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The nexus between water, energy, and food in the context of the global risks: An analysis of the interactions between food, water, and energy security

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ABSTRACT

The purpose of this article is to analyze the interactions between water, energy, and food security, referenced in this study as the nexus between water, energy, and food, and the impacts of global risks using the World Economic Forum's, 2017 Global Risks Report as a guideline. In this analysis, the authors reveal that water, energy, and food are interdependent and essential resources demanding sustainable, integrated and intelligent management. These vital resources are susceptible to many global risks which are maximized by extreme weather events, mass involuntary human migrations, and other hazards that predominantly endanger the vulnerable communities of less developed countries. In conclusion, policies carried out by the international community, decision-makers, civil society, and the private sector, must align to target and mitigate global risks, specifically, water, energy and food security.

1. Introduction

The international community is tasked with solving a variety of complex and interrelated issues which disproportionately affect vulnerable nations most and include many challenges linked to management of water, energy, and food resources (Bazilian et al., 2011). If these problems are not effectively administered, human civilization could face major threats (Diamond, 2005). The world's population is expected to reach 8.5 billion people by 2030, rising to 9.7 billion in 2050 and to 11.2 billion in 2100 (UN, 2015). Thus, the increase in water, energy, and food demand, combined with population growth and economic development, has the potential to result in a shortage of resources.

Aside from the challenges mentioned above, humanity faces several risks, acknowledged as "global risks" which have been deeply analyzed by the World Economic Forum (WEF) in its annual Global Risks Report. These risks not only affect people and companies around the globe, but also have potential impacts on water, energy, and food security.

In this context, the nexus between water, energy, and food security emerges from a different perspective which aims to promote the understanding of the interconnections between the management of natural resources and the importance of ensuring universal rights such as water, energy, and food (WEF, 2011; OECD, 2014; Scott et al., 2015; Mohtar and Lawford, 2016; WEC, 2016).

The main objective of this article is to understand how the global risks impact the nexus between water, energy, and food. Through a systemic analysis of the global risks, this article examines the interdependencies and vulnerabilities among these resources; moreover, it facilitates the comprehension of today's chaotic reality, promoting the development of new adaptation strategies in academia, civil society, politics and other sectors. These actions may not only diminish threats but also stimulate the development of a more secure and sustainable world.

To adequately analyze the nexus between water, energy, and food and the threats they face concerning the Global Risks Report, this paper aims to demonstrate that these resources are: a) essential, b) vulnerable, c) interdependent and, d) demanding of sustainable management.

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1.1. Water security

Ensuring permanent access to water is becoming increasingly difficult due to global transformations in today's economy, climate, and society (Hope et al., 2012). It is estimated that about 40% of the world's population will live under water-stressed conditions by the middle of the next century (OECD, 2013). Nowadays, less than 3% of the world's water is potable, and 2.5% of this freshwater is frozen (WBCSD, 2005; UN Water, 2013), creating a global scenario of vulnerability and insecurity.

According to the Global Water Partnership (GWP, 2010), water security is connected to integrated water resources management among all sectors (agriculture, energy, health…). Researchers from the Program on Water Governance (PoWG, p. 17, 2012) state that water security exists when there is “sustainable access on a watershed basis, to adequate quantities of water, of acceptable quality, to ensure human and ecosystem health”. The UN Water (2013) states that water security is associated with sustainable accessibility and availability, moreover, is essential for responding to other development problems like malnutrition and child mortality.

According to the GWP (2014), sustainable water management will improve the quality of life around the world. However, considering the dynamic changes in the world's physical and economic conditions, such as population growth and modifications in climatological conditions, which demand continuous attention and water systems adaptations, water security will never be achieved entirely.

1.2. Energy security

In the early 20th century, studies related to energy security arose in the political realm due to demands for coal and oil for use by naval fleets and armies (Yergin, 1991). In 1970, as a result of the beginning of the oil crisis, many academic institutions initiated studies analyzing the energy field (Hancock and Vivoda, 2014). In recent years, the term “energy security” has gained prominence as a consequence of terrorist threats, instability among oil-exporting countries, geopolitical conflicts, and demands to increased energy supply and boost economic growth (Yergin, 2006; Löschel et al., 2010; Cox, 2017).

The International Energy Agency (IEA, 2016) defines energy security as “the uninterrupted availability of energy sources at an affordable price”. According to IEA, energy security is composed of three main categories a) long-term energy security, which mainly concerns long-term investments planned to provide energy according to a country's economic development and sustainable environmental needs; b) short-term energy security, which focuses on the ability of the energy system to respond promptly to sudden changes in the balance of supply and demand; and c) lack of energy security, which is linked to its economic and social impacts, as a result of price volatility and noncompetitiveness.

Energy security is essential to support basic human needs and economic necessities (Kruyt et al., 2009) and represents a critical feature regarding systems planning in the environmental, technical, political and social realm (Augutis et al., 2017). However, energy security may be vulnerable to climate change and other global risks, increasing tensions around this resource.

