International Journal Of Humanities Education And Social Sciences ***(IJHESS)*** *E-ISSN:* **2808-1765**
Volume 3, Number 5, April 2024, *Page. 2405 – 2413*
Email : editorijhess@gmail.com

Carbon Footprint in Fossil Power Plants and Nuclear Energy Systems

Ida Nurfaida Nur[1)]*, Nugroho Adi Sasongko [2)] Mohammad Sidik Boedoyo [3)]
[1,3)] Energy Security, Defense Management, Republic Indonesia Defense University
[2)] National Research and Innovation Agency (BRIN)

*Corresponding Author
Email: idhanur99@gmail.com

Abstract

The energy sector, including electricity, heat, and transportation, is the main contributorto GHG emissions because it handles 73.2%. Given the increasingly real threat of the climate crisis, a commitment to reduce the amountof emissions released into the environment needs to bemade. One of the emission avoidance measures is an energy transition that shifts dependence on fossil energy to other, cleaner energy sources. As a less polluting technology, nuclear energy ensures a pure environment, thereby enhancing human well-being. Nuclear energy provides and develops greater efficiency and adaptability. It provides access to cheap, reliable, carbon-free energy for industrialized and developing countries. Sixty gigatons of carbon emissions avoided over the last 50 years because of nuclear energy. This form of energy distributes a lot of energy without releasing a lot of contaminants. The criterion of technical advancement mustbe considered when determining the relationship between the use of nuclear energy and carbon footprint because it can lead to the production of cleaner and alternative sources of energy while lowering the danger of air pollution. The findings support the hypothesis that nuclear energy use may have a negative effect on carbon footprint. These findings imply that the widespread use of nuclear energy can help minimize environmental pollution because it almost entirely eliminates carbon emissions when compared to traditional power plants that use non-renewable energy.

Keywords: Carbon Footprint, Fossil Energy, Greenhouse Gasses (Ghg), Nuclear Energy, PowerPlants

INTRODUCTION

The need for electrical energy from year to year is increasing. With the increasing demand for electrical energy, more power plants will be needed which will result in increased exploitation ofnatural resources (Artiningrum et al., 2019). To support sustainable development, the Indonesian government has formulated a national energy policy by taking an integral approach to all development sectors by paying attention to conservation issues and the carrying capacity of the environment. Therefore, the exploitation of natural resources and human resources must be optimal by taking into accountthe needs of the present generation and also future generations(Apridayani et al., 2021).

Given the increasingly real threat of the climate crisis, a commitment to reduce the amountof emissions released into the environment needs to be made. One of the emission avoidance measures is an energy transition that shifts dependence on fossil energy to other, cleaner energy sources. While the production of renewable energy is increasing, consumption of non-renewable energy, especially fossil fuels is also increasing due to the increase in global population and the rapid expansion of the global economy which can lead to a slowdown in carbon emissions. reduction globally (Behm et al., 2022; Suer et al., 2022). For example, 2.5x109 tons of CO_2 from fossil fuels is emitted into theatmosphere every year. CO_2 concentrations were almost 40% higher in 2013 than in the 1850s which were equivalent to 396 parts per millionvolume (ppmv). Therefore, showing that in the lastten years, there has been an average increase of 2 ppmv (Tetteh et al., 2021).

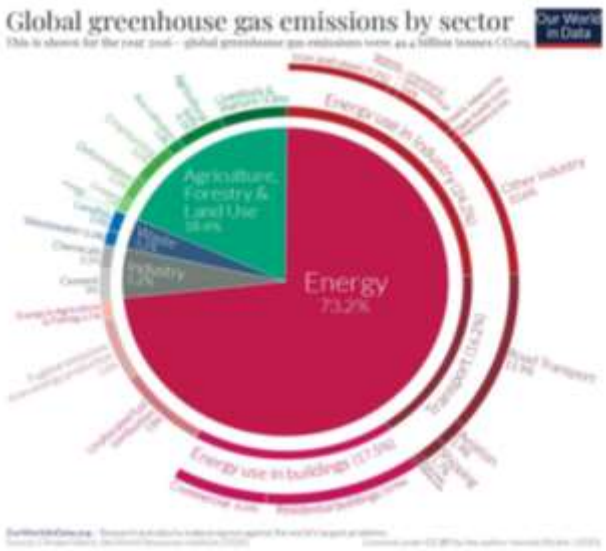


Fig 1. Percentage of direct and indirect sources of the global greenhouse gas emissions by sector (Mneimneh et. al., 2022)

