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ABSTRACT

The purpose of this research is to see what impact nuclear energy has on the environment. The method used synthesis analysis with a systematic literature review of the data obtained through Google Scholar. This research then makes a review or conclusion based on 20 previous studies that discuss the impact of nuclear energy on the environment. The results showed that nuclear energy had a negative impact on the environment, especially the Chernobyl and Fukushima tragedies. Seventy percent (70%) of previous studies explained that nuclear energy has a negative impact on the environment, mainly due to the risk of accidents and the dangers of nuclear fuel waste. Several previous studies have presented mitigations carried out in overcoming the negative impacts of nuclear energy such as health monitoring and increasing safety standards.

1. Introduction

The industrial revolution occurred between 1760 and 1840 resulting in a change in the economic system which previously focused on agriculture and handmade into industry and machine manufacturing (Haupert, 2019). The demand for energy then increased drastically due to the industrial revolution. To meet this demand, the use of fossil fuels is predominantly used globally such as oil and coal. However, the use of these fossil fuels causes carbon dioxide (CO_2) emissions, greenhouse gases, and climate change (Azam et al., 2021). Based on data by the US Energy Information Administration, global CO_2 emissions in 2011 were at 31 billion tons, this figure then increased to 36 billion tons in 2020, and is projected to increase to 45 billion tons in 2040. Total oil consumption has increased around 10% from 2010 to 2018. Natural gas consumption increased 16% from 2010 to 2018, while coal consumption increased 50% from 2000 to 2018. Renewable energy consumption tripled from 2010 to 2018. However, the use of fossil fuels which are still dominantly used globally increases the threat of a balance between economic growth and its impact on the environment (Vo et al., 2020).

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In order to tackle climate change and greenhouse gases, the use of nuclear energy is growing globally. Where in the last few decades, there have been more studies linking climate change with nuclear energy. Based on the 2015 United Nations Conference on Climate Change (COP21), climate change must be suppressed by mitigating global warming with a limit of two degrees celsius. Therefore, nuclear energy is considered to have great potential and opportunities in decarbonization and in suppressing global warming (Verbruggen & Laes, 2015). Based on data in 2013, nuclear energy contributed around 11% of total global energy consumption. Nuclear energy is increasingly needed in the future due to the increasing demand for energy and the production capacity that can be produced by nuclear energy (Nuclear Energy Agency, 2015). In meeting the scenario of a two-degree celsius limit, nuclear energy is projected to be able to contribute up from 11% to 17% in 2050. Nuclear energy then in this projection is the largest low-carbon energy producer when compared to other renewable energies with a figure of 65% of a total of 29% contribution of renewable energy in global energy production (Nuclear Energy Agency, 2015).

2. Literature Review

There are 448 Nuclear Power Plants (NPPs) spread across 31 countries in 2015. Of these, the United States is the country with the most NPP owners at 99, followed by France with 58 NPP, Japan with 48 NPP, Russia with 35 NPP, and many other countries. Based on data from the same year, there were 60 nuclear power plants under construction in 16 countries, with 20 of them in China. Of the 16 countries that are building the nuclear power plant, there are two countries that will have the first nuclear power plant, namely Belarus and the United Arab Emirates (Schneider & Froggatt, 2015).

Nuclear energy has contributed to tackle the acceleration of global warming by preventing around 60 billion tons of CO_2 from spreading into the environment since 1970. This figure is obtained by assuming that around 2,400 TWh of energy produced by nuclear energy is produced by non-renewable energy or fossil fuels (IAEA, 2016). The results showed that on average each nuclear power plant produces 15g CO_2/KWh. This figure shows that the resulting emissions are 30 times smaller than gas, 50 times smaller than oil, and 70 times smaller than coal and the resulting emissions are comparable to those produced by wind energy (Prăvălie & Bandoc, 2018).

Even though nuclear energy has various advantages as previously explained, there are disadvantages or risks from using nuclear energy itself. There have been two fatal accidents caused by nuclear power plants, namely the Chernobyl tragedy in 1986 and the Fukushima tragedy in 2011 (Evangeliou et al., 2014). The Chernobyl tragedy in 1986 had a significant impact on the environment. Based on research results, it is estimated that in 2005 there were 7,000 cases of thyroid cancer in groups of people exposed to radioactive radiation from the Chernobyl tragedy (Högberg, 2013). Apart from that, the tragedy which was mainly caused by very minimal safety standards at the local and national level resulted in the evacuation and relocation of around 300,000 citizens of the Soviet Union. Contamination from the Chernobyl tragedy had an impact on the forestry sector which affected plant growth in various forests in the Soviet Union and Northern Europe and increased the potential for forest fires in these areas. Meanwhile, various freshwater ecosystems in both Western Europe and the Soviet Union experienced high levels of contamination for several years since the tragedy occurred (Bourguignon & Scholz, 2016).

