Life Cycle Environmental Impacts and Mitigation Options for Bhumibol Hydropower Plant

Rathasart Wansweat*, Dawan Wiwattanadate**‡, Parnuwat Usapein***

* Environment Development and Sustainability Program, Graduate School, Chulalongkorn University, Phayathai Road, Patumwan, Bangkok 10330, Thailand.

** Faculty of Engineering, Chulalongkorn University, Phayathai Road, Patumwan, Bangkok 10330

*** Rattanakosin College for Sustainable Energy and Environment, Rajamangala University of Technology Rattanakosin, Phutthamonthon, Nakhon Pathom, 73170

(r.wansweat@yahoo.cm.au, dawancu@gmail.com, parnuwat.usa@rmutr.ac.th,)

‡ Corresponding Author; Dawan Wiwattanadate, Faculty of Engineering, Chulalongkorn University, Phayathai Road, Patumwan, Bangkok 10330, Tel: +6689 489 2568, dawancu@gmail.com

Received: 31.07.2023 Accepted:25.09.2023

Abstract - The activities of humans are important factors that cause global warming through the release of various toxic gases from industrial sectors and vehicle transportation. This paper evaluated the environmental impacts of the Bhumibol Hydropower Plant since construction, operation and maintenance, and decommissioning phases and also explored the possible impact mitigation options that may be possible in each phase. 1 MWh of electricity production was used as a functional unit. All raw material input and emission output were based on this unit. Data on the construction, operation, and decommissioning of the powerplant were gathered from Bhumibol Hydropower Plant through a questionaire survey and an interview. The life cycle impact assessment was analyzed using The International Reference Life Cycle Data 2011 passing through SimaPro 8.0 software. The result of characterization showed that the construction phase had the highest impact, and the main sources of construction materials came from using cement and steel. After normalization impacts, the results indicated that climate change, water resources depletion, and human toxicity-cancer effects should be given importance. To reduce the environmental impact, replacing eco-concrete for future dam construction could mitigate greenhouse gas emissions by 52.2% and human toxicity by 55.0%. Recycling steel during power plant decommissioning could mitigate greenhouse gas emissions by up to 84.0%. Aside from this, integrating both options could potentially reduce 88.4% of greenhouse gas emissions and 74% of human toxicity.

Keywords Life cycle impacts, hydropower plant, construction materials, eco-concrete, steel recycling.

1. Introduction

Hydroelectricity is one of the cleanest energy sources due to no pollutant from fuel combustion. By the way, a dam with large reservoir must be constructed followed with a big damage of forest and ecosystem. At the same time, a dam provides various advantages such as a sustainable water resource for both daily life utilization and agriculture. The dam is also used for drought and flood management. In order to achieve sustainable management or minimize environmental impacts of hydropower plant. The hydropower plant must be started with dam construction, while most of which exhibit various impacts, including ecology, and environment would like to assess on how much impacts throughout the life cycle of a hydropower plant and what would be any options to mitigate the life cycle impacts of a hydropower plant would be worthy studied. Globally, the construction of large dams has massive environmental and social impacts, especially the mitigation option on greenhouse gases emission could be helped to minimize the environmental impact for promoting the country into carbon neutrality.

According to several LCA studies of various types of power plants [1–6], similar trends can be observed in that life cycle GHG emissions from renewable energy power plants are much lower than those from fuel-fired power plants (see also Fig. 1).

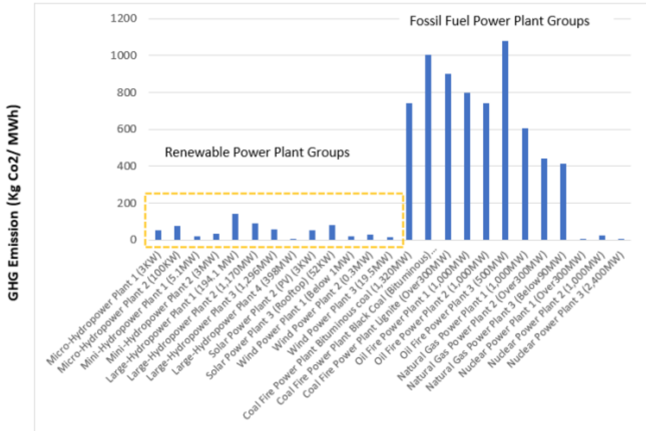


Fig. 1. Life Cycle GHG emissions Comparison of Various Types of Power Plants

Another LCA study of power plants in Thailand reported that the life cycle impacts of hydropower plants were significantly lower than those of various kinds of thermal power plants [7]. Also, the life cycle GHG emissions of large hydropower plants are remarkably lower than those of both mini and micro hydropower plants. Both figures confirm that electricity from large hydropower plants is one of the cleanest energy sources, as shown in Fig. 2.

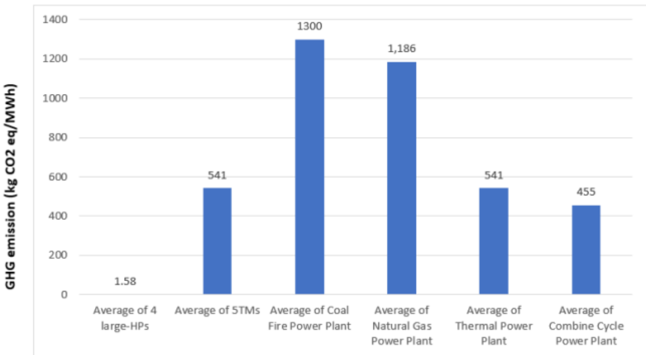


Fig. 2. Life Cycle GHG Emissions per MWh Comparison of Various Sizes and Types of Power Plants in Thailand

Some studies also reported that the highest impacts were exhibited during the construction phase for hydropower plants and during operation for fuel-fired power plants [8]. Therefore, mitigation options suggested by the previous studies mostly focused on eco-design (which considers environmental aspects at all stages of the product development process) as well as supplementary eco-construction-friendly materials for future construction, as well as maximizing recycling of steel and utilization of demolition waste [9].