The energy sector including electricity, heat, and transportation is a major contributor to GHG emissions as it handles 73.2% of these emissions; the energy sector is followed by agriculture, forestry, and land use which generate 18.4% of GHG, while direct industrial processes and waste produce 5.2% and 3.2% of GHG, respectively. As stated earlier, these emissions are calculated on the basis of CO2eq which is defined as the sum of all the warming impacts of the different GHGs together to provide a single measure of total GHG emissions (Mneimneh et. al., 2022). Environmental issues are also a major issue in the provision of electricity, where the still large dominance of the use of fossil-based fuels will result in greenhouse gas (GHG) emissions in its utilization. The Kyoto Protocol on the United Nations Framework Convention on Climate Change regulates the reduction of GHG emissions due to human activities so as to stabilize GHG concentrations in the atmosphere and not harm the earth's climate system. The Kyoto Protocol establishes rules regarding procedures, targets, emission reduction mechanisms, institutions, and compliance and dispute resolution procedures (Shaikh et. al., 2017). Inequality of carbon emissions is one of the most relevant issues in designing climate change mitigation policies. Inequality of carbon emissions is of particular relevance to sustainable development and this topic remains largely an unstudied dimension of climate change mitigation (Studi et al., 2019) saevarsdottir.

The International Energy Agency (IEA) published its latest statistical study in August 2021 which reported that total final consumption is highly dependent on the use of fossil fuels. This is distributed as 21% electricity (61.3% of the demand for electrical energy is generated through fossil fuels2), 64% heat from burning fossil fuels (oil burned in engines, coking coal, and steel manufacturing), 11.2% from biofuels and waste, and less than 1% of renewable energy (wind, solar, etc.) However, the energy conversion process that takes place to meet energy needs is accompanied by carbon emissions and other air pollutants which are considered to be the main contributors to global warming (Seriño, 2020). These emissions are defined as greenhouse gases (GHGs) including water vapor, carbon dioxide, methane, ozone, nitrous oxide, and chlorofluorocarbons. They cause climate change by trapping heat that causes extreme weather, food supply disruptions, and increased wildfires. The world emits about 50 billion tonnes of GHG each year measured in carbon dioxide equivalents (CO2eq) (Edwards et. al., 2022). As a less polluting technology, nuclear energy ensures a pure environment, thereby enhancing human well-being. Nuclear energy provides and develops greater efficiency and adaptability. It provides access to cheap, reliable, carbon-free energy for industrialized and developing countries. Sixty

gigatons of carbon emissions avoided over the last 50 years because of nuclear energy. This type of energy transmits a large amount of energy without emitting a large amountof pollutants while operating (Poinssot et al., 2014). Since technological advances can result in the production of cleaner and alternative forms of energy while reducing the risk of atmospheric pollution, the parameter of technological development is one that must be evaluated as part of the relationship between nuclear energy utilization and carbon footprint (Mostert et al., 2018).

RESEARCH METHODS

The literature review is aresearch conducted by researchers by collecting several books and magazines related to the problem and research objectives. The technique used in thisstudies to conduct the evaluation consists of 5 important steps: (1) establishing the goals of the evaluation; (2) determine appropriate databases, key phrases, and search and choice standards; (three) search for and pick out related files; (4) whole the precis table; and (five) examine the facts amassed. This synthesis targets to consolidate present knowledge, identify studies gaps, and spotlight areas requiring further research. The literature search turned into finished at the Google scholar database because it has a wider literature coverage than different databases, consists of publications that may not be indexed in different directories, and is freely available to every person. The search question is created using a set of phrases: one related to carbon (along with carbon footprint, carbon emissions, carbon effect). Documents needed to comprise seek terms from both collections in their titles to be listed, and also be published in English all through the duration 2000–2023 This technique reveals various theoriesrelevant to the problems being faced/researched as reference material in discussing research results. Literature reviews can be carried out from several sources, such as national and international journals, and the relevant textbook or handbook on carbon footprint research and taxation.

