artificial superintelligence (ASI), world domination and the extinction of humans. ASI does not exist yet, but it may come with the risks above. ASI is also defined as a technology which is superior to humans. Thus, Barrett and Baum (2017) write about several models to reduce the risk of future AI and ASI. The most important strategy for future generations is to find a balance between technology and society.

Geoengineering, or so called climate manipulation, has become an important topic in the last decade, raising the questioning, if it is okay to manipulate our climate (Corner and Pidgeon, 2010). According to Clingerman (2014), geoengineering emerged due to our failure to deal with climate change. Thus, with the new technology emerging from geoengineering, new types of terror may occur, such as engineered pandemics. Furthermore, other GCRs can occur, but since we are in a pre-research and development phase of geoengineering, the consequences are difficult to predict. The main part of it is to prevent climate change. There are two main techniques emphasized: Carbon dioxide removal (CDR) and solar radiation management (SRM) (Corner and Pidgeon, 2010). Considering geoengineering as an unpredictable new technology which is a result of human failure, what will happen on a global scale when humans start to modify nature earth? CDR involves techniques as ocean fertilization, enhanced weathering and afforestation. SRM, on the other hand, involves techniques as space-based reflection, enhanced surface albedo and enhanced cloud albedo. It is both a moral and political question, if geoengineering is the right path to follow.

4.6 Other/unknown risks

Previously, we have already outlined five categories of global catastrophic risks that possess a substantial likelihood of occurrence and high potential impact which makes it worth to be discussed. Other risks that are not covered in more detail may be supernovas and gamma-ray bursts, global totalitarian state and conventional or chemical wars.
As supernovas and gamma-ray bursts are in science undoubtedly considered as a global catastrophic risk due to its impact, we will briefly review a paper that reflects the status quo in this field. In contrast, risks, based on a global totalitarian state or conventional/chemical wars, are not focused due to its improbability that these phenomena reach the extent of a global catastrophic risk. Nevertheless, Caplan (2008) is giving a good overview on totalitarian threat including risk factors.

Cirkovic and Vukotic (2016) have provided a recent paper about mitigation of supernova and gamma-ray burst threat to intelligent beings. They compactly linked this type of risk, that is related to cosmic explosions, to a global scale and the impact on human population. In conclusion, it is seen as existential risk with low probability of impact and high potential damage. Useful mitigation strategies are desirable, but not developable in the near future. Nevertheless, the authors suggest local construction of shielding swarms to get prepared for cosmic explosions.

Since anthropogenic risks, such as nuclear war, climate change or artificial intelligence, emerge because of fast economic and technological development, it is logical that some future risks are not exposed and covered yet by humans (Cotton-Barratt et al., 2016, p. 64). We can observe an established scientific community within global catastrophic risk that includes several disciplines and contributors. Hence, in combination with the interest of the society that these risks will not occur, researchers will probably react quickly on new emerging global-scale risks.

5. DISCUSSION

In this paper, we have touched several areas that are associated with the topic global catastrophic risk. Catastrophic climate change, nuclear war/winter, natural pandemics, exogenous risks, emerging risks and other/unknown risks. They all have in common that they are a threat to the earth and all living species on it. These global risks should be of concern, as Cotton-Barratt et al. (2016) states that all of them have the ability to affect at least 10 per cent of the human population. The global catastrophic risks have different chances to become reality, some have a higher risk than others. But when considering the risk it is important to keep in mind what Toby et al. (2010) suggest, namely that there are problems calculating the exact risk. To be able to calculate global catastrophic risks, some given conditions are required. We think that this should be highlighted, since even the smallest error can lead to major percentage deviations of the risk. This should be considered by politicians and other decision makers when planning and implementing strategies about countermeasures. The conditions need to be understood well to make the correct estimation of the risk.