As already explained that Japan is the country with the third largest number of nuclear power plants in the world in 2015, the energy production produced by nuclear power plants is among the lowest in the world due to the Fukushima tragedy. NPP contributed 31% of the total energy mix in Japan in February 2011 and then dropped to 0% in May 2012 for thorough inspection and checking (Hayashi & Hughes, 2013). Research also shows that freshwater biota in Fukushima is exposed to severe pollution and the greater the exposure of animals, the greater the level of radionuclide pollution (Okamura et al., 2016). Various radionuclide contents are found in various types of fish and this can be spread mainly by migratory animal species such as tuna.

Apart from the risk of a nuclear power plant disaster which can endanger the environment and the people around the nuclear power plant, the waste of nuclear fuel can be a risk to the environment and society. The waste fuel used in the operation of a nuclear power plant requires a high level of management in its processing. Based on data for 2010, it is estimated that there are 250,000 tons of nuclear fuel waste that require permanent disposal. Permanent disposal sites are increasingly important because the waste has a high level of radioactivity for up to one million years (Rosa et al., 2010). However, a place for storing or disposing of nuclear waste cannot be used as a long-term solution, mainly because of the space needed and the increasing use of nuclear energy. There is a need for careful planning, direction, and

funding to create a sustainable and permanent solution to addressing the problem of nuclear fuel waste (Alwaeli & Mannheim, 2022).

Based on the background and literature review previously described, the researcher is interested in studying the dilemma that occurs regarding the advantages or advantages that can be generated by nuclear energy with the risks or disasters that can occur from nuclear energy itself. The question in this research is what impact can nuclear energy have on the environment sector. Apart from that, the question in this research is how the mitigation is done in overcoming the impact of nuclear energy on the environment.

3. Research Methodology

This study uses a descriptive qualitative research method with synthesis analysis. Synthesis analysis is used to look at issues regarding the impact of nuclear energy on the environment and make conclusions from a variety of different perspectives (Valentine et al., 2009). The data collection carried out in this study used the PRISMA diagram which was then categorized into several stages, namely identification, filtering, and synthesis (Page et al., 2021). There are several criteria regarding previous studies used in this study. The inclusion criteria of the research used by the authors are articles that discuss the impact of nuclear energy on the environment, as well as articles that use statistical or empirical data to answer research questions. Exclusion criteria from this study were articles that did not address the impact of

nuclear energy on the environment and articles that did not use statistical or empirical data to answer research questions.
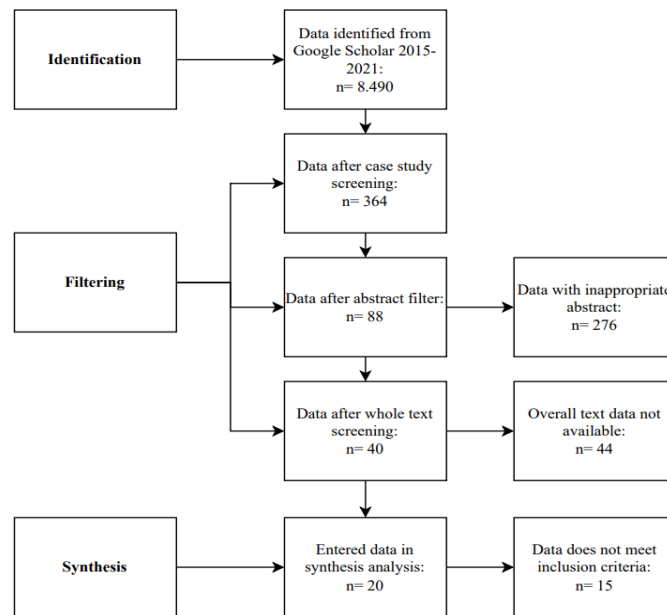
Figure 1. Systematic Literature Review based on Prism Diagrams

Previous research on the impact of nuclear on the environment was obtained from Google Scholar. As for the research time frame, the researcher is looking for is research from 2015 to 2021. There are several keywords used by researchers in searching for previous research such as "the impact of nuclear energy on the environment", "the impact of nuclear energy in the Chernobyl tragedy", "the impact nuclear energy in the Fukushima tragedy", and "the impact of nuclear fuel waste on the environment". Based on the search results conducted by researchers using PRISMA diagrams, there are 20 previous studies that are used in synthesis analysis. In this study, there are several hypotheses regarding the impact of nuclear energy on the environment, some of these hypotheses are:

H0: There is no effect of nuclear energy on the environment

H1: There is an effect of nuclear energy on the environment

4. Results

Based on the explanation that has been made before, the authors use 20 previous studies as synthesis analysis reference. Various previous studies that discussed the impact of nuclear on the environment were then discussed descriptively in order to obtain results or conclusions regarding these issues.