In terms of methodology, the review identified and compared the diverse approaches utilized by the studies to assess the Footprint in coal power plant and nuclear power plant. This comparison sheds light on to the different frameworks, scopes, data sources, and system boundaries. It is worth noting that system boundaries were not used as exclusion criteria because there is a significant disparity in the defined system boundaries across the studies and applying a strict criterion in this regard would have resulted in a limited number of documents available for review. The review also compared the results obtained from the studies in terms of Footprint indicators: kg CO2-eq/m3.

RESULT AND DISCUSSION

1. Environmental Impact Of Fossil Fuel Power Plant

Non-renewable energy contributes to an increase in carbon footprints in countries with high levelsof nuclear energy production. Non-renewable energy sources, such as coal, jet fuel, petroleum, etc., have long been recognized in the scientific literature as a major contributor to carbon and other greenhouse gases to atmospheric pollution. In contrast to the unsustainable and limited natureof renewable energy sources, such as fossil fuels, which also contribute to climate change and global warming through increased greenhouse gas emissions, renewable energy sources are abundant and widely available, and also help to reduce environmental degradation (Mostert et al., 2018). Taking into account the energy-intensive circumstances of countries that produce a lot of nuclear energy,increasing the level of energy expertise in reducing carbon emissions by encouraging the use of energy-efficient technologies is another policy option, one

of the most important. green growth input for countries (Kiss & Szalay, 2023). Basically every power generation system will produce CO_2 gas emissions or often referred to as a "carbon footprint" both during construction and during operation. The carbon footprint is defined as the total amount of CO_2 and other greenhouse gases emitted throughout the full life cycle of a process or product. For power plants the carbon footprint is calculated in grams of CO_2 gas equivalent per kWh of electricity generated (gCO_2 eq/kWh) (Harjanto, 2008).

Apart from coal-based power plants, the second largest source of emissions is the biomass transportation process. Considering that trains and trucks transporting biomass use the same type of fuel and the average fuel consumption of trains is much higher, it can be concluded that the capacity of the transport vehicle is the dominant factor in emissions from the fuel transportation process. Truckload capacities are much lower than trains, resulting in more biomass fuel shipments, higher diesel fuel consumption and higher carbon emissions. In addition, the use of rail transport for biomass is impractical due to power plant storage capacity issues (high cargo volume due to low biomass density) and conditions (temperature and humidity) (Feng et al., 2021). Research conducted (Onyeaka et al., 2021) shows that large-scale investment in carbon capture is expected to make a significant contribution to reducing emissions, especially from power plants. Carbon utilization involves capturing carbon dioxide and converting it into useful products or using it directly. Application areas include enhanced oil recovery, syngas synthesis, extraction, mineralization and carbonization. However, this process is energy intensive and involves difficult operating conditions, raising safety and environmental concerns. Therefore, biological technologies that utilize microorganisms to capture carbon dioxide and convert it into food, chemicals, or fuel are more environmentally friendly, eco-friendly, and cost-effective.

Climate change is widely recognized as one of the greatest global threats with far-reaching impacts. These include: Rising sea levels, increasing concentrations of greenhouse gases in the atmosphere, longer and more frequent heat waves, mass loss of the Greenland and Antarctic ice sheets, and loss of biodiversity. Unfortunately, changes in these natural phenomena also have a negative impact on human health. These negative impacts continue to be exacerbated by the thinning of the ozone layer and the increase in heat waves, which directly or indirectly increase heat-related illnesses and deaths, and at the same time increase temperatures and rainfall. The rate of spread of infectious diseases due to changes in patterns has also increased. Likewise, the global economy cannot be separated from climate change and its impact on agriculture. It is known that carbon dioxide contributes significantly to global warming and climate change. This is because carbon dioxide, a greenhouse gas (GHG), can trap and absorb sunlight from the atmosphere. Power generation, transport, industrial facilities and cement production emit about 5 Gt of carbon dioxide per year. In addition, increasing CO_2 emissions into the environment due to burning of fossil fuels and anthropogenic activities have created sustainable and economical chemical synthesis pathways (Lander et al., 2021; Wang & Ge, 2020).