1.3. Food security

The definition of food security has been widely discussed by the academic field (Godfray et al., 2010) due to its global significance and its social and economic impacts on the development of nations (Gentilini and Webb, 2008). The concept of food security encompasses a broad scope, allowing different interpretations of its definition (Maxwell and Smith, 1992).

The need to create a particular concept for the term arose in 1974 when the World Food Conference defined food security as the global availability of food supply resources to sustain the increasing demand for food and to recompense market prices (UN, 1975). The World Food Summit (1996) declared that “food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life”. These definitions reinforce the multidimensionality of food security (accessibility, availability, stability, and utilization).

Food insecurity, on the other hand, occurs when people do not have social, physical and economic access to food (FAO, 2009). According to Gundersen and Ziliak (2015), this insecurity also significantly impacts public health, making it challenging to fight off chronic diseases, diabetes, asthma, and insomnia.

Many world leaders recognize the need to minimize the adverse consequences of food production on the environment. As a result, agricultural producers face greater competition for land, water, and energy (Godfray et al., 2010; Lal, 2010). This paired with population growth, which will increase demand for food by 60% by 2050, creates a complex and chaotic scenario (Alexandratos and Bruinsma, 2012) that demands global cooperation and exhaustive research regarding food security and adaptation strategies to promote environmental protection.

1.4. The Nexus between water, energy and food

The Integrated Water Resource Management (IWRM), formed in 1971, is a sustainable development process that aims to promote awareness concerning the issue of global water security through education, investigations, and the exchange of information between countries (Mohtar and Lawford, 2016). The establishment of the IWRM represents the acknowledgment of the interconnections between water, energy, and food. The IWRM recognizes water as a fundamental resource for social and economic development. At the Bonn 2011 Nexus Conference, the term “water, energy, and food security nexus” was popularized and diffused internationally, especially among academic, political, and business fields (OECD, 2014).

Water, energy, and food are inseparable resources (WWAP, 2014; Wolfe et al., 2016). Many regions face significant water, energy, and food security challenges (Miralles-Wilhelm, 2016; ESCWA, 2015). Understanding the relationship between these resources allows countries to establish effective sustainable development strategies and policies based on accurate and systemic data, avoiding and mitigating interconnected risks (IRENA, 2015).

The establishment of food, water, and energy security is a global challenge. Thus, as the demands for these resources rise, it is becoming increasingly necessary to fully understand the interdependencies between them. The adverse consequences of climate change, in addition to political, social and economic obstacles, intensify these difficulties, affecting the management, availability, allocation, and usage of resources (Miralles-Wilhelm, 2016).

Analyzing the nexus between water, energy, and food not only ensures a better understanding of these resources and their interconnections but also allows for the comprehension of their production and distribution systems. The importance of this study also arises from legal, social and economic matters, which share a deep connection with these resources. Hence, the profound and sensitive interactions between water, energy, and food, demand attention and awareness to the risks and unexpected consequences that faced by society (King and Carbajales-Dale, 2016).

The interdependencies concerning the nexus between water, energy, and food are the result of an extremely complex system. Thus, developing a viable solution that provides stability for these resources simultaneously is extremely challenging (Meadows, 2008).

As shortages in natural resources increase and economic and population growth rates rise, the significance of the nexus becomes evident. The demand for a profound examination regarding the interrelations between water, energy, and food is urgent (Hoff, 2011). It will not only stimulate sustainable objectives and stability between resource users, but will also facilitate the transition to a globally integrated ecosystem through encouraging strategic and integrated management (Mohtar and Lawford, 2016).

2. Methodology

First, a broad analysis of the 2017 WEF Global Risks Report was conducted. The Annual Global Risks Report (2017) focuses on the global risks impacting countries and large companies and assesses the risks to each type of security (water, energy, and food). This article seeks to study the direct interconnections between these risks.

According to Jackson (2000), a system represents more than the sum of its parts. This statement can be applied to nature as well since nature cannot be divided into isolated sections; it requires connectivity between its components instead. Bider et al. (2011), analyzes that three concepts must be examined for a full-comprehension of systemic analysis: a) the interrelation: the way things are connected and their consequences; b) the perspectives: the form in which scenarios of different global visions are overseen; and c) the limits: prevention of a system that reaches everyone.

Finally, an analysis contemplating examples of each of the risks and its impacts on water, energy, and food security was conducted. This study, using scientific methodology, describes how extreme weather events, large-scale involuntary migrations, large-scale terrorist attacks, natural catastrophes and other risks impact water, energy, and food security.

3. The global risks

The global risks are linked to specific events which negatively impact security, health, environmental, economic or technological matters. According to Cutter et al. (2015), Engel and Strasser (1998), the global risks are connected to the globalization process and to society's individualization, which leads to instability and insecurity. According to the WEF (2014), the global risks are events that cause significant negative impacts to countries and industries over a 10-year period.

The global risks are “systemic risks”. This concept implies that when something impacts one portion of an interdependent system, there is a high probability that the entire system will be consequently affected since it is composed of interconnected parts (Kaufman and Scott, 2003).