As shown in Fig. 2, previous studies related to the life cycle impacts of various-scale hydropower plants, both in Thailand and other countries, report similar trends, the highest impacts occur during the construction phase and the lowest during the operation and maintenance phase, excluding the decommissioning phase. Even though there are many studies on the LCA of hydropower plants, there are not yet any studies on a large-scale hydropower plant to compare the environmental impacts of the three phases (construction, operation and maintenance, and commissioning) in Thailand. The majority did not focus on the impact contribution of each phase of the power plant life cycle, and life cycle inventory data are mostly referred to from databases.

This research aims to evaluate the life cycle environmental impacts of the Bhumibol Hydropower Plant during the construction phase, operation and maintenance phase, and decommissioning phase, as well as explore possible impact mitigation options for each phase. Section 2 provides the methods, including impact categories and indicators. In Section 3, highlights highlight the outcome of this study under impact assessment using the International Reference Life Cycle Data at midpoint technique, and in Section 4, this study concludes with recommendations for mitigation options for large hydropower plants.

2. Methodology

Environmental impacts throughout the life cycle of the Bhumibol hydropower plant were evaluated using SimaPro 8.0 LCA software with a functional unit of 1 MWh. The International Reference Life Cycle Data (ILCD) system was applied to characterize the environmental impacts, as shown in Table 1.

Table 1. Impact Category According to ILCD 2011 Midpoint Version 1.09

Impact Category/Indicators	Unit
Climate change	kg CO2 eq
Ozone depletion	kg CFC-11 eq
Human toxicity, non-cancer effects	CTUh
Human toxicity, cancer effects	CTUh
Particulate matter	kg PM2.5 eq
Ionizing radiation HH	kBq U235 eq
Ionizing radiation E (interim)	CTUe
Photochemical ozone formation	kg NMVOC eq
Acidification	molc H+ eq
Terrestrial eutrophication	molc N eq
Freshwater eutrophication	kg P eq
Marine eutrophication	kg N eq
Freshwater ecotoxicity	CTUe
Land use	kg C deficit
Water resource depletion	m3 water eq
Mineral, fossil & ren resource depletion	kg Sb eq

Normalization analysis was performed to identify the key contribution and compare the impact priority for proposing mitigation options. The LCA study started with the identification of goals, scope, system boundaries, and functional unit definitions. Followed by data inventory design and on-site data collection. After inventory analysis, the results were interpreted based on selected impact categories and indicators. Also, the boundary condition of the present study, as shown in Fig. 3, and details of the LCA process for this study are briefly described below.

a. Goal and scope definition, the goal of LCA in this study is to evaluate the life cycle environmental impacts of the Bhumibol hydropower plant using SimaPro 8.0 software and ILCD 2011 Midpoint version 1.09. The scope of this study covers three phases: (1) plant construction; (2) operation and maintenance; (3) end of life (decommissioning).

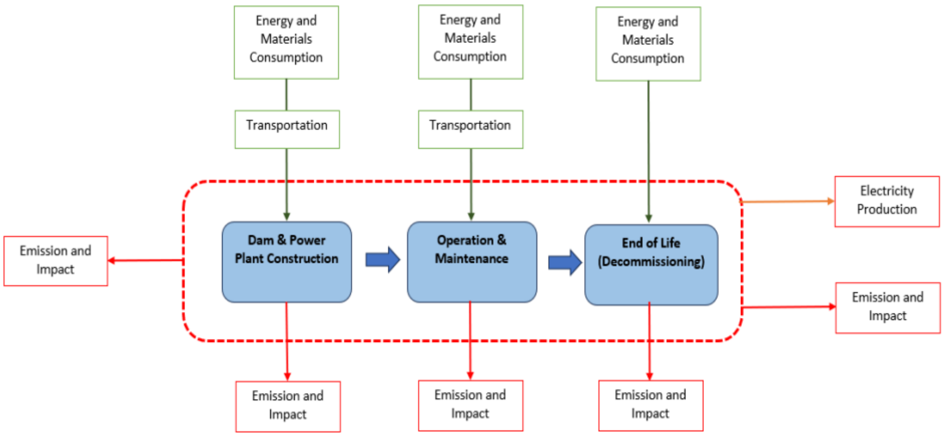


Fig. 3. System Boundary in The Present LCA Study

Life Cycle Inventory, this step involves creating an inventory of input and output flows for the electricity generation system such flows include inputs of water, energy, raw materials, and emission releases to the air, land, and water. All materials used for construction were collected from a bill of quantity directly provided by the Electricity Generating Authority of Thailand (EGAT). All materials and energy used during operation and maintenance were collected from bills provided by EGAT's specialist for the power plant. Thus, the list of inventory inputs for this study received from the Electricity Generating Authority of Thailand (EGAT) is summarized in Table 2.