4.1. Literature Description

Table 1. Literature Description

No	Name of Researcher and Year of Research	Research Title	The Scope of The Research	Research Purposes	Research Methods
1	(Beresford et al.,2016)	*Thirty Years after the Chernobyl accident:What lessons have we Learned?*	Chernobyl City	To analyze how the science of radioecologyis used for repairs after the Chernobyl tragedy	Descriptive Qualitative
2	(Lerebours et al.,2018)	*Impact of Environmental Radiation on the Health and Reproductive Status of Fish from Chernobyl*	Chernobyl City	How will the Chernobyltragedy affect the health of fish species in Chernobyl and the surrounding area?	Quantitative Regression Dependent Variable: fish species Independent Variable: nuclear radiation
3	(Omar-Nazir etal., 2018)	*Long-term Effects of Ionizing Radiationafter the Chernobyl Accident: Possible Contribution of Historic Dose*	Chernobyl City	How does the impact of the radiation produced by the Chernobyl tragedy compare to bird species at the time of the tragedy with bird species today?	Quantitative regression Dependent variable: bird species Independent variable: nuclear radiation
4	(Beresford et al.,2020)	*Field Effect Studies in The Chernobyl Exclusion Zone: Lessons to be Learned*	Chernobyl City	What are the long-term effects of radiationexposure on the environment in theChernobyl ExclusionZone?	Quantitative regression Dependent variable: environment in the Chernobyl Exclusion Zone Independent variable: nuclear radiation
5	(Bonzom et al.,2016)	*Effects of Radionuclide Contamination on Leaf Litter Decomposition in the Chernobyl Exclusion Zone*	Chernobyl City	Analyzing the impact of radioactive contamination on the decomposition process of leaf litter in the Chernobyl exclusion area	Quantitative regression Dependent Variable: leaf litter Independent variable: nuclear radiation

No	Name of Researcher and Year of Research	Research Title	The Scope of The Research	Research Purposes	Research Methods
6	(Antwis et al., 2021)	*Impacts of Radiation Exposure on the Bacterial and Fungal Microbiome of Smal Mammals in the Chernobyl Exclusion Zone*	Chernobyl City	What impact did the Chernobyl tragedy radionuclide radiationhave on mammals in the Chernobyl exclusion zone?	Quantitative regression Dependent variable: mammal species Independent variable: nuclear radiation
7	(Imanaka et al.,2015)	*Comparison of the Accident Process, Radioactivity Release and Ground Contamination between Chernobyl and Fukushima-1*	Chernobyl City and Fukushima City	What is the comparisonbetween the accidentprocess and the impact of radiation between the Chernobyl tragedy and Fukushima?	Quantitative regression Dependent variable: accident process and radiation contamination Independent variable: Nuclear radiation at Fukushima and Chernobyl
8	(Steinhauser & Saey, 2016)	*137Cs in the Meat of Wild Boars: A Comparison of theImpacts of Chernobyl and Fukushima*	Chernobyl city and Fukushima city	How does the impact ofthe Chernobyl and Fukushima tragedies compare to the level of wild boar contamination in the two regions?	Quantitative regression Dependent variable: wild boar species Independent variable: nuclear radiation at Chernobyl and Fukushima
9	(Uyba et al., 2018)	*Comparative Analysis of the Countermeasures Taken to Mitigate Exposure of the Public to Radioiodine following the Chernobyl and Fukushima Accidents: Lessons from both accidents*	Chernobyl city and Fukushima city	How do the mitigation measures taken at Chernobyl and Fukushima compare to the public's exposure to thyroid radiation?	Qualitative comparative analysis