The impact of global risks on water, energy, and food security is different for each of the sources. Among the 30 risks introduced by the 2017 Global Risks Report, 26 of them may impact water, and/or energy, and/or food security. Concerning these 26, only 9 risks manifest direct impacts on the nexus between water, energy, and food security simultaneously, as shown in Table 1. Cases and examples will support the explanation of how the global risks impact these securities.

Analysis of the global risks impacting food, water and energy security, shows that the geopolitical and environmental risks are the most threatening risks concerning the nexus. The demand for elaborating a more detailed reflection of how each risk impacts these resources is urgent. Below is a detailed analysis, describing how each global risk can impact the nexus between water, energy, and food.

3.1. Economic risk

Among the current economic risks, only failure of critical infrastructure impacts the nexus. The lack of investments in infrastructure affects key sectors, such as transportation, electricity, telephony, and sanitation. The degradation of these services disturbs economic and social development. The table below (Table 2) presents some potential impacts of economic risk on food, water, and energy security.

3.1.1. Failure/Shortfall of critical infrastructure

Failure/Shortfall of critical infrastructure impacts many regions globally. For example, in Africa food security has been deeply affected due to this matter. In order to address the continent's problem, it is crucial to understand the founding reason for this enormous vulnerability concerning food insecurity. First, food insecurity arises when: a) there is a shortage of food production due to weather events (droughts, flood etc.); b) when the food supply production is smaller than the population it reaches; and c) when these food prices are expensive due to high oil prices, transportation, and commodities market fluctuation. In order for countries to mitigate and adapt from these vulnerabilities, traditional living methods must be substituted by highly technological approaches and increasing infrastructure investments in rural areas, consequently rising food production (AfDB, 2012).

Failure or shortfall of critical infrastructure is probably the most significant risk concerning water security. The lack of investments towards adequate water infrastructures, especially in developing and underdeveloped countries, generates many adverse consequences, including discrepancies in basic services (Van Leuven, 2011; OECD, 2014a).

Failure or shortfall of critical infrastructures (lack of investment in energy, transportation, and communication) influences energy security by increasing fuel costs, raising the price of commodities, and causing potential debts for consumers. A failure of a major financial mechanism may intensify the energy crisis or ensure its persistence (O ECO, 2007; IPEA, 2015; WEF, 2016).

3.2. Environmental risks

Two of the five global risks listed on the 2017 Global Risks Report display direct connections to the nexus. The extreme weather events and the failure of climate-change mitigation and adaptation significantly threaten the nexus between water, energy, and food, as shown in the following table (Table 3).

3.2.1. Extreme weather events and failure of climate-change mitigation and adaptation

The extreme weather events consequences regarding food security are historically recognized. In 2011, a drought struck East Africa, triggering a regional food crisis, which affected 13 million people. In Somalia, more than a quarter of a million people died of starvation (WEF, 2016). In 2015, in the United States, the ten disasters and damages related to climate change issues exceeded over $ 1 billion each in expenses (NRDC, 2016).

Failure of climate-change mitigation and adaptation affects food security in a diverse range of ways. When governments and companies do not promote preventative and adaptive actions, companies are affected, lose protection, and the global community is negatively impacted (WEF, 2016).

In South America and Central America, projections predict several risks concerning water security triggered by extreme weather events. Because of the reduction of the Andean glaciers, a decrease in rainfall, and an increase in evapotranspiration in South and Central America's semi-arid regions, these semi-arid zones and the tropical Andes are becoming extremely susceptible to water shortages (IPCC, 2014).

These events directly impact energy security. The demand for energy is proportional to increases in temperature. In the United States, if temperatures increase to 1 °C, the demand for energy will rise by 5–20% (for cooling environments) and demand for energy to heat will drop to 3–15% (CCSP, 2008; EPA, 2016). The increase in temperatures will limit our capacity of power generation and ability to reliably deliver electricity (EPA, 2016). Warmer weather reduces the efficiency of nuclear power plants due to an increased need for cold water to cool generators. Hence, warmer air and water reduces the ability of power plants to convert oil into electricity (U.S. Global Change Research Program, 2014).

Table 1
Main global risks impacting food security, water security and energy security.

	Risks	Water	Energy	Food
Economic	**Failure/shortfall of critical infrastructure**	■	■	■
	Asset bubbles in a major economy		■	■
	Deflation in a major economy		■	■
	Failure of a major financial mechanism or institution		■	■
	Severe energy price shock		■	
	Unmanageable inflation		■	■
	Fiscal crises in key economies			■
	High structural unemployment or underemployment			■
Environmental	**Extreme weather events**	■	■	■
	Failure of climate-change mitigation and adaptation	■	■	■
	Major biodiversity loss and ecosystem collapse (terrestrial or marine)	■		■
	Major natural disasters	■		■
	Man-made environmental damage and disasters	■		■
Geopolitical	**Failure of national governance**	■	■	■
	Failure of regional or global governance	■	■	■
	Interstate conflict with regional consequences	■	■	■
	Large-scale terrorist attacks	■	■	■
	State collapse or crisis			■
Societal	**Failure of urban planning**	■	■	■
	Rapid and massive spread of infectious diseases	■		
	Water crisis	■		■
	Food crises			■
	Large-scale involuntary migrations			■
Technological	**Adverse consequences of technological advances**	■	■	■
	Breakdown of critical information infrastructure and networks		■	
	Large scale cyberattacks		■	

Table 2
Economic risk.