2. Impact on Natural Resources

A study by (Wang & Ge, 2020) a China-based company found that China's top three exporters of carbon dioxide emissions are the United States, Japan, and Hong Kong. In 1990, China exported most of its carbon to Japan, and in 2010, the United States became China's largest carbon exporter. It focuses on 15 regions with exceptional symptoms, mostly in developed countries (including the United States, Japan, Hong Kong, Germany, the United Kingdom, France, and South Korea). This shows that consumer demand in developed countries is the main driver of carbon emissions in China's exports. However, in the next survey period, the amount of carbon emissions imported by developing countries (India, Thailand) from China also increased significantly. It was previously known that carbon dioxide results in global warming and an increase in the volume of sea water, which of course also has an impact on living creatures and the natural resources below. The temperature which was initially in line with their body

temperature then rose due to global warming and caused some natural resources to be unable to survive in this situation.

All of the system's emission sources need to be largely identified in order to do the carbon footprint analysis. It is evident from the observed power plant co-firing system that the combustion of coal and several transportation operations are the sources of the emissions. As was previously said, it is believed that growing plants consume all of the carbon dioxide released during the combustion of biomass to replace the biomass store. The authors consequently presume that the emissions from that source are not taken into account. Transport vehicles' interior combustion engines require the combustion of diesel fuel for fuel transportation, which results in the transportation of coal and biomass pollutants. The emissions from ash transportation should be considered since ash from the combustion process needs to be transported to landfills or the cement industry (Azam et al., 2021).

With the increasing demand for electrical energy, more power plants will be needed which will result in increased exploitation of natural resources. This will have an impact on decreasing existing natural resource reserves. Energy resources, especially non-renewable ones such as oil, gas, coal (fossil energy) will continue to decrease over time in accordance with the increasing use (Serp, et. al., 2017). This will cause an energy crisis in the future, especially for future generations. Data on provenenergy reserves in Indonesia shows that oil energy lasts 10 years, Gas 30 years, and Coal 146 years, with the assumption that proven reserves are fixed and there is no increase in production. The amount of carbon emissions in fossil-based power plants as shown in Table 1 shows a large number and makes Indonesia a country with poor air hygiene (Feng et al., 2021).

Table 1. Total carbon footprint of several power plants in Indonesia

Carbon Footprint (gCO_2 eq/kWh)	**Type of Power Generation**		
	PLTU Batu Bara	***PLTG BBM***	***PLTG Gas***
	>1000	650	500

Based on the table presented, it can be seen that the carbon footprint of coal-based power plants in Indonesia produces more than half the carbon footprint of gas-fired power plants. The generator that is currently most widely used in Indonesia is this coal-based power plant. You can imagine how much carbon footprint is produced in Indonesia just from coal-fired power plants alone apart from other power plants, the number of which may also be large, although not as big as the coal-based power plant

3. Nexus between Nuclear Energy Consumption and Carbon Footprint

Researchers are currently starting to develop renewable energy to reduce carbon emissions, one ofwhich is nuclear energy. In addition, central agencies and governments are heavily supportive of investment in the nuclear energy industry. Figure 2 depicts CO_2 emissions, and Figure 3 depicts nuclear energy consumption in selected Asia Pacific countries (Ahmed et al., 2022).