No	Name of Researcher and Year of Research	Research Title	The Scope of The Research	Research Purposes	Research Methods
10	(Shimura et al.,2015)	*Public Health Activities for Mitigation of Radiation Exposures and Risk Communication Challenges after the Fukushima Nuclear Accident*	Fukushima City	What steps in the publichealth sector were used to mitigate the threat of radiation after the Fukushima tragedy in 2011?	Explanative qualitative
11	(Hirose, 2016)	*Fukushima Daiichi Nuclear Plant Accident: Atmospheric and Oceanic Impacts over the Five Years*	Fukushima City	What impact did the Fukushima tragedy have on the atmosphere and oceans around the Fukushima area?	Quantitative regression Dependent variable: atmospheric and oceanic Independent variable: nuclear radiation
12	(Aliyu et al., 2015)	*An Overview of Current Knowledge Concerning the Health and Consequence of the Fukushima Daiichi Nuclear Power Plant (FDNPP) Accident*	Fukushima City	What impact did the Fukushima tragedy have on the surrounding environment?	Descriptive quantitative Dependent variable: environment and health Independent variable: nuclear radiation
13	(Onda et al., 2020)	*Radionuclides from the Fukushima Daiichi Nuclear Power Plant in Terrestrial Systems*	Fukushima City	What impact did the Fukushima tragedy, especially the outpouring of radionuclides, have on the surrounding environment?	Quantitative regression Dependent variable: environment of the Fukushima region Independent variable: nuclear radiation

No	Name of Researcher and Year of Research	Research Title	The Scope of The Research	Research Purposes	Research Methods
14	(Vayssier, 2016)	*Severe Accident Management Guidance: Lessons Still to be Learned after Fukushima – The Need for an Industrial Standard*	Fukushima City	What are the weaknesses of the nuclear reactor disaster guide (SAMG) and how to overcome these weaknesses?	Descriptive quantitative Dependent variable: nuclear reactor disaster guide Independent variable: Fukushima nuclear power plant accident
15	(Kharecha & Sato, 2019)	*Implications of Energy and CO_2 Emission Changes in Japan and Germany after the Fukushima Accident*	Fukushima City	What impact did the Fukushima tragedy have on CO_2 emission levels in Japan and Germany after the tragedy?	Quantitative regression Dependent variable: CO_2 emission levels in Japan and Germany Independent variable: Fukushima nuclear power plant accident
16	(Ramana, 2018)	*Technical and Social Problems of Nuclear Waste*	Country	What are the challenges and solutions for handling nuclear fuel waste, especially high-level fuel waste?	Qualitative descriptive
17	(Cotton, 2018)	*Environmental Justice as Scalar Parity: Lessons from Nuclear Waste Management*	Country	Does the nuclear fuel processing infrastructure planning system consider environmental justice?	Explanative qualitative
18	(Richter, 2017)	*Energopolitics and Nuclear Waste: Containing the Threat of Radioactivity*	Community	What is the justification for accepting a community group for nuclear fuel waste?	Descriptive qualitative

No	Name of Researcher and Year of Research	Research Title	The Scope of The Research	Research Purposes	Research Methods
19	(McCombie & Jefferson, 2016)	*Renewable and Nuclear Electricity: Comparison of Environmental Impacts*	Country	What is the comparisonbetween nuclear energyand other renewable energy regarding the resulting impact on the environment?	Quantitative regression Dependent variable: environment Independent variables: nuclear and renewable energy
20	(Mahmood et al, 2020)	*The Role of NuclearEnergy in the Correction of Environmental Pollution: Evidence from Pakistan*	Country	Did nuclear energy produce CO_2 emissionsin Pakistan in 1973-2017?	Descriptive quantitative Dependent variable: CO_2 emissions Independent variable: nuclear energy

Based on the results of 20 studies conducted from 2015 to 2021, it showed that most of the research uses case study objects for nuclear power plant accidents in Chernobyl and Fukushima. The impact of nuclear on the environment itself is represented in various objects such as animals, plants, humans, oceans, air, and CO2 emissions. Most of the research uses quantitative regression methods by obtaining data through direct observation to obtain accurate data. Apart from that, several studies use a comparative approach, especially to compare the situation that occurred after the Chernobyl tragedy with Fukushima.

Table 2. Research Results

No	Environment Object	Research Impact	Research Recommendations
1	Animal	Various animal species such as fish, birds, mammals and wild boar were significantly affected by the nuclear power plant accidents in Chernobyl and Fukushima. Nuclear radiation causes disruption to the health system of various animal species.	Periodic surveillance is routinely carried out on animal species in the area where the nuclear power plant accident occurred.