	Water security	Energy security	Food security
Failure of critical infrastructure	Lack of investments in infrastructure, sanitation, and maintenance of water supply (Dickson et al., 2016; Hanjra and Qureshi, 2010; Grey and Sadoff, 2007).	Energy is both a determining and limiting factor for economic growth and development (Goldemberg, 2000; Kessides and Wade, 2011; Vosylius et al., 2013).	Infrastructure is crucial for food production and processing (Godfray et al., 2010; Hanjra and Qureshi, 2010; Shively and Thapa, 2017).

3.3. Geopolitical risks

Table 4 shows that of the six geopolitical risks mentioned in the 2017 Global Risks Report, four directly impact the nexus. Interstate conflicts and large-scale terrorist attacks threaten food, water, and energy security on a global level resulting potential failures regarding national, regional or global governance in the international community. These are delicate risks which could jeopardize society and thus demand global awareness.

3.3.1. Failure of national governance and failure of regional or global governance

According to Bakker et al. (2008), failure of global and regional governance regarding water management causes: a) decrease in consumer rights to essential services; b) lack of political rights; c) neglection of poor communities by a government focused on serving the elite; and d) economic hindrances which connect more impoverished families.

Failure of national, regional or global governance arises when problems related to famine and food insecurity occur. Sovereign governments are responsible for developing programs and policies that stimulate agricultural business and lead to food security (Paarlberg, 2002).

Some researchers believe that global and local energy governance is the most important part of energy security (Goldthau and Witte, 2009; Mckenzie, 2011), while others prefer to focus on the “deficiencies” of energy security (Florini and Sovacool, 2009, 2011). Failure of national governance, in this scope, could result in energy distribution instability, increased monopolies, market disruption, and price volatility (Karlsson, 2007; Goldthau, 2012).

3.3.2. Interstate conflict with regional consequences

Interstate conflicts significantly impact energy security by reshaping urban and rural areas, raising the likelihood of humanitarian crises, increasing countries vulnerabilities, affecting populations, industries, and the transportation sector (Cornelius and Story, 2008; USAID, 2010). “Resource wars”, especially concerning the global oil industry, will transform future international dynamics. For example, Africa, a significant producer of oil, will be drastically affected by this conflict. Additionally, since oil extractions typically occur in regions secluded from hostile territories, resource wars will be more likely to occur in depopulated or marine areas (Colgan, 2013).

The connections between food insecurity and interstate conflicts are less prominent; however, these impacts occur on different levels caused by increasing food prices, forced migrations, the spread of diseases, social collapses and violence; thus, the outcomes of interstate conflicts trigger food insecurity, especially in the most vulnerable countries (WFP, 2011).

Toset et al., 2000 identifies that “the previous war in the Middle East was about oil, the next war will be about water”. This statement represents a real concern to interstate conflicts on water security which will certainly have regional consequences. Wars in some regions will occur more frequently due to disputes over water access; therefore, water supply will become a war instrument. Many countries with high population and economic growth will increase their demands for and reliance on water resources, potentially under another nation's control, generating conflicts and disagreements (Gleick, 1993).

3.3.3. Large-scale terrorist attacks

The concept of “agroterrorism” suggests the development of terrorist strategies focused on agriculture with the potential to endanger food security (Laqueur, 1999; WFP, 2011). Damaged infrastructures lead to contamination of water reservoirs through chemical or biological agents, interrupting fresh water supply, and threatening humankind, the environment and water security (Gleick, 2006; Copeland, 2010). Water has been used throughout history politically and militarily as a strategic resource; thus, when water demand increases, the value and vulnerability of water advances proportionally (Gleick, 2006).

Terrorist attacks on oil processing facilities, transportation, tanks and oil terminals (especially in the Middle East and the Pacific) may have several negative outcomes: millions of oil barrels could be destroyed; millions of barrels will not be able to be shipped by traditional routes; and countries, such as the United States, will demand increased production from other refineries and increase importation rates to compensate for gas shortages (Cohen et al., 2011). The attacks on

Table 3
Environmental risks.