Furthermore, the main focus today, as we can see in politics and social contexts, is the catastrophic climate change. This is the case, because it is the risk which is most plausible for us to relate to and, as Baum (2015a) writes in his report, we humans have more motivation to act and reduce the risk of events that can happen in our lifetime. The climate change has still uncertain consequences on a global scale, but according to Tsur and Withagen (2011) it has already started to show a devastating effect on our planet and since it is affecting the earth in general, international efforts must be taken to reduce the negative trend. We have to act fast, as Schuur et al. (2015) mention, when the permafrost in the arctic starts to melt in huge scales, because then the point of no return for catastrophic global risk will be achieved. At this time, it will no longer be a risk, it will be reality. Global catastrophic climate change will not solely affect the planet, it will also be catastrophic for human health, since the access to fresh water will be reduced around the world (Papworth et al., 2015).

Another GCR that is discussed and a relevant topic for our generation is nuclear war. Ever since the end of World War 2 the moral questions about nuclear technology
have been a hot topic around the globe. If we just look at the history, we have already seen what catastrophic impact nuclear technology can have on our planet. Toon et al. (2008) write in their paper what consequences nuclear technology can have on the environment and humanity, but they additionally mention implications for political actions that could be done to prevent a catastrophe. The important point to highlight is that there are countermeasures which should be implemented by politicians. In many ways, nuclear technology is a political factor, to show strength in form of army power. As a consequence to the cold war between the U.S. and Russia, the number of nuclear weapons in the world increased, a way for the countries to emphasize strength (Figure 2). Even if this is only between two countries and no nuclear rockets were fired, it could have gone wrong for the entire world. According to Barrett et al. (2013) and Mosher et al. (2003), a nuclear war between the U.S. and Russia would be devastating for the entire planet. Several authors mention consequences about what nuclear technology can result in. One of the consequences of a nuclear war is nuclear winter, which is a side effect of a nuclear war. This should not be forgotten, although politicians often talk primarily about the direct impact of nuclear war and not about the other consequences that will follow many years after. We think, in the future it will be important to include education about nuclear technology in the regular school education for example. Hence, the next generation will grow up with a deeper understanding about the impacts and how a sustainable future without weapons of mass destruction can be built.

Nuclear war/winter is a risk that humans have created themselves. Not as the natural pandemics, that is a part of nature, it is linked to human activity but not fully created by humans. Natural pandemics will always involve high uncertainty and can occur at any time. Since pandemics are complex and often hard for scientists to understand, we may not be able to have a proper vaccine ready for an outburst. The frequency of pandemics is high and since we are becoming a more global world, the spread of a huge pandemic could have devastating consequences. Possibly, we could observe a spread in a way that we have never seen before in history. According to Wraith and Stephenson (2009) and Cotton-Barratt et al. (2016), the next pandemic event could be the avian influenza which has the potential to spread across the globe in more rapid speed, compared to events in the past. If the reader wants to know more about the avian influenza, we recommend the article by Fouchier et al. (2012). Since it is that hard to exactly know how the next pandemic will rise, the best way to reduce the impact is progress in healthcare technology.

Moving on to something that is completely independent from humans and often difficult to fully understand, the exogenous risks. This includes super-volcanic eruptions, large asteroid and comet impacts on earth. This risk is an existential risk with high level of uncertainty. It is nearly impossible to predict or know when the next event will occur. Additionally, if this happens, most of us will not survive probably. The impact from super-volcanic eruptions may have similar effects, compared to a nuclear war (Rampino, 2008). One of the most well-known potential super-volcanoes is in Yellowstone, North America. Christiansen et al. (2007) explains the hazards of Yellowstone in more detail and Lowenstern et al. (2006) focus on how to monitor super-volcanoes. This will give an overview of the potential risk that stem from super-volcanoes, and what impact an eruption in Yellowstone can have for the planet. It is not very likely that an eruption will happen during our generation. Additionally, it is hard to do anything to reduce the risk.