No	Environment Object	Research Impact	Research Recommendations
2	Plant	The nuclear power plant accidents in Fukushima and Chernobyl had a significant impact on plants in the two regions. There are various disturbances in the growth system until the death of various types of plants.	Routine control measures are taken in contaminated areas. Apart from that, decontamination efforts are carried out in areas affected by radiation.
3	Human	Nuclear power plant accidents have a significant impact on humans such as population displacement and cancer. Other long-term effects on human health often emerge after the accident.	Various steps such as regular monitoring and decontamination are carried out for the people affected by the nuclear power plant accident.
4	Marine	Although the Chernobyl nuclear power plant accident did not have an impact on the ocean, the Fukushima nuclear power plant accident did have a radiation impact on the surrounding ocean area.	Various mitigation measures have been taken, such as monitoring and decontamination measures to minimize radiation exposure to fish biota and waters around the Fukushima area.
5	Air	Nuclear radiation spread in the air and atmosphere after the nuclear power plant accidents at Chernobyl and Fukushima. The spread of the radiation resulted in contamination and radioactive content in various areas other than the accident area.	Various decontamination and cleaning steps are carried out to prevent more radiation exposure to the air.
6.	CO_2 Emission	Nuclear energy can make a significant contribution to reducing CO_2 emissions globally. The operational life of a nuclear power plant, which is relatively long, in the range of 40 to 60 years, makes nuclear energy a substitution option for fossil energy.	There is a need for collaboration between stakeholders to ensure that the PLTN construction has qualified safety standards to prevent accidents.

5. Discussion

5.1. Nuclear Impact on Environmental Damage

Based on the findings of researchers regarding previous studies discussing the impact of nuclear energy on the environment, 14 out of 20 studies explained that nuclear energy has a negative impact on the environment. 1 out of 20 studies explained that nuclear energy has a positive impact on the environment, and 5 studies focused on other factors such as society

and disaster guidance in terms of the impact of nuclear energy on the environment. Of the 14 studies that discussed the negative impacts of nuclear energy on the environment, 5 of them explained the mitigation measures taken while the other 9 only presented data regarding the negative impacts of nuclear energy on the environment. 6 out of 20 studies used the Chernobyl tragedy case study as the research focus, 15 Previous studies discussing the impact of nuclear power plant accidents on the environment in Chernobyl and Fukushima explained in depth the environmental damage caused by nuclear. The nuclear power plant accidents in Fukushima and Chernobyl had a significant impact on both living things around the accident area and the environment itself in the short and long term. Apart from that, nuclear fuel waste requires special attention because nuclear fuel waste that is not managed effectively can damage the environment and the people living around the waste.

5.2. Mitigation Policy to Overcome Negative Impacts of Nuclear on the Environment

When viewed collectively and based on case studies and the focus used by previous researchers, nuclear energy has a negative impact on the environment. However, these negative impacts already have several mitigation measures that can be taken or used to prevent similar incidents from occurring in the future. Various mitigation efforts have been carried out, including decontamination and cleaning efforts carried out after the accident at the Chernobyl Nuclear Power Plant to mitigate its impact on the environment. Long-term health checks are also carried out for people living around the Chernobyl area to treat people exposed to radiation. Mitigation carried out after the Fukushima tragedy is the evacuation and closing of various areas to prevent radiation exposure to the people in the area.

Table 3. Results of grouping journals based on hypotheses

No	Hypothesis	Articles/Journals	Percentage
1	Nuclear energy has a negative impact on the environment	1,2,3,4,5,6,7,8,9,11,12,13,15,20	70%
2	Nuclear energy has a positive impact on the environment	19	5%

The journals used in the synthesis analysis in this study are journals that are related to the impact of nuclear energy on the environment. Based on 20 journals that have been analyzed by researchers, 70% explained that nuclear energy has a negative impact on the environment

and 5% explained that nuclear energy has a positive impact on the environment. Other than that, 25% of the research analyzed is inconclusive because these studies focus on other aspects such as social aspects regarding the impact of nuclear energy and community aspects in their acceptance of nuclear fuel waste. This shows that there is a need for further research on the impact of nuclear energy on the environment from other perspectives and further analysis of inconclusive results.

6. Conclusion

Based on the results of synthesis analysis that has been carried out from previous studies, especially regarding the Chernobyl, Fukushima, and nuclear fuel waste, there are various important findings. Various previous studies have explained that nuclear power plant accidents can have a significant impact on the environment, especially various species of living things caused by radiation contamination. Nuclear energy can also make a significant contribution to reducing CO2 emissions globally. The operational age of nuclear power plants which can last 40 to 60 years makes nuclear power plants one of the alternatives to replace fossil energy.

Apart from that, there are limitations to this study, mainly due to research that focuses on certain case studies thereby limiting the generalizability of these findings. This conclusion requires attention and further research as a reference material for making nuclear power plants. The author here suggests further research discussing security and mitigation that was carried out after the Chernobyl and Fukushima tragedies and nuclear fuel waste. To develop knowledge in the field of nuclear energy, interdisciplinary collaboration is needed between researchers, policy makers, and stakeholders to develop effective strategies to improve the security system of nuclear power plants and the processing of nuclear fuel waste.

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