	Water security	Energy security	Food security
Extreme weather events	Floods, landslides, heavy storms and earthquakes trigger environmental and socioeconomic consequences, affecting rivers and increasing the probability of the spread of infectious diseases due to the degradation of sanitary conditions which obstructs water accessibility for the population (Mata-Lima et al., 2013).	Storms, landslides, floods, and forest fires, for instance, could affect the production and distribution of energy globally (IEA, 2015).	Intensification of extreme weather events (IPCC, 2001, 2007) can negatively impact the food supply and food security of vulnerable regions (Schmidhuber and Tubiello, 2007).
Failure of climate-change mitigation and adaptation	Failure of climate-change mitigation and adaptation will affect river flows and cause sea-levels to rise, impacting all people and all sectors related to water, such as the energy and agriculture business. This directly endangers water security. Additionally, as temperature intensifies, water evaporates which results in more droughts (GRACE, 2016).	Rising temperatures will require more energy production to cool homes, reduce the efficiency of nuclear power plants, and hinder the production and distribution of energy (CCSP, 2008; EPA, 2016; U.S. Global Change Research Program, 2014).	Climate change, which impacts and changes society's habits, will spread water scarcity around the world. Additionally, extreme weather events will become more frequent, affecting agriculture. This will risk global security and result in involuntary migrations (University of Oxford, 2016; Nature Climate Change, 2016).

Table 4
Geopolitical risks.

	Water security	Energy security	Food security
Failure of National Governance Failure of Regional or Global Governance	The lack of integrative water management approaches on local and regional administrations (Bigas, 2012; Bakker et al., 2008; Pahl-Wostl et al., 2008; Moss, 2004).	Instability of energy distribution, increased monopolies, market disruption, and price instability (Karlsson, 2007; Goldthau, 2012; Florini and Sovacool, 2011).	Hinderance of the development of policies that lead to food security (Paarlberg, 2002; Ericksen et al., 2009; Windfuhr and Jonsén, 2005; Godfray et al., 2010).
Interstate conflict with regional consequences	Poor distribution of water and contamination of water can both arise from a conflict and be the cause of the conflict itself (Molen and Hildering, 2005; Toset et al., 2000; Gleick, 1993; Link et al., 2016; Petersen-Perlman et al., 2017).	Energy resources, especially fossil fuels, can motivate conflicts and lead to infrastructure breakdown when these disputes increase (Månsson, 2014; Colgan, 2014; Mercille, 2010; Giordano et al., 2005).	Destruction of sources of food can cause increases in food prices as well as food shortages (Scanlan and Jenkins, 2001; Hendrix and Brinkman, 2013).
Large-scale terrorist attacks	Interruption of the supply of basic services, threatening human life, the environment, and water security (Haimes, 2002; Gleick, 2006; Copeland, 2010).	Attacks on energy infrastructures threaten energy supply, affecting energy security (Yergin, 2006; Toft et al., 2010; Cohen et al., 2011).	A potential threat to food security is the so-called agroterrorism, attacks which compromises agricultural infrastructure. These attacks could be carried out through concentrated viruses, entomophilic (disseminated by pollinating insects), botanical or bacteriological viruses against birds, livestock and agricultural production itself (Foxell Jr, 2001; Casagrande, 2000; Prescott, 2016).

Nigeria's oil facilities by the terrorist group MEND (Movement for the Emancipation of the Niger Delta) in 2007, for instance, caused about 61 million dollars losses per day, inducing massive disruptions in the oil supply industry (Giroux, 2010; Toft et al., 2010).

3.4. Societal risk

Regarding all of the societal risks, only failure of urban planning has a prominent impact on the nexus. The following table (Table 5) suggests that the failure of urban planning might pose an even greater challenge to food, water, and energy security, since these resources are already undergoing an increasing demand due to climate change and population growth.

3.4.1. Failure of urban planning

Providing healthy and nutritious food to a growing urban population is a challenge that requires efficient urban planning and an inclusive agricultural and food supply system, promoting an efficient network between rural producers and urban markets (FAO, 2015). The interconnections between urban areas and food security are critical to securing sustainable international development (Dickson et al., 2015).

Failure of urban planning is a significant threat to water security. A vast part of the world's population lives in urban areas (in 2014, 54% of the world's population lived in urban areas). Urban life demands substantial amounts of water resources. Thus, resource abundance, as well as efficient urban management, is necessary to supply these demands (GWP, 2015).

More than 60% of the global energy demand comes from cities where half the world's population is concentrated (ICLEI and UN HABITAT, 2009; IEA, 2012). Studies estimate that by 2050, two-thirds of the global population will inhabit urban areas. Cities are fundamental for local and regional development and poverty reduction. Cities are also important for economic, governmental, commercial and transportation activities (UN, 2014). Urban planning techniques must be innovative, and should respond proportionally to population growth (Barnett, 1989). Therefore, urban contexts are ideal locations to implement efficient and sustainable energy practices (Cajot et al., 2017).

3.5. Technological risk

After analyses of the four different technological risks acknowledged in the 2017 Global Risks Report, it was found that only one has an impact on the nexus: the adverse consequences of technological advances. The table below (Table 6) provides an analysis of the impacts of this risk on food, water, and energy security.

3.5.1. The adverse consequences of technological advances

Aside from the increasing risks caused by the acceleration of technological processes, radical technological transformations, such as nanotechnology and intelligent machines, may also impose unprecedented threats to humanity, endangering food security (Bostrom, 2002).