Table 2. Life Cycle Inventory Input per Functional Unit for the Production of 1 MWh of Electricity

Item	**Materials**	**Unit**	**Total per FU (1 MWh)**
Construction Phase			
Materials Parts			
1	Structural Steel	Kg/FU	2.48E-03
2	Metalwork – Steel	Kg/FU	2.19E-03
3	Grouting	Sack/FU	9.55E-04
4	Porous concrete	Kg/FU	4.87E-08
5	Reinforcement Steel Bars	Kg/FU	6.24E-02
6	Concrete for Dam	Kg/FU	3.49E-01
7	Concrete for Power plant and appurtenant work	Kg/FU	2.68E-01
8	Timber	M3/FU	-2.18E-05
Equipment Parts			
9	Penstock	Kg/FU	3.14E-03
10	Water Gates-Steel	Kg/FU	1.68E-03
11	Valve-Steel	Kg/FU	4.01E-04
12	Cast Iron Pipe	Kg/FU	8.39E-04
13	Carbon Steel Pipe	Kg/FU	2.12E-04
14	Copper	Kg/FU	1.25E-05

Item	Materials	Unit	Total per FU (1 MWh)
15	Asphalt	Mton/FU	4.41E-06
16	Asbestos Cement	Kg/FU	4.59E-06
17	Aluminium	Kg/FU	-8.13E-08
18	Concrete Sewer Pipe	Kg/FU	7.62E-08
Operation and Maintenance Phase			
1	Transformer/Lubricant Oil	Liters /FU	3.34E-04
2	Gasoline for administrative activities	Liters /FU	8.15E-06
3	Diesel for administrative activities	Liters /FU	1.81E-05
Decommissioning Phase			
1	Structural Steel	Kg/FU	-2.37E-03
2	Metalwork - Steel	Kg/FU	-3.55E-03
3	Reinforcement Steel Bars	Kg/FU	8.24E-06
4	Copper	Kg/FU	-2.78E-02

Source: EGAT,2022

b. Impact Assessment using ILCD 2011 Midpoint Version 1.09 as well as Ecoinvent Database Version 3 were used for life cycle impact assessment in this study. Impact categories with 16 indicators according to the ILCD 2011 midpoint method.

c. Interpretation, results from the impact assessment were interpreted to evaluate environmental impact categories in order that appropriate impact mitigation options could be considered.

3. Result and Discussion

The LCA results of the Bhumibol hydropower plant, as presented in Fig. 4, clearly show that the construction phase is evaluated as having the highest environmental effect compared to operation and maintenance and decommissioning phases, respectively acts as a filter: Ensures research is properly verified before being published improves the quality of the research.

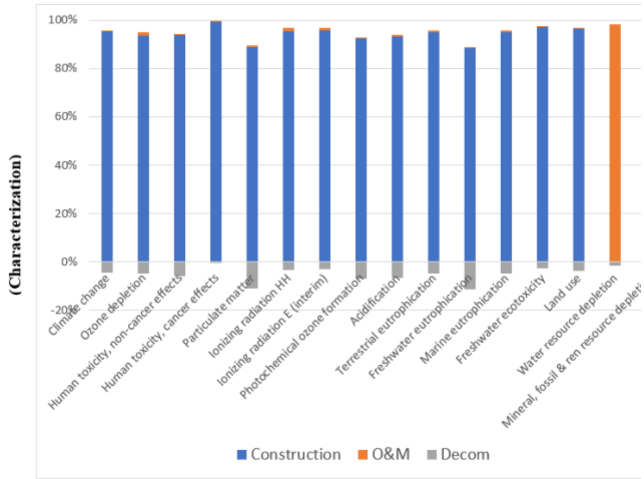


Fig. 4. Characterization Results of the Bhumibol Hydropower Plant

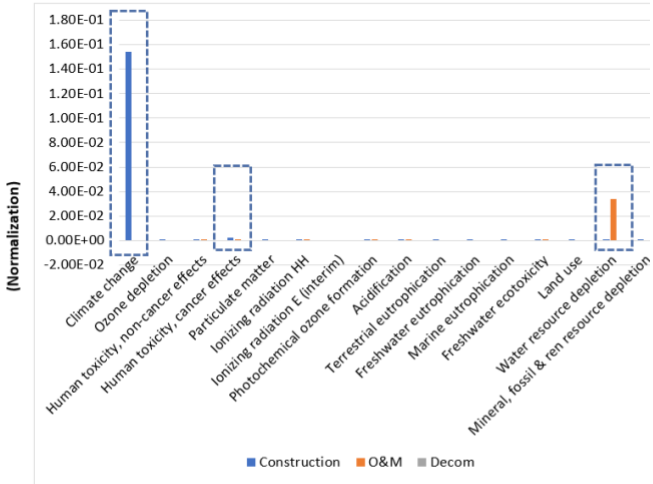


Fig. 5. Normalization of Environmental Impacts of the Bhumibol Hydropower Plant

Beside of this, in part of normalization, the three key environmental impacts, namely climate change (0.69 kg CO_2-eq/MWh), human toxicity-cancer effects (9.85E-09 CTUh/MWh), and water resources depletion (2.34 m3 water eq/MWh), are high enough to be observed from the graph of all 16 impact categories as shown in Fig 5. It is noticed that climate change and human toxicity impacts mainly exhibit during the construction phase, while water resource depletion exhibits during operation and maintenance phase. The figure clearly confirms that climate change and human toxicity impacts dominate during the construction phase, while water resource depletion dominates during operation and maintenance phase.