Regarding large asteroid and comet impacts, there is a small chance that the earth will be affected during this century (Chapman and Morrison, 1994). So, it is a topic which may not be focused until asteroids or comets closely miss or even hit
the earth. Napier (2008) and Morrison (2006) give a good overview on the risk from asteroids and comets and what could be done to prevent a potential disaster. By looking at our planet history, we already know what damage asteroids and comets can do. This is a GCR that is in many ways hard to understand, because the universe is extremely large and we do not know what space objects will be exposed and a threat for the earth in the future.

Emerging risks, that grow slowly and may be a GCR in the future, are artificial (super-) intelligence and geoengineering. We can call them modern risks, since humans are creating them (anthropogenic). With these merging risks, new political and social questions will come up. How will the civilization adapt to artificial intelligence and is it ethically wrong to change our climate with geoengineering? The artificial intelligence question is raised by Gill (2016) and Barrett and Baum (2017) who mention pros and cons as well as describing a model that should be used to reduce the risk of artificial intelligence in the future. The geoengineering question is addressed by Corner and Pidgeon (2010) and Clingerman (2014), they conclude that geoengineering has started to emerge because humans have failed at reducing the impact that our population has on the environment. The uncertainty of the risks in this area is high. We do not know what consequences follow, if humans start to manipulate the climate on a global scale. Certainly, there will be many discussions on how to approach artificial intelligence and geoengineering in order to be able to build a sustainable future.

Considering other and unknown risks, such as supernovas and gamma-ray bursts, Cirkovic and Vukotic (2016) suggest some future possibilities to reduce or handle the risk of cosmic explosions, even though the risk for an impact on earth is assumed to be low. This risk is hard to understand, since a cosmic explosion would happen far away in deep space. How can we motivate ourselves to reduce GCRs that seem so notional and almost as a part of fiction? Research should therefore also include reasons to motivate the society and politicians for investing money in countermeasures.

6. FUTURE STUDIES

As the general topic of GCR is studied quite fragmented, depending on the type of risk, we suggest to integrate specific contributions in the context of global catastrophic risk as a field of research, aiming to understand the risks in order to prevent its occurrence and/or to reduce the damage of impact. Hence, research should always refer to a sustainable protection of humanity under the umbrella term and context of GCR. This, not only to strengthen the field of research, but also to foster the progress of developing material for experts, politicians, regulators, the society and others. Bostrom and Cirkovic (2008), for example, provide a good collective volume about GCR, including research of many different risks. Although there is a bit of a lack in response strategies, it is a good book for raising awareness among people and decision makers. In fact, the development of adequate mitigation strategies is one of the most important points for future studies in order to benefit from all the contributions, that were made in the past, to protect the human population when a global catastrophic event takes place.

Research and action on the matter of GCR may also unite different societies on earth, because collective effort is necessary to act accordingly to the risks that presumably harm the whole population on earth. This is especially the case when it comes to existential risks.

Beside previous notes on global catastrophic risk in general, we recommend further investigation within the following areas:

Catastrophic climate change: Future studies should focus more on the natural carbon dioxide that is frozen within the arctic permafrost, because it is the largest trigger at the moment that could increase global warming rapidly which results in catastrophic effects (Schuur et al., 2015).
Nuclear war/winter: Connecting the topic of nuclear warfare with measures on prevention as the probability is still relatively high that an (accidental) incident will occur. Additionally, we suggest to include political sciences in order to prevent a war, because if nuclear missiles are activated, it is primarily a political decision.

Natural pandemics: In this area, research should focus on how fast potential pandemics will spread over the globe and what strategies may be useful to limit this spread. Not surprisingly, international strategies will be necessary.

Exogenous risks: Although there is some specific research on the monitoring of super-volcanoes, it is important to continue emphasizing this in future studies, because it is a risk which is not influenceable by human population. Although opportunities of preventing eruptions are low, studies in geology may find a way to do it, or find proper metrics for precise measuring volcanic activity at least. Mitigation strategies should also be more on the asteroid and comet risk, considering technical perspectives.