The adverse consequences of technological advances also offer significant dangers to global water security (WEF, 2016). The WEF (2017) and highlights the importance to the survival of humanity, of studying the potential impacts of emerging technologies, such as biotechnology, artificial intelligence robots, geoengineering, and other Fourth Industrial Revolution (4IR) innovations which will cause major changes in vital water infrastructure networks (e.g. supply, wastewater treatment, flood protection, etc.).

Different forms of energy production influence the environment and energy security differently. While nuclear fusions pollute the water with radioactivity, hydroelectric plants destroy habitats and alter water flow (CMU, 2016). Therefore, it is important to increase awareness concerning these vulnerabilities among powerful policy makers (WEF, 2016).

Table 5
Societal risk.

	Water security	Energy security	Food security
Failure of urban planning	Overall, water security has been under great pressure in various urban areas as a result of population growth, poor wastewater and sanitation management, lifestyle changes, and water demand conflicts. Water consumption is expected to double until 2025 (GWP, 2015).	Population growth, especially in urban areas, will put pressure on energy resources, inducing potential risks to several regions of the world (ICLEI and UN HABITAT, 2009; IEA, 2012).	Climate change, summed up with unhealthy lifestyles in urban centers and increasing pressure on food resources, provokes societal challenges which must be defeated through intelligent planning (Dickson et al., 2015; FAO, 2015).

Table 6
Technological risk.

	Water security	Energy security	Food security
The adverse consequences of technological advances	The limitless increase in production and consumption, combined with technological advance, can impact soils, ecosystems, and water. There is a possibility Existential Risks might occur, threatening water security (Bostrom, 2002, 2013; Jebari, 2014; CSER, 2016).	The Fourth Industrial Revolution will dramatically change how we understand logistics, communication, and transportation systems. An interdependent world, which requires more energy, must be prepared to guarantee energy security (UCS, 2016; WEF, 2016; CMU, 2016).	The increasing population and demand for food will drastically change the way we produce food, which directly impacts food security (Bostrom, 2002; Bernauer and Meins, 2003).

3.6. Trends, future shocks and their impacts on nexus

The Global Risks Report describes certain global tendencies which will reshape the global agenda in the next following decades "that could contribute to amplifying global risks and/or altering the relationship between them" (WEF, p. 62, 2018). Furthermore, the report provides a special session regarding the "future shocks", an innovation available in the 2018 Global Risks Report. These shocks are analyzed as "dramatic disruptions that can cause rapid and irreversible deterioration in the systems we rely on" (WEF, p. 5, 2018). Trends and future shocks are not as tangible as the global risks since most of these challenges have not occurred yet, mainly due to its complex, speculative and future nature, demanding strategic measures to impede them from materializing. This study analyses these movements as indirect risks concerning their impacts on the nexus between water, energy, and food.

The Grim Reaping, for instance, is considered one future shock which is triggered by the increase of environmental tensions, extreme weather events, plant pests, and political instability. The consequences and impacts of this shock encompass key food producing regions provoking food scarcity, price increases, demand increases, and disputes concerning food, water, and energy supply inducing political, economic and geopolitical crisis. Therefore, the Grim Reaping's impacts on the nexus between water, energy, and food are evident, considering that these resources demand favorable climatic conditions and stability to be appropriately distributed and delivered globally (WEF, 2018).

Regarding future tendencies, there is an undeniable variety of challenges concerning the nexus between water, energy, and food. Rapid urbanization, for example, will stress these resources and might induce conflicts concerning demand and supply. Climate change will modify the composition of earth's atmosphere, resulting in a diversity of obstacles especially concerning vulnerable communities and the countryside, regions that rely on favorable climate conditions for their subsistence and growth. Finally, among the various trends addressed by the WEF, the growing middle class in emerging economies will unquestionably demand reliable water, energy, and food infrastructures guaranteeing the accessibility and availability of these resources (WEF, 2018). The aforementioned risks will be systemically analyzed throughout this paper particularly regarding its interconnections between the nexus of water, energy, and food.

4. A systemic analysis of the global risks regarding water, energy and food security

As previously analyzed, the global risks drastically impact water, energy and food security. By emphasizing the global risks systemic complexion, this study concentrates on analyzing two specific aspects stated on the Global Risks Report: how likely a phenomenon is to occur; and its potential implications. Fig. 1 represents the global risks that impact water security, energy security, and food security.

Concerning the thirty global risks, nine simultaneously impact the nexus, four of which remain among the ten most likely to occur. Other four global risks are among the most impactful risks for business and society. The Global Risks Report methodology aims to assess and rank the risks regarding probability and impact. The following measures are used to qualify the potential impact: minimal, minor, moderate, severe and catastrophic. The probability scale uses a score from 1 to 7. Overall, 745 interviews were conducted in order to gather the data analyzed by the report.

Systemic challenges and global instabilities increasingly jeopardize water, energy, and food resources. Over time, humankind has learned to mitigate traditional risks separately; however, it is still incapable of coping and preventing complex and interconnected risk systems rooted in the modern world (WEF, 2018).