Life cycle GHG emissions of the Bhumibol hydropower plant are roughly compared with those of various sizes of hydropower plants in Thailand, as shown in Fig. 6. Importantly, the comparison results reveal that the life cycle GHG emissions per MWh of the Bhumibol hydropower plant are significantly lower than the average emissions of four large hydropower plants as well as mini and micro hydropower plants in Thailand. Furthermore, the current study could conclude that large hydropower plants emit less GHG emissions than micro and mini hydropower plants, despite the fact that their capacity is lower in comparison to this study. Also, the assessed GHG emissions of hydropower plants, both large and small, should vary based on differences in geographic location, age, climate condition, reservoir characteristics, and installed capacity.

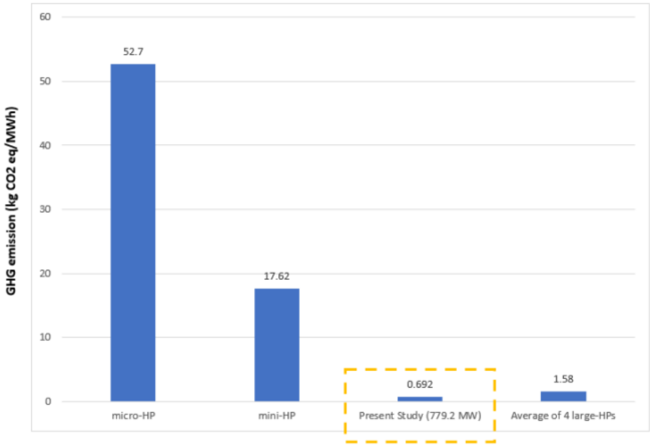


Fig. 6. GHG emissions in this study were compared with those of various-size hydropower plants in Thailand.

Regarding key sources of GHG emissions during the construction phase of the Bhumibol hydropower plant, it was observed from Fig. 7 that concrete and steel are two major sources of GHG emissions during the construction phase, which mainly come from embodied GHGs in cement and steel. The embodied GHGs of cement are mainly CO_2 emissions from limestone during cement production, while the embodied GHGs of steel are mainly CO_2 emissions during the energy-intensive blast furnace steelmaking process.

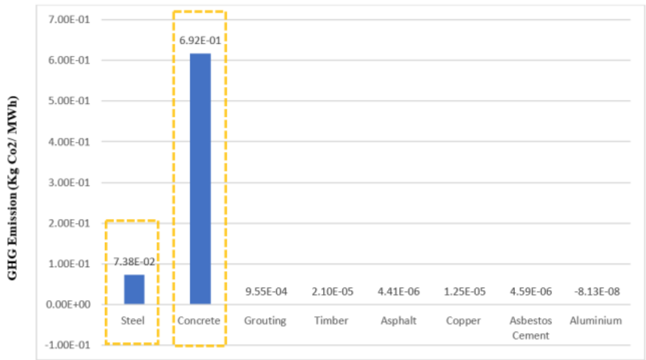


Fig 7. Key Sources of GHG emissions during Construction phase of the Bhumibol Hydropower Plant

GHG mitigation by eco-concrete replacement for future construction is generally suggested in many studies [10]. Using rock-fill concrete technology is one more mitigation option suggested in some studies [11].

In general, eco-concrete can be either cement-free (like Geopolymer concrete) or general cement mixed with supplementary cementous inclusions (like fly ash or ground granulated blast furnace slag) [12]. The cement may be manufactured with lower embodied GHG by using waste or residual materials from industries as alternative fuels and raw materials, resulting in less consumption of both fuels and materials resources and, hence, reducing carbon dioxide emissions during cement manufacturing.

Eco-concretes used for evaluation of impact mitigation in the present study are two types of general cement mixed with supplementary cementous inclusion and other additives. Each of them has its specific properties as summarized below.

- Eco-concrete 1 is under experimental research in Thailand and is not yet commercially available [13]. It is Portland cement mixed with silica powder to increase acid resistance and mixed with high CaO Mae Moh fly ash to increase compressive strength. The mixing with silica powder would reduce the consumption of cement raw materials, especially limestone, reducing both cost and CO_2 emissions.
- Eco-concrete 2 is a product of Thailand developed by SCG, INSEE, Asia Cement, Jalapathan Cement, Thai Pride Cement Company, and Globe Cement and is commercially available by Thai Cement Industry Association. It is Portland cement mixed with hydraulic cement and pozzolanic (both natural and fly ash), silica fume, and smelting sludge to increase cement's important properties, and mixed with some additives to increase alkali resistance. It also uses alternative fuel and raw material wastes as co-processing, which reduces consumption of both fuel and raw materials, reducing both cost and CO_2 emissions.

Maximizing the recycling of steel for the construction of both dams and power plants is one of the highest potential mitigation options suggested by several studies [14,15]. The life cycle GHG emissions of the Bhumibol hydropower plant were then evaluated based on the assumption of either eco-concrete replacement or steel recycling, or both. The results of the evaluation are shown in Figs. 8–10.