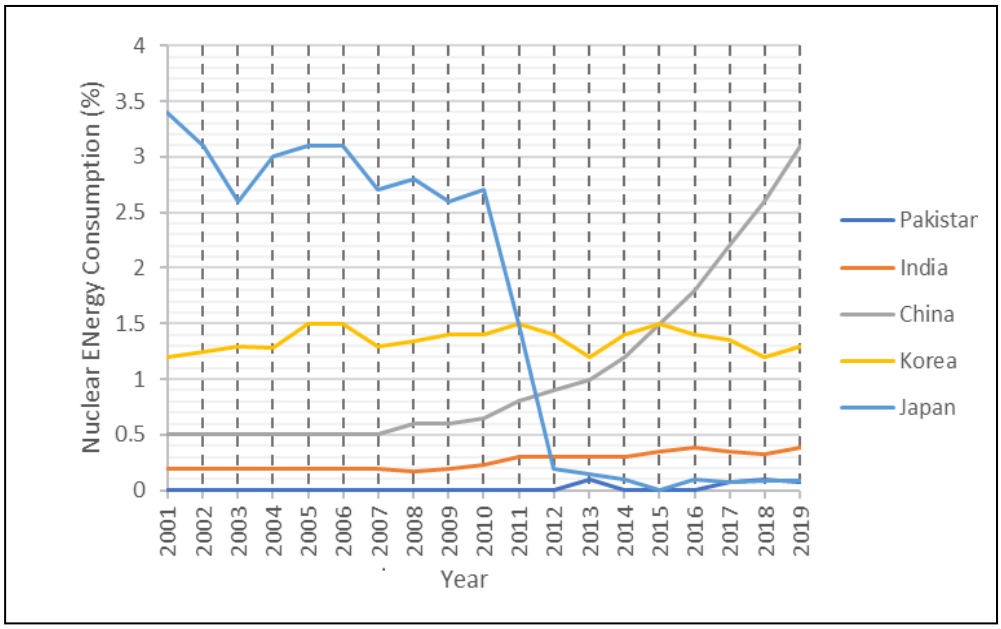
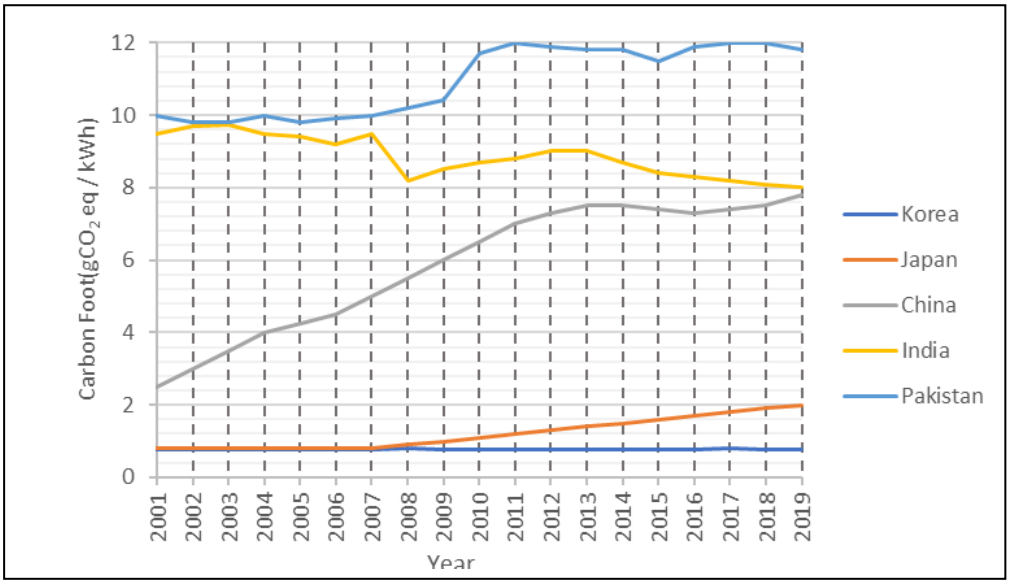


Fig. 1. Nuclear Energy Consumption in Selected Asia Pasific Countries

Fig. 2. CO_2 Emission in Selected Asia Pasific Countries



Based on research conducted by (Ahmed et al., 2022) shows, in Japan in 2014 to 2019 carbon emissions were successfully reduced by about 20% by developing nuclear power plants which were widely proclaimed by the Japanese government. In addition, nuclear energy and renewable energy are statistically inversely related to the amount of carbon emissions. Comparison of carbon emissionsfrom fossil energy power plants, nuclear energy, and additional energy storage devices in this casebatteries. Research conducted (Lander et al., 2021) shows that extending battery life through effective thermal management significantly reduces battery life cycle costs and carbon footprint. Electric vehicles using lithium-ion batteries are currently the most promising technology for decarbonizing the transportation sector from fossil fuels. Therefore, it is critical to reduce battery life cycle costs and greenhouse gas emissions to make this transition economically and environmentally beneficial. Battery life simulation for each thermal management system is implemented in a techno-economic and life cycle assessment

