LONG-TERM SAFETY AND GOVERNANCE OF NUCLEAR ENERGY IN CLIMATE EMERGENCY CITIES

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Abstract

The advance of urbanisation and climate change are the greatest challenges facing humanity in the coming decades. Today 55% of the human population lives in cities and it is estimated that 6.4 billion people will live in an urban environment by 2050. The inevitable consequences of global climate change can result in hard-to-measure losses and damages that include loss of life and livelihoods, degradation of physical structures, territories and agricultural land, and impairment of cultural heritage, social and cultural identity, cultural heritage, and biodiversity. Adaptation efforts are not sufficient to adequately reduce the risks associated with current and future climate impacts, and even with effective adaptation, losses and damages will not be averted. In regions that are most vulnerable to climate change, the ecological, socio-economic and physical systems are losing resilience, with human vulnerability increasing in susceptible regions such as densely populated coastal regions, with real risk of forced displacement and direct or indirect impacts on hundreds of millions of people and key infrastructure. Given the relevance of nuclear energy in achieving climate change goals as low-carbon energy and its potential to contribute in net zero transitions, the study investigates the association between the impacts of climate change and the risks posed by nuclear installations in coastal locations. The first commercial nuclear power plants began operating in the 1950s, and today nuclear power accounts for about 10 percent of all electricity worldwide, making it the world's second largest source of low-carbon energy (26 percent of the total by 2020), with more than 50 countries using nuclear power and about 420 nuclear power reactors in operation around the world, in 182 different locations, of which a good part are coastal. We identified 82 locations that correspond to the conditions. The 5 countries with the greatest number of vulnerable locations are China (18), Japan (16), United States (9), Republic of Korea (6), and the United Kingdom (5). These locations also include four megacities, with populations of over ten million people: Shenzhen e Dalian (China), Karachi (Pakistan) e Surat (India). Since the coastal locations with nuclear power reactors that are vulnerable to sea level rise concentrate millions of inhabitants, it is critical that climate resilient energy systems are designed that consider the anticipated impact of climate change, both for slow onset events and climate extremes, with a focus on the safety of people and the environment surrounding these nuclear facilities.

1. INTRODUCTION

Urban areas have grown exponentially in the last decades and have projected that 62% of the world's population will be housed in cities by 2035. Both urbanisation and the adverse impacts of climate change bring significant challenges to biodiversity and populations, with coastal cities and locations being significantly at risk [1–2]. Coastal cities and settlements concentrate intense urbanisation processes and are on the front line of climate change, exposed to the interaction of climatic and non-climatic coastal hazards, with a tendency for severe disruptions by 2100 [3–5]. The risks associated with climate change for coastal cities take on an even greater dimension when one realises that the planet's urban areas concentrate more than half of the global population in about 3% of the territory and that about 40% of the world's population lives in coastal areas, with estimates of adverse impacts on one billion people living in coastal cities [2].

When considering the increasing effects of climate change, there are still important knowledge gaps on climate emergency issues [6], including those related to the integration of climate and nuclear risks in coastal cities, the theme of the study. Despite the fact that coastal cities are home to about 3.155 billion people and that about 45% of the locations that hold nuclear power reactors are in coastal zones, these regions lack information that supports integrated policies for managing risks and losses and damages arising from the impacts of climate change. Few studies have addressed the intersection of climate risks and siting of nuclear facilities in coastal urban areas [7–9], despite the adverse consequences of the combined effects of the earthquake and tsunami (known as Tohoku), which devastated the northeastern area of Japan in 2011 and caused damage to nuclear power plants along the coast and the subsequent release of radioactive elements into the environment [10-11].

In general, these studies refer to certain countries and regions, however, we have not found comprehensive scientific studies on these correlations and that include fundamental dimensions for territorial planning in a context of climate change. The integrated analysis of these factors is essential to extend the vulnerability of these agglomerations and the safety of nuclear power plants in the face of the challenges posed by climate change.