Failure of climate-change mitigation and adaptation as well as the increase of extreme weather events such as floods, storms, hurricanes and intense droughts, severely impacts water security. Dramatic consequences rise when water potability or supply infrastructure is affected (Vörösmarty et al., 2000). Irrigation and water distribution challenges might also impact food production and biofuel generation (Berchin et al., 2018). Biofuels are important energy resources that play a prominent economic role in many countries such as Brazil and China, which hold the world's largest hydroelectric plants (Hamududu and Killingtveit, 2012). These countries tend to suffer serious damage when extreme weather events affect their existing infrastructures through a failure of critical infrastructures.

Examples of the failure of critical infrastructures include failure in hydroelectric lines, thermoelectric lines, transmission cables and goods distribution lines, which impact the entire production system. These failures impact the flow of food and distribution of water and energy for irrigation or for the population itself. Regarding technology, equipment to mitigate the detrimental impacts of climate change can also be affected. The challenge of failure of critical infrastructures is characterized by a lack of investments, upgrades, or protections of infrastructure networks and strategic activities, which has implications for the entire system (Evans et al., 2017).

These impacts are profoundly connected to the failure of regional or global governance and failure of national governance, which represent the inefficiency of governments and institutions in developing and implementing risk reduction and mitigation strategies on a local and global level. Deficiencies in policies regarding water management, such as lack of basic sanitation, pollution of rivers, and low navigability, might impede the generations of sustainable hydropower (Moe and Rheingans, 2006), representing failure of governance in terms of water security. Policies centered on the generation of biofuels might increase competition for land between the food production and energy industry resulting in increased prices and rising water and energy demand due to the increased need for crop irrigation and energy for transportation (Harvey and Pilgrim, 2011). Thus, policies must be developed systemically regarding local, national, and global systems.

A failure of global governance can lead to interstate conflicts with regional consequences. Increasing water demand and its consequent scarcity results in conflicts between countries, inducing food and energy crises in several regions since water is an essential resource concerning food and energy security (Wolf, 1998; Swain, 2015).

Failure of urban planning produces several impacts and challenges to social, health and environmental development (Andrade et al., 2016). Efficient urban planning prevents water pollution and electrical overloads and increases waste and resource management which is

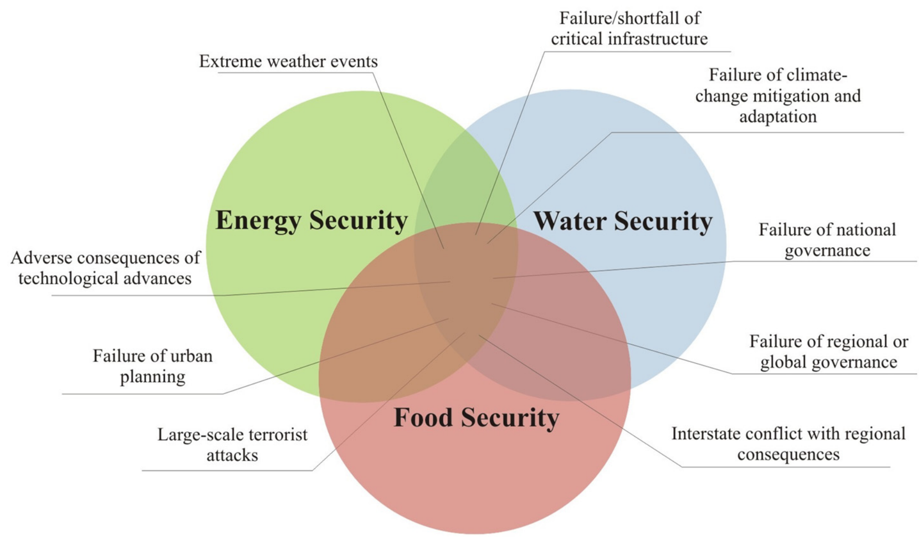

Fig. 1. Global risks impacting the nexus between water, energy and food security.

essential for society's livelihood. Disregarding new energy consumption patterns, inefficient urban planning with inadequate water supply systems and a lack of innovative energy production methods not only affects each sector separately but also puts the entire system in jeopardy (Berke, 2016) since water, energy, and food are interconnected and dependent resources.

Lack of governance implies governmental and institutional failure regarding social, political, economic, geopolitical and environmental concerns, producing a delicate institutional scenario which can lead to many crises and destructive events, including large-scale terrorist attacks. According to Copeland and Cody (2003), terrorist attacks or infrastructure failures could profoundly affect water security concerning the vulnerability of water as a resource regarding these risks in particular. The partial or entire destruction of infrastructure used for national water supply, for instance, could cause a shortage in primary resources, threatening public health, the environment, transportation, industrial activities, energy supply and food production (Hua and Bapna, 2013; Nickolov, 2005).