model to calculate life cycle costs. and the carbon footprint for the production and use phases of electric vehicles. This shows that by optimizing the battery thermal management system, battery life cycle costs and carbon footprint can be reduced by 27% and 25%. In addition, the importance of cell design on cost and environmental impact is revealed and an improved cell design is also proposed, which reduces the carbon footprint and life cycle costs by 35%, respectively, compared to a conventional cell design combined with an aircooling system.

Table 2. Carbon footprint of several type of power plants energy

Carbon Footprint (gCO_2 eq/kWh)	**Type Energy**		
	Fossil	***Nuclear***	***Batteries***
	>1000[a]	8[a]	53[a]

Source : (Ahmed et al., 2022; Artiningrum et al., 2019)

Based on the experimental results above, it can be stated that the use of nuclear energy can have anegative impact on the carbon footprint. These results indicate that, because nuclear energy produces almost no carbon emissions, replacing traditional power plants using non-renewable energy with nuclear power plants can help reduce environmental pollution caused by the widespread use of nuclear energy. This finding is consistent with research conducted by (Mostert et al., 2018) whofound that the carbon footprint of renewable energy-based energy storage such as batteries is less.However, it is important to note that, despite the fact that nuclear energy plays an important role in reducing carbon emissions, the organization of a nuclear power unit always involves some risks.This risk is largely dependent on broad cross-country differences in political, economic and socialfactors. Despite the fact that nuclear energy plays an important role in reducing carbon emissions,the organization of a nuclear power unit always involves some risks (Shaikh et. al., 2017; Serp et. al., 2017) When considering the effects on human health and the environment that nuclear power and other forms of energy consumption and production have, these risks should be evaluated, and efforts should be made to reduce their impacts (e.g., renewable and non-renewable energy sources). However, keep in mind that nuclear power demands protection and cost management to avoid disasters that may harm humans and the environment (Edwards et al., 2022; Poinssot et al., 2014)

CONCLUSION

Comparatively, renewable energy sources are both sustainable and abundant, and they help reduceenvironmental degradation, while non-renewable energy sources such as fossil fuels are limited and unsustainable, and their intensive deployment contributes to climate change and global warming by increasing greenhouse gases (GHG emissions). Further ecological decline due to carbon emissions can be slowed if we continue to use fossil fuels as an energy source [9]. Lastly,in countries that produce a lot of nuclear energy, extracting natural resources has a negative effecton the environment. Therefore, we all win because the exploitation of natural resources has apositive direct impact on both economic growth and, by extension, environmental degradation.

REFERENCES

Ahmed, N., Mahboob, F., Hamid, Z., Sheikh, A. A., Sibt, M., Senkus, P., Glabiszewski, W., & Wysoki, A. (2022). *Nexus between Nuclear Energy Consumption and Carbon Footprint in Asia Pacific Region : Policy toward Environmental Sustainability*. 1–17.

Apridayani, L., Yoesgiantoro, D., Sasongko, N. A., & Apridayani, L. (2021). *Analisis Daur Hidup Green Gasoline Pada Teknologi Co-Processing Di Pertamina Ru-Iii Plaju Dalam Memperkuat Ketahanan Energi Dan Pertahanan Negara Life Cycle Assessment Green Gasoline on Co-Processing Technology At Pertamina Ru-Iii Plaju To Strengthen Energy Security and National Defense*. *1*, 1–13.

Artiningrum, T., Havianto, J., Lingkungan, S. T., Teknik, F., Mukti, U. W., Matahari, S., Listrik, P., & Surya, T. (2019). Meningkatkan Peran Energi Bersih Lewat Pemanfaatan Sinar Matahari (Improve The Role of Clean Energy Through The Utilization). *Meningkatkan Peran Energi Bersih Lewat Pemanfaatan Sinar Matahari (Improve The Role of Clean Energy Through The Utilization)*, *2*(2), 100–115.