In addition, few studies have been dedicated to assessing the vulnerability of nuclear plants to extreme weather events and what adaptation measures are needed to ensure their safety. Thus, little research has investigated how urban planning and risk management should be integrated to protect coastal cities with nuclear facilities from the adverse effects of climate change. To contribute to the issue, we investigate the association between climate change impacts and nuclear risk in coastal cities that host nuclear facilities in their territory. Recognizing these associations and challenges and sharing best practices and experiences between countries can help identify effective innovative solutions for risk management and climate change adaptation.

2. METHODOLOGY

A combination of data sources and analyses was employed to develop this study. Initially, a literature review was conducted. Searches were conducted and records compiled in the Web of Science database, with the selection of documents corresponding to "article" and "review", published in any period. The following keywords were used: climate risk; nuclear power plants; coastal vulnerability; climate change; nuclear risk; sea level rise; coastal cities; coastal nuclear power plants; urban expansion; land use change; land use planning; world population projection. The descriptors were combined to identify the most relevant sources, selected based on the "Analyse Results" and "Citation Report" tools. The retrieved records were analysed and selected those of greater convergence and relevance to the study, which were categorised in relation to the themes and sub-themes, according to the research objectives.

An analysis of documents produced by the UN system was also carried out for the themes of migration, biodiversity and ecosystem services, urbanisation, climate change and global demography. Next, data from the platform PRIS - Power Reactor Information System (https://pris.iaea.org/pris/) from IAEA were analysed. The data converging with the objectives of the present study were systematised and compiled into a document. The location of each nuclear reactor was verified using Google Maps. For locations corresponding to coastal regions, the information was incorporated into the study metadata.

3. RESULTS AND DISCUSSION

In urban and peri-urban areas, anthropogenic pressures such as land use change can interact with climate change and result in complex and non-linear responses in biodiversity and human mobility [1–2] [12] . Nuclear disasters such as the one in Fukushima, Japan, in 2011, which in turn can compromise response options to address climate change related challenges.

Especially in coastal areas, population concentration causes serious damage to ecosystems, social problems and conflicts, and loss of important ecosystem services due to their rapid development, high consumption rates and high population density [13–14].

In an analysis of the complex interactions between large and mega coastal cities and the environment, the following components can be highlighted: i) drivers: urbanisation; energy consumption; transport; industry; agriculture; water consumption; tourism; ii) pressures; waste generation; gas emissions to the atmosphere; alteration of hydrological and sediment flow; pressures on groundwater recharge and supply; habitat loss; pressures on fish stocks; iii) status: Degraded air quality; degraded water quality; degraded drinking water; decrease in coastal vegetation; land subsidence; and iv) impacts: coastal erosion; decline in biodiversity; altered ecosystem functions; human health impacts; socioeconomic impacts [14]. These interactions highlight the obstacles faced by large coastal urban agglomerations in implementing global development policies. The intense development of the coastal zone and the imminence of increasingly widespread GCC impacts have significantly increased the associated economic, social and environmental risks [6]. Understanding this issue as a whole and knowing the potential widespread impacts of climate change and sea level rise on critical infrastructure such as nuclear power plants is essential for formulating effective response strategies, especially given the evidence that nuclear power, which is a low-carbon source of electricity, is exposed to risks such as intensified storms, droughts, extreme precipitation, wildfires, rising temperatures and sea level rise that pose damage to facilities and threaten supply interruptions [15].

However, in our reviews, we found that studies on nuclear infrastructure resilience in coastal zones have been incipient, with long-term planning gaps. While nuclear power is considered an important ally for climate change mitigation, these efforts interact with existing and new nuclear power plants that must also face dilemmas between adaptation and mitigation loss and damage.