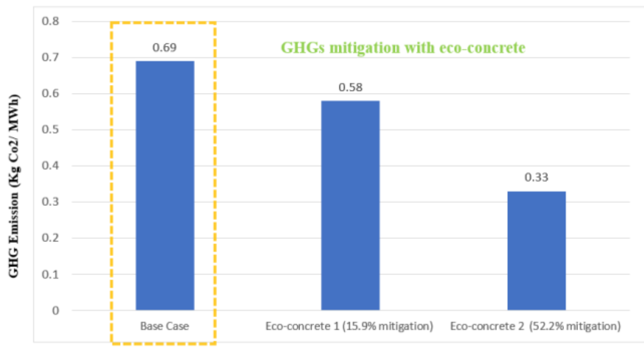


Fig 8. Mitigation of Construction Phase GHG emissions of the Present Hydropower Plant upon Replacement with Various Types of Eco-concrete

Upon evaluation of the GHG mitigation of the Bhumibol hydropower plant with eco-cement replacement, as illustrated in Fig. 8, it is observed that the GHG emissions would reduce from 0.69 to 0.58 $kgCO_2/MWh$ (15.9% mitigation) if replacing with eco-concrete 1 and reduce to 0.33 $kgCO_2/MWh$ (52.2% mitigation) if replacing with eco-concrete 2. By the way, due to the fact that only eco-concrete 2 is commercially available in Thailand at present, eco-concrete 2 was used for the evaluation of various mitigation options in this study.

Regarding GHG mitigation with various percentages of steel recycling, the results as shown in Fig. 9. indicate that the life cycle GHG emissions was reduced from 0.69 to 0.46, 0.30, 0.11, and 0.06 $kgCO_2$/MWh, with 40%, 60%, 80%, and 100% steel recycling. Therefore, maximizing steel recycling would be highly recommended for the GHG mitigation options. By the way, some studies reported about 20% natural deterioration. In addition, due to the lack of a plan for the Bhumibol dam removal soon, only steel from power plant decommissioning was used for mitigation of steel recycling, excluding steel from dam removal [16].

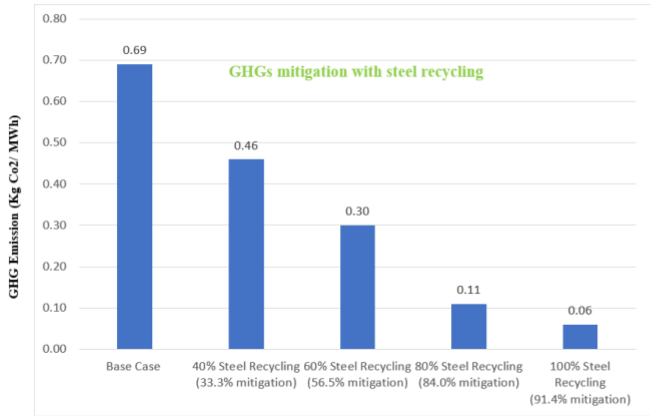


Fig. 9. Mitigation of Construction Phase GHG emissions of the Present Hydropower Plant upon Various Percentages of Steel Recycling

It was observed from Fig. 10. that the life cycle GHG emissions of Bhumibol hydropower plant would be reduced from 0.69 kg CO_2/MWh to 0.33 kg CO_2/MWh (52.1% reduction) if replacing with eco-concrete 2, but mitigated up to 84% if 80% steel recycling, and mitigated up to 88.4% if integration of both mitigation options.

It was observed from Fig. 10. that the life cycle GHG emissions of Bhumibol hydropower plant would be reduced from 0.69 kg CO_2/MWh to 0.33 kg CO_2/MWh (52.1% reduction) if replacing with eco-concrete 2, but mitigated up to 84% if 80% steel recycling, and mitigated up to 88.4% if integration of both mitigation options.

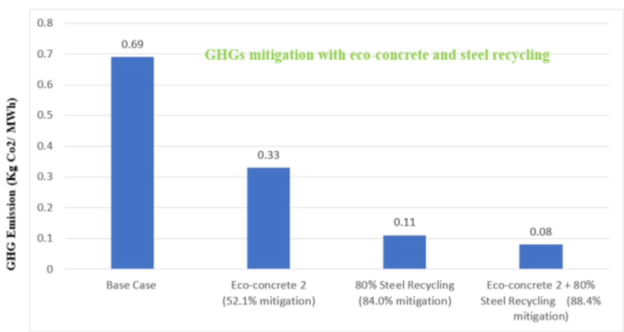


Fig. 10. Mitigation of Construction Phase GHG emissions of the Present Hydropower Plant upon Various Mitigation Options

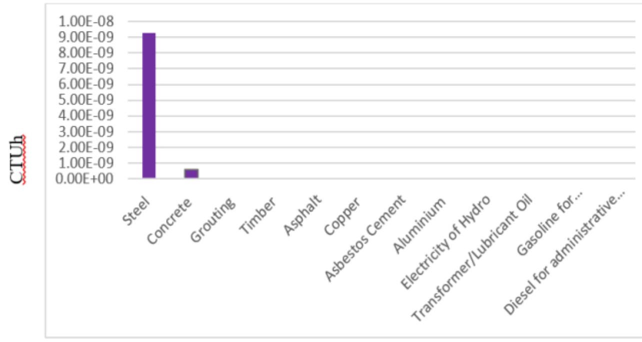


Fig. 11. Key Sources of Life Cycle Human Toxicity-Cancer Effect.

Regarding key sources of human toxicity-cancer effect, which is another hot spot environmental impact exhibit during the construction phase, even slightly, it is noticed from Fig. 11. that steel is a major source of the human toxicity impacts, followed by the much lower impact from concrete. Therefore, replacement with eco-concrete as well as maximizing steel recycling would mitigate not only GHG emissions but also the human toxicity impact. The life cycle human toxicity and cancer effect of the Bhumibol hydropower plant was then evaluated under various mitigation options and shown in Figs. 12–13.