Azam, A., Rafiq, M., Shafique, M., Zhang, H., & Yuan, J. (2021). Analyzing the effect of natural gas, nuclear energy and renewable energy on GDP and carbon emissions: A multi-variate panel data analysis. *Energy*, *219*, 119592. https://doi.org/10.1016/j.energy.2020.119592

Behm, K., Nappa, M., Aro, N., Welman, A., Ledgard, S., Suomalainen, M., & Hill, J. (2022). Comparison of carbon footprint and water scarcity footprint of milk protein produced by cellular agriculture and the dairy industry. *International Journal of Life Cycle Assessment*, *27*(8), 1017–1034. https://doi.org/10.1007/s11367-022-02087-0

Feng, Y., Yang, B., Hou, Y., Duan, T. H., Yang, L., & Wang, Y. (2021). Comparative environmental benefits of power generation from underground and surface coal gasification with carbon capture and storage. *Journal of Cleaner Production*, *310*(February), 127383. https://doi.org/10.1016/j.jclepro.2021.127383

Harjanto, N. T. (2008). *Dampak lingkungan pusat listrik tenaga fosil dan prospek pltn sebagai sumber energi listrik nasional* . 39–50.

Kiss, B., & Szalay, Z. (2023). Sensitivity of buildings ' carbon footprint to electricity decarbonization : a life cycle – based multi - objective optimization approach. *The International Journal of Life Cycle Assessment*, *28*(7), 933–952. https://doi.org/10.1007/s11367-022-02043-y

Lander, L., Kallitsis, E., Hales, A., Edge, J. S., Korre, A., & Offer, G. (2021). Cost and carbon footprint reduction of electric vehicle lithium-ion batteries through efficient thermal management. *Applied Energy*, *289*(February), 116737. https://doi.org/10.1016/j.apenergy.2021.116737

Mostert, C., Ostrander, B., Stefan, B., & Tanja, M. K. (2018). Comparing Electrical Energy Storage Technologies Regarding Their Material and Carbon Footprint. *Energies*. https://doi.org/10.3390/en11123386

Onyeaka, H., Miri, T., Obileke, K. C., Hart, A., Anumudu, C., & Al-Sharify, Z. T. (2021). Minimizing carbon footprint via microalgae as a biological capture. *Carbon Capture Science and Technology*, *1*(September). https://doi.org/10.1016/j.ccst.2021.100007

Poinssot, C., Bourg, S., Ouvrier, N., Combernoux, N., Rostaing, C., Vargas-gonzalez, M., & Bruno, J. (2014). Assessment of the environmental footprint of nuclear energy systems . Comparison between closed and open fuel cycles. *Energy*. https://doi.org/10.1016/j.energy.2014.02.069

Seriño, M. N. V. (2020). Rising carbon footprint inequality in the Philippines. *Environmental Economics and Policy Studies*, *22*(2), 173–195. https://doi.org/10.1007/s10018-019-00253-7

Studi, P., Energi, K., & Pertahanan, F. M. (2019). *Listrik Di Indonesia Dalam Mendukung Ketahanan Energi Life Cycle Assessment Of Battery For Electric Vehicle Development In Indonesia To Support Energy Security*. *1*, 85–101.

Suer, J., Ahrenhold, F., & Traverso, M. (2022). Carbon Footprint and Energy Transformation Analysis of Steel Produced via a Direct Reduction Plant with an Integrated Electric Melting Unit. *Journal of Sustainable Metallurgy*, *8*(4), 1532–1545. https://doi.org/10.1007/s40831-022-00585-x

Tetteh, E. K., Amankwa, M. O., Yeboah, C., & Amankwa, M. O. (2021). Emerging carbon abatement technologies to mitigate energy-carbon footprint- a review. *Cleaner Materials*, *2*(September), 100020. https://doi.org/10.1016/j.clema.2021.100020

Wang, Q., & Ge, S. (2020). Carbon footprint and water footprint in China: Similarities and differences. *Science of the Total Environment*, *739*, 140070. https://doi.org/10.1016/j.scitotenv.2020.140070