In the United States, the passage of Hurricane Andrew in 1992 marked one of the first significant impacts on a nuclear facility, when the storm hit the Turkey Point Nuclear Power Plant south of Miami; however, despite revised emergency procedures, many of the same problems occurred again more than a decade later [16]. Sea level rise models for nine coastal locations, review of documents from the US Nuclear Regulatory Commission and reports from France's nuclear regulatory agency provided information on issues related to sea level rise, coastal erosion, coastal storms, heat waves and flooding, highlighting that extreme weather events pose a security challenge for coastal locations [9].

Examination of Japanese nuclear power plants affected by the 2011 earthquake and tsunami shows that three variables were crucial in the early stages of the crisis: plant elevation, sea wall elevation and location, and status of backup generators. A comparative assessment of these variables for 89 coastal nuclear power plants in the world showed that both Japanese plants were relatively unprotected against possible flooding in international comparison, and older plants and those owned by the largest utilities appear to be particularly unprotected [11]. Approximately 64% of installed capacity began operating between 30 and 50 years ago, before GCC was considered in plant design or construction. More than 500 million people reside within 80 km of at least one operating nuclear power plant and 20 million people live within 16 km and may face risks from climate change-induced extreme events [15].

While extreme weather events do not often pose a threat to nuclear plant safety, when they do, the consequences can be severe, especially by compromising critical infrastructure such as roads, communication systems, rescue and medical relief, water supply, food and power - making emergency responses to nuclear facilities even more difficult. Reports of storms and floods that have occurred provide an opportunity to improve safety, provided that these lessons are transferred to all operators at all facilities, in a true exchange of experiences and information - which does not seem to occur [16], with strong evidence of little or no coordination between international agencies and national governments to assess and respond to emerging risks to nuclear power from global climate change [15]. These assessments must necessarily include multiple hazards that are the combination of more than two natural hazards and that can lead to severe outcomes, such as what occurred at the Fukushima nuclear power plant [17].

In addition to direct impacts on nuclear facilities, increased nuclear risks from the effects of climate change include exacerbation of political and economic disruption and diminished strength of global institutions [18]. Besides the risks detailed in the study directly associated with sea level rise, cyclones and hurricanes, evidence also shows that inland plants face exposure to other climate risks that can similarly compromise the operation and safety of these facilities. Increasingly high ambient and water temperatures, increasingly severe wildfires [15], decreasing supply of cooling water for plants located in water-stressed regions; heating of cooling water [19].

About 43% of the European Union's water demand is used as cooling water by energy authorities, which tend to be seriously challenged and affected by climate change, with periods of cooling water shortages recurring in Europe. In 2003, more than 30 nuclear power plant units had to reduce their production due to limitations in cooling water discharge possibilities. In France, a heat wave in the summer of 2009 caused a shortage of cooling water for nuclear power plants, leading to the closure of one third of their facilities; in the future, the threat of climate change-induced electricity supply shortages will become a very important issue both for countries with a high share of nuclear power production and for those relying on electricity imports [20].

We identified 82 coastal locations that hold nuclear power facilities. The 5 countries with the greatest number of vulnerable locations are China (18), Japan (16), United States (9), Republic of Korea (6), and the United Kingdom (5). It is important to develop further studies on the specific conditions of the locations to assess their vulnerabilities, as well as take into account other aspects of the potential impacts, such as population and biodiversity.

3. CONCLUSIONS

Nuclear power is an important asset to supply the low-carbon energy demands going and achieve net zero emissions in the following years. On the other hand, taking into account the impacts of climate change and the adaptation efforts needed, there is a necessity to assess the associations between those impacts and the risks posed by nuclear installations. There is evidence that nuclear facilities will face exposure to different climate risks associated with sea level rise, cyclones and hurricanes, increasingly high ambient and water temperatures and increasingly severe wildfires. In coastal locations, issues related to sea level rise, erosion, storms, heat waves and flooding, and extreme weather events pose a particular security challenge, accentuating the need for studies on nuclear infrastructure resilience. There is also a necessity for increased exchange of experience and information from studies and incidents that already occurred as a way to improve safety protocols and best practices.

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