Regarding mitigating human toxicity with steel recycling, it is noticed from Fig. 12. that the life cycle human toxicity for which the volume of mitigation would be reduced from 9.85E-09 to 8.08E-09, 6.62E-09, 3.56E-09, and 2.92E-09 CTUh, respectively, with portions of 40%, 60%, 80%, and 100% steel recycling. This confirms that steel recycling is one of the most important mitigation options, with a high recommendation. Thus, this study confirmed that maximizing steel recycling would also be recommended for human toxicity mitigation options.

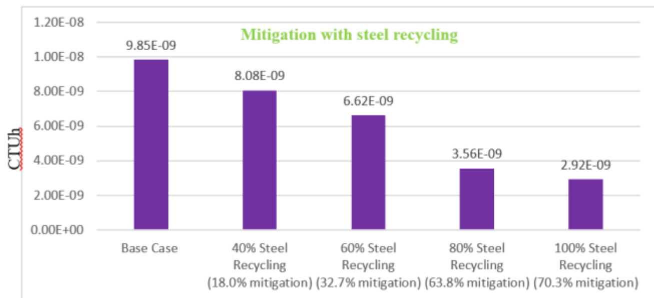


Fig. 12. Mitigation of Human Toxicity-Cancer Effect Impacts from Steel Recycling Options.

Mitigation of human toxicity, as shown in Fig.13. indicates that the volume of human toxicity would be mitigated up to 55% upon eco-concrete 2 replacement and mitigated up to 63.8% if recycling 80% of steel from power plant decommissioning. Meanwhile, it would be mitigated up to 74.0% with the integration of both mitigation options.

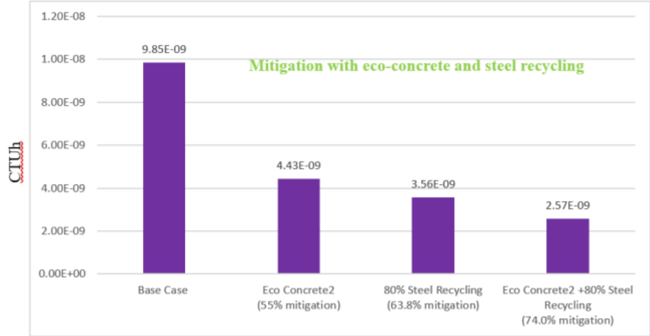


Fig. 13. Mitigation of Human Toxicity-Cancer Effects with Eco-concrete Replacement and/or Steel Recycling

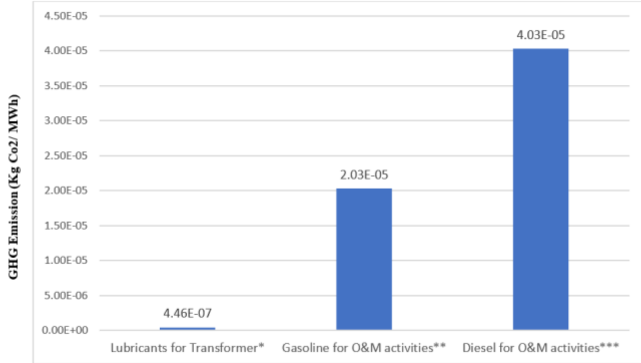
Reducing the human health effect can be done by constraining the quantity of steel and/or using eco-steel materials in the engineering design process to minimize it, and the volume of mitigation options will be reduced as recommended.

By the way, these two mitigation options cannot be implemented at present and need to wait until the power plant is decommissioned or a new dam is constructed. The options that can be implemented at present are limited to the mitigation of impacts during O&M, one of which is water resource depletion. Another is GHG emissions from O&M activities.

Water resource depletion is one of the three hot spots for environmental impacts of the Bhumibol hydropower plant found in the present study. Even though not many mitigation options for water resource depletion have been reported, the researcher would recommend increasing water resource capability by maximizing reforestation at the dam upstream areas as well as in the northern part of Thailand. This is similar to the suggestion by Yeo and Lim [16] in North Korea.

Another option to mitigate water resource depletion is increasing the efficiency of hydro turbines by applying variable gear to reduce the turbine speed. A Francis turbine recommended by [17,18] is a popular example at present.

Regarding GHG emissions during the O&M phase, which mainly come from materials and energy used during O&M activities, the present study found them to be much lower than the emissions during the construction phase, so that the emissions during O&M cannot be observed from the graph in Fig. 4. The GHG emissions during the O&M phase, as shown in Fig. 14, illustrate that diesel for administrative cars as well as dam tourism boats exhibit the highest emissions, followed by gasoline for administrative cars and lubricants for transformers.



Remark:
* Embodied GHGs (Cradle-to-Gate)
** Gasoline used for admin vehicles, cradle-to-grave (embodied + combustion GHGs)
*** Diesel used for both admin vehicles and boats for dam tourism, cradle-to-grave (embodied + combustion GHGs)

Fig. 14. Key Resource of GHG emission during O&M Phase

The emissions from gasoline and diesel for O&M-related activities as well as diesel for dam tourism would be mitigated by replacing the existing cars or boats with electric vehicles, solar-powered boats, or hybrids of electric and solar-powered boats [19-21].

A possible mitigation option for emissions from lubricants would be replacing them with low-carbon or carbon-neutral lubricants. An example is a product developed by replacing oil with low-carbon, carbon-neutral, or biodegradable lubricants.

It is noticed that mitigation of GHG emissions is the only impact mitigation option that can be implemented at present, there is no need to wait for new construction or decommissioning. By the way, direct mitigation from activities during O&M is quite low. Therefore, maximizing indirect mitigation or sequestration with reforestation is highly recommended for the Bhumibol hydropower plant.