The adverse consequences of technological advances are another set of future challenges requiring adaptation by society. Shocks such as the "Precision Extinction" and the technological advances englobing artificial intelligence, geoengineering, and synthetical biology might cause unprecedented environmental, human, and economic calamities (WEF, 2018). Processes such as management, extraction, and transportation involving water, energy, and food resources continuously demand careful proceedings in consideration of their vulnerabilities. Therefore, innovative technology might stimulate and facilitate these mechanisms; however it may also produce and increase risks and generate more vulnerabilities to these resources. Computing systems develop and manage relevant functions associated with water, energy, and food resources such as controlling water and nuclear power plants, controlling different levels of food production and overseeing the signaling of mass transportation. These considerations imply a potential scenario for systems vulnerabilities and failures regarding the interconnections between these three resources.

Technology allows the creation of genetically improved species; the development of innovative and powerful machines, and the generation of devices capable of replacing manual crop labor; however, through the expansion of plantation land into forest habitats, it induces deforestation, modifying microclimates and increasing the demand for water in growing planting areas (Marques et al., 2007). These new technologies in the agricultural world transform it into a significant energy consumer, leading to disputes over energy resources between the other sectors.

Recognizing how the risks interact and impact the nexus offers an opportunity to develop mitigation strategies, create new technologies, and stimulate cooperation among the international community. According to Morin and Lisboa (2007), complexity arises in environments where simplicity seems to fail. Thus, the complex nature of the systemic analysis promotes the understanding of the interactions between different fields, which are often disjointed by disjunctive thinking.

A global risk that impacts three resources simultaneously (i.e. nexus) is naturally more alarming, precisely because of its systemic complexity and interdependencies. Studying different risks (economic, environmental, geopolitical, social, and technological) that affect several resources (water, energy, and food) requires the construction of complex solutions and strategies. The international community along with decision-makers, and other stakeholders must work collectively towards strategic natural resources management. The global risks featured in this analysis should be top priority compared to those risks that impact only one or two resources.

The risks that impact the nexus between water, energy, and food (Fig. 1) are not necessarily related to each other, even though all global risks "communicate" and share a strong interdependence; however, this connection does not justify a possible similarity between them. A terrorist attack (a geopolitical risk), for instance, may impact other risks, such as the failure of critical infrastructure (an economic risk). The correlation between those risks does not imply that they are similar. It is important that this relationship between interdependence and "singularity" among the global risks is understood. Moreover, decision-makers (public or private agents) can plan a more efficient management of resources through acknowledgement this pattern of data crossing and through observation of resource supply and availability. Risk management can contribute to a more effective governance, which will pragmatically improve the daily lives of people and their relationship with the environment.

5. Conclusions

The purpose of this article is to analyze the impacts of global risks on the nexus between water, energy, and food, based on bibliographical and qualitative research regarding the 2017 Global Risks Report. The report required extensive analysis concerning the concepts of global risks, the nexus between water, energy, and food, and the security of each resource.

First, a definition regarding the nexus between water, energy, and food was established. Then, the global risks stated on the current WEF

Risks Report were identified and clarified. Afterwards, an analysis was developed regarding the potential impacts of the thirty global risks on water, food, and energy security.

The analysis led to the conclusion that: a) 22 risks impact food security, b) 16 risks impact energy affordability and supply availability, c) 14 risks threaten water security, and d) 9 risks can cause significant short or long-term effects on the nexus between water, energy, and food.

The impacts of the global risks on the nexus are evident but complex. In order to overcome the various challenges these resources encounter (political; economic; social; technological; environmental; geographical - local, national and regional; and historical - current and future), countries must collaborate and implement strategic and integrated policies to improve the management of natural resources.

This research subject importance is apparent since it predicts future difficulties concerning water, energy, and food security that countries and great corporations will face. Considering it is a relatively innovative subject, these issues have been carefully discussed in international settings in conferences among chiefs of state and decision-makers.

The cooperation between multi-stakeholders to stimulate sustainable development regarding the global risks and nexus is also of great significance. Important events discussing the management of sustainable resources such as the 2017 Dresden Nexus Conference; the Paris 2015 Climate Change agreement; the Bonn2011 Nexus Conference, and the development of the United Nations Sustainable Development Goals raised awareness for discussion and empowered governments and societies to develop policies, sustainable management plans and resolutions in order to ensure food, water, and energy security. Thus, agents must work together to manage specific resources sustainably as well as in providing suggestions on how to incorporate the nexus or manage resources more sustainably.

Throughout this article, water, energy, and food security are examined as highly interconnected and interdependent resources. Therefore, the recognition of the nexus and its relationship to global risks should inspire the mitigation of adverse climate change consequences and stimulate sustainable development processes. Moreover, the development of adaptation strategies is required to avoid the global risks negative consequences, preserving water, energy, and food security.

It is reasonable to recognize that countries must overcome existing challenges and obstacles to ensure sustainable management global resources. Thus, decision-makers, heads of state, stakeholders, academics and the civil society must commit to developing relevant measures, policies, and resource management strategies considering the variety of global risks, the alarming data and projections for the future.

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