Emerging risks: Investigations on how international agreements can be established to protect the planet from future misusage of AI/ASI and geoengineering. Also, how humans can integrate AI/ASI in the civilization in a safe way must be a priority for further research.

Other future studies: What will happen to the modern civilization, if the internet is failing? Since everything is built on this kind of system today, we also become dependent on it and its functionality. We consider this topic as an emerging global catastrophic risk.

Despite the necessity of integrating subtopics into one, we are certainly aware of the need for different disciplines, as the various risks stem from several starting points. Furthermore, this interdisciplinarity should also be considered as a unique strength of the study field, which should be enhanced.

Lastly, with respect to the theory of risk and uncertainty, we have to improve specific models for risk assessment, so that predictions become even more accurate, which should be a basis for every further research. This will also help to facilitate long- and short-term survivability for humans. Solberg Søilen and Baback Alipour (2011), for example, developed a surveillance model to classify emerging risks, limited to a present time horizon. As a result, an average probability for anthropogenic and non-anthropogenic events is calculated, stating that human-made catastrophes are more likely by now than others. With this contribution, which includes data from relevant private and public organizations such as NASA, both scientists react to the large demand for accurate models on GCR in order to emphasize potential macro factors. This is important, because in a very final perspective, decision makers must invest in effective mitigation strategies, that root in accurate research.

7. CONCLUSION

This paper gives an overview on the topic global catastrophic risk (GCR). The five outlined risk categories, that have been highlighted in this paper, are areas with a high potential to become catastrophic on a global scale. The assigned risk probabilities of these events are different though. Events as nuclear wars, climate change, artificial intelligence, etc. have emerged because of a developing civilization. Both the speed of economic growth and technical development on earth have never been faster than today. In contrast, exogenous risks, such as super-volcanic eruptions and asteroid/comet impacts, are not anthropogenic and therefore with separate conditions to address. According to Cotton-Barratt et al. (2016) there may be risks that we have not discovered yet. Nevertheless, they will emerge in the future due to a developing civilization.

Since GCR is a field that stems from many different disciplines, there is still effort needed to combine all contributions into one context. This should be done with maintaining several perspectives from
every research field, because diversity will improve the substance and importance of GCR.

Calculating risks, when events do not occur on a regular basis, is another essential challenge for researchers which makes it difficult to provide plausible results on probability and impact. Particularly referring to existential risks. Therefore, the scientific community should focus studies on risk assessment on the one hand, and also be aware of the distinction of risk and uncertainty to suit conducted research in a theoretical framework on the other hand. For example, supernovas and gamma-ray bursts, that are outlined briefly in chapter 4.6, may have a lack of defining these phenomena as a risk. There is sometimes no sufficient argument for assigning mathematical probabilities according to the school of thought. Hence, this may be more an uncertainty than a risk yet. Despite these detailed terminology, we argue that research must basically result in recommendations for action, received by politicians and decision makers mainly. We value collections which support the general and particular understanding on GCR, so that awareness is increased and actions can be taken.

In a nutshell, contributions on GCR are increasing since the past 10 to 15 years. Especially, artificial intelligence is covered quite often in literature. We state that research in this area must finally refer to effective countermeasures, taken by human population to survive for all future generations. When we cannot reduce the risk of these potential disasters, it does not matter in the long-run, if we reduce other risks. Matheny (2007) points out that if we all die, it is not just our generation that dies, also all future generations including billions of humans. The contribution therefore helps to get a deeper understanding why each generation is important. It would be enough for one generation to make mistakes; as a consequence, our species would end to exist forever. Therefore, we must change the way how humans think about the future and come together internationally to work on these risks. Furthermore, we need to change how our political and social system works in order to become a more united world. But as we can see today, we have a divided planet; Religion, beliefs, corruption and political problems are hindering international agreements to reduce global risks. We have to remember that we are all humans who have just one planet to live on. Thus, if we cannot reduce these risks or other political problems, we will have no planet to live on in the future.

8. REFERENCES