4. Conclusion

The Bhumibol Hydropower Plant's effects on the environment during the building, operation and maintenance (O&M), and decommissioning stages were assessed in this study, along with potential methods for impact mitigation in each phase. The evaluation of environmental hot spot of the Bhumibol Hydropower Plant can be confirmed that the construction phase is the highest emission compared with O&M and decommissioning phases. The LCA results reveal that there are three key environmental impacts, namely climate change (life cycle GHG emissions 0.69 $kgCO_2$ per MWh), human toxicity - cancer effects (9.85E-09 CTUh), and water resource depletion (3.41E-02 m^3 water per MWh).

The results also indicate that key sources of the climate change and human toxicity impacts are mainly embodied GHGs of construction materials, especially concrete and steel. Hence, both impacts dominate during the construction phase and cannot be directly mitigated except by planning to maximize steel recycling during decommissioning and/or using eco-concrete for future dam construction (if any).

To mitigate the environmental impact, mitigation options were proposed based on a literature review. It was observed that the life cycle GHG emissions per MWh could be mitigated from 0.69 kg CO_2/MWh to 033 kg CO_2/MWh if replaced with eco-concrete commercially available in Thailand at present. The life cycle GHG emissions were also observed to be mitigated by 40%, 60%, 80%, and 100% steel recycling. If both mitigation options were integrated, using eco-concrete in conjunction with 80% steel recycling would result in up to 88.4% life cycle GHG emissions.

Apart from GHG emissions during construction phase, some activities during O&M also emit GHGs even very much lower than the emissions during the construction phase, and some can be mitigated at present. The results reveal that key sources of GHG emissions during O&M are lubricant for transformer maintenance. A possible mitigation option for the lubricant is replacing it with carbon neutral or biodegradable lubricant [22]. Meanwhile, the mitigation options for admin transport would be maximize utilization of electric cars as well as electric and/or solar-powered boats for dam tourism. In addition, energy efficiency measures would be implemented for all activities. Also, increasing carbon sink with reforestation is highly recommended to maximize compensation of the emissions during construction which cannot be directly mitigated at present.

One more environmental impact during O&M is water resource depletion. Even though no direct mitigation option has yet been reported, the present study would recommend increasing water resource capability by maximizing reforestation at the dam upstream as well as any areas in the northern part of Thailand. Also, increasing turbine efficiency is another option to be recommended for mitigation of water resource depletion.

As summarized, hydropower plants are environmentally friendly, and renewable energy sources have a positive impact more than the fossil power plant. This could be referred to in applying to eco-design and eco-construction materials such as eco-cement and eco-steel for the new future dam investment project in an international country, which are the main parts of dam and power plant construction to reduce GHG emissions and promote a balance between emitting carbon and absorbing carbon from the atmosphere, as called carbon neutrality. A recommendation for the benefit of this study as part of the sustainability development of hydropower plants is shown as follows.

- Being a guideline to the potential mitigation option in future dam construction study in global and local country.
- Use for the new knowledge and guild line about future dam construction to reduce concrete quantity in case of a global project if Thailand government and neighbouring country to invest in building in the new dam in neighbouring country for energy development between the country in the future.
- For being guild line in additional solution of EIA (Environmental Impact Assessment) to add the part of the LCA (Life Cycle Assessment) into its document for completion in part of management and technique in dimension of policy to promotion and conservation of environmental quality Act.
- Being a guideline to make a community near the dam without having negative impacts from the dam and as a tourist site to study about the dam and interact with local communities near the dam.
- Policy proposal from the present research such as promoting the construction materials such as Eco-cement and Eco-steel technology on user organization.

Limitation

Data source limitations regarding transportation and electricity consumption during construction periods of dams and power plants were insufficient to consider in the present study. Also, the implementation of mitigation options could apply to their organization, which is still under strategic development by EGAT.

Acknowledgements

The authors would like to acknowledge Graduate School, Chulalongkorn University for supporting 60/40 PhD scholarship, where this manuscript is a part of the PhD study.

References

[1] A. Al Monsur, A. R. Paddo and F. M. Mohammedy, "Life Cycle Assessment of Climate Change and GHG Emission from Natural Gas Thermal Power Plant," 2020 IEEE Region 10 Symposium (TENSYMP), Dhaka, Bangladesh, 2020, pp. 1628-1631, doi: 10.1109/TENSYMP50017.2020.9230465.

[2] C. Sun, J. Zhao and L. Wang, "Environmental Life Cycle Assessment of a Small Wind Farm," 2021 IEEE International Conference on Electronic Technology, Communication and Information (ICETCI), Changchun, China, 2021, pp. 255-257, doi: 10.1109/ICETCI53161.2021.9563449.

[3] A. Karmaker, M. Rahman, M. Hossain, and R. Ahmed, “Exploration and corrective measures of greenhouse gas emission from fossil fuel power stations for Bangladesh” In journal of Cleaner Production, 2020, vol 244,118645,https://doi.org/10.1016/j.jclepro.2019.118645.

[4] P.Mahmud, M. Huda, N. Farjana, S. H., and C. Lang, C, “Environmental Life-Cycle Assessment and Techno-Economic Analysis of Photovoltaic (PV) and Photovoltaic/Thermal (PV/T) Systems”, IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Palermo, Italy, pp. 1-5, doi: 10.1109/EEEIC.2018.8493967.

[5] B.Chhun, S.Bonnet and S.H. Gheewala, “Life cycle assessment of the Kamchay hydropower plant in Cambodia”, Journal of Sustainable Energy & Environment, 2021. 12: p. 23-33.

[6] I. Tarannum and F. M. Mohammedy, "Life Cycle Assessment of Natural Gas and Heavy Fuel Oil Power Plants in Bangladesh," TENCON 2019 - 2019 IEEE Region 10 Conference (TENCON), Kochi, India, 2019, pp. 2240-2244, doi: 10.1109/TENCON.2019.8929492.

[7] M.Inoussah, M.Ngangue, S.Ngoh, F.Koffi, J.Tamba, and L.Monkam, "Assessment of Green House Gas Emissions from Thermal Technologies for Electricity Generation in Cameroon Using Life Cycle Analysis Method", 2023, OALib. 10. 1-17. 10.4236/oalib.1110481.

[8] N. Mardi, L. Ean, K.H Chua and M.Malek, "Application of Life Cycle Assessment (LCA) in measuring the environmental impact of coalfired power plant" in 2nd International Conference on Civil and Environmental Engineering, 2022,347,04021. 10.1051/e3sconf/202234704021.

[9] P.M. Pereira and C.S. Vieira, "A Literature Review on the Use of Recycled Construction and Demolition Materials in Unbound Pavement Applications," Sustainability 14 (2022) 13918, https://doi.org/10.3390/su142113918.

[10] E.Ekhaese, and O.Ndimako, "Eco-friendly construction materials and health benefits in the design of an all-inclusive health resorts, Nigeria", 2023, Frontiers in Built Environment. 9. 1011759. 10.3389/fbuil.2023.1011759.

[11] X. Xu, F. Jin, L. Fu and H. Zhou, "Construction information management system for rock-filled concrete dam (CIM4R)," 2021 7th International Conference on Hydraulic and Civil Engineering & Smart Water Conservancy and Intelligent Disaster Reduction Forum (ICHCE & SWIDR), Nanjing, China, 2021, pp. 457-460, doi: 10.1109/ICHCESWIDR54323.2021.9656283.

[12] B. Guo, Z. Fang, A. Ren, Q. Gao and T. Zhu, "The Preparation of Eco-cementing Materials in Utilization of Semidry Desulphurization Ash with Steel Slag and Mineral Materials," 2009 International Conference on Energy and Environment Technology, Guilin, China, 2009, pp. 441-444, doi: 10.1109/ICEET.2009.113.

[13] S.Wanna, W.Saengsoy, P.Toochinda, and S.Tangtermsirikul, "Effects of Sand Powder on Sulfuric Acid Resistance, Compressive Strength, Cost Benefits, and CO2 Reduction of High CaO Fly Ash Concrete", Advances in Materials Science and Engineering. 2020. 1-12. 10.1155/2020/3284975.

[14] Y.Mohan, M.Gavin, P.G. Ranjith, A. Tharumarajah, "Environmental life-cycle comparisons of steel production and recycling: sustainability issues, problems and prospects", 2011, Environmental Science and Policy, 14, 650 - 663. https://doi.org/10.1016/j.envsci.2011.04.008

[15] S.Julian Suer, T.Marzia, and J.Nils Jäger, "Review of Life Cycle Assessments for Steel and Environmental Analysis of Future Steel Production Scenarios. Sustainability" 2022, 14(21), 14131. https://doi.org/10.3390/su142114131

[16] H.-C. Yeo and C.-H. Lim, "Can Forest Restoration Enhance the Water Supply to Respond to Climate Change?The Case of North Korea," Forests 13 (2022) 1533

[17] D. S. Semerci and T. Yavuz, "Increasing efficiency of an existing francis turbine by rehabilitation process," 2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA), Birmingham, UK, 2016, pp. 107-111, doi: 10.1109/ICRERA.2016.7884440.

[18] H. Jin, S. H. Nengroo, S. Lee and D. Har, "Power Management of Microgrid Integrated with Electric Vehicles in Residential Parking Station," 2021 10th International Conference on Renewable Energy Research and Application (ICRERA), Istanbul, Turkey, 2021, pp. 65-70, doi: 10.1109/ICRERA52334.2021.9598765.

[19] Y. Wei, N. Altin, Q. Luo and A. Nasiri, "A High Efficiency, Decoupled On-board Battery Charger with Magnetic Control," 2018 7th International Conference on Renewable Energy Research and Applications (ICRERA), Paris, France, 2018, pp. 920-925, doi: 10.1109/ICRERA.2018.8566835.

[20] R. Maeno, H. Omori, H. Michikoshi, N. Kimura and T. Morizane, "A 3kW Single-Ended Wireless EV Charger with a Newly Developed SiC-VMOSFET," 2018 7th International Conference on Renewable Energy Research and Applications (ICRERA), Paris, France, 2018, pp. 1-6, doi: 10.1109/ICRERA.2018.8566866.

[21] R. C. Nacu and D. Fodorean, "Harmonics Mitigation in DC Based Charging Stations for EVs," 2021 10th International Conference on Renewable Energy Research and Application (ICRERA), Istanbul, Turkey, 2021, pp. 226-230, doi: 10.1109/ICRERA52334.2021.9598559.

[22] I.S. Aisyah, W. Caesarendra, D. Kurniawati, M. Maftuchah, D. Agung, A. Glowacz, K. Oprzędkiewicz and H. Liu, "Study of Jatropha curcas Linn and Olea europaea as Bio-Oil Lubricant to Physical Properties and Wear Rate," Lubricants 9 (2021) 39.