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Life Cycle Impact Assessment Priok Power Generation Unit: Comparison Based on Operating Time Span*

A. Wicaksono*, H.P. Prayitno, H.K. Prabowo

Priok Power Generation Unit
PLN Indonesia Power
Jakarta, Indonesia
E-mail: *adam.wicaksono@plnindonesiapower.c o.id

Abstrak
Unit Pembangkit Listrik (PGU) Priok adalah pembangkit listrik tenaga siklus gabungan (Combined Cycle Power Plant/CCPP) yang merupakan salah satu objek vital nasional dengan kapasitas pembangkitan sebesar 2.723 MW yang berfungsi sebagai *load follower* dan *peaker* dalam sistem jaringan kelistrikan. Studi ini bertujuan untuk melihat kinerja dampak lingkungan yang dihasilkan dari pola operasi pembangkit selama Januari hingga Desember pada tahun 2020 dan 2022, yang dilakukan dengan menggunakan metode *life cycle assessment* (LCA) dengan perangkat lunak SimaPro. Metode penilaian dampak daur hidup yang digunakan adalah ReCipe dan CML IA baseline. Tujuan dari perbandingan ini adalah untuk melihat perbaikan kinerja lingkungan dari unit pembangkit guna mendukung keberlanjutan. Hasil dari studi ini menunjukkan bahwa telah terjadi perubahan dalam hasil penilaian dampak lingkungan, di mana kategori dampak *Green House Gases* (GHG) dan *Land Use Change* (LUC) menunjukkan penurunan paling signifikan, yaitu lebih dari 90%. Sementara itu, *water footprint* merupakan satu-satunya kategori dampak yang mengalami peningkatan dampak lingkungan selama periode operasi tahun 2020 dibandingkan dengan periode operasi tahun 2022.

Kata kunci : pembangkit tenaga, listrik, lingkungan, LCA, keberlanjutan

Abstract
Priok Power Generation Unit (PGU) is a combined cycle power plant (CCPP) which is one of the national vital objects with a generating capacity of 2,723 MW which functions as a load follower and Peaker in the electricity network system. This study aims to look at the environmental impact performance resulting from plant operating patterns January-December in 2020 and 2022, which was carried out using the life cycle assessment (LCA) method with SimaPro. The method life cycle impact assessment uses the ReCipe and CML IA baseline methods. The purpose of this comparison is to see improvements in the environmental performance of generating units to support sustainability. The results of this study show that there has been a change in the results of the environmental impact assessment in the Green House Gases (GHG) and Land Use Change (LUC) are the impact categories with the most significant reduction, namely more than 90%. Meanwhile, water footprints are the only impact that experiences an increase in environmental impacts during the 2020 operating period compared to the 2022 operating period.

Keywords: *power plant, electricity, environmental, LCA, sustainability*

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1. INTRODUCTION

As a vital national object, power plants have an important role in a country's economic growth. Electricity has become one of the basic needs in the modern era in various levels of society (Wicaksono *et al.,* 2020). Electricity energy demand continues to increase due to the increasing population and industrial development that occurs in the world (Karapekmez *et al.*, 2019; Wicaksono *et al.*, 2020). Electricity can strengthen production effectiveness, support business activities, and improve the quality of life (Sinaga *et al.*, 2021). Burning conventional fuels in the production of polluting electricity encourages people to study cleaner energy conversion innovations (Annisa *et al.*, 2021).

Priok Power Generation Unit is one of the combined cycle power plants in Indonesia. Priok PGU can be operated with two types of fuel, namely natural gas and high speed diesel (HSD). Apart from that, CCPP is considered to have quite high efficiency of up to 56% compared to other types of generators (Ibrahim *et al.,* 2017). This is because it can optimize the residual heat from combustion in the gas turbine to create steam in the steam turbine. Increasing electricity consumption by burning more fossil fuels can contribute to increasing global concentrations of greenhouse gases and other environmental impacts (Sinaga *et al.,* 2021). So a comprehensive study is needed to determine the level of environmental impact produced (Annisa *et al.,* 2021). One method that can be used is LCA. The LCA method is a collection and evaluation of inputs, outputs, and potential impacts throughout its life cycle, which refers to ISO 14040 and 14044 to examine the environmental performance of all different stages of a product that can be identified during its life cycle (Annisa *et al.,* 2021; ISO 14044, 2006; ISO 14040, 2006).

The aim of this study is to quantitatively compare the potential life cycle impacts on the environment of PLTGU through a comprehensive approach with the LCA method. The LCA study that will be carried out is a comparative study based on the operating period, namely 2020 and 2022. This study compares the environment performance of Priok PGU in 2020 and 2022 because in 2020 the first LCA study was conducted in Priok, the study was used as a baseline used to carry out interventions to reduce environmental impacts. These interventions include policy making, efficiency innovations and environmental management programs. Then to see the results of the intervention, an LCA study was conducted again in 2022 for evaluation purposes. In addition, it will look at the significance of the impact of the operational and environmental management policy interventions carried out.

2. MATERIAL AND METHOD

The method used in this study is the Life Cycle Assessment method as in Figure.1 which is adopted in the ISO 14040 and 14044 standards)(ISO 14044, 2006)(ISO 14040, 2006). Then modeling was carried out using SimaPro software, LCIA was estimated based on ReCiPe 2016 Midpoint (H) V1.06 and CML-IA Baseline V3.05. This is a problem-oriented method, often referred to as the 'midpoint' approach, because it considers the environmental burden at the midpoint between the intervention points (resource extraction and resources) (Wicaksono *et al.,* 2023), (Guinée*,* 2015), (Brizmohun *et al.,* 2015).

The impact categories considered in this research are: greenhouse gases (GHG), acidification potential (AP), ozone layer depletion (ODP), eutrophication potential (EP), photochemical oxidation potential (POP), abiotic depletion potential (fossil fuels) (ADPF), abiotic depletion potential (ADP), terrestrial eco-toxicity potential (TETP), freshwater eco-toxicity potential (FETP), marine eco-toxicity potential (METP), Carcinogenic Potential (CP), Water Footprint (WF), Land Use Change (LUC), Toxicity (T). The indicators or impact categories that will be analyzed in this LCA study are adjusted to the needs of the regulations in force in Indonesia.

A. Preliminary Identification

This study was conducted at the Priok Power Generation Unit located in Tanjung Priok, North Jakarta. Priok PGU has 4 generating units with a total generating capacity of 2,723 MW which function as load follower and peaker generators. Priok PGU uses natural gas and HSD fuel in its operations. Aim and Scope of this study:

- Object : Combined Cycle Power Plant
- Location: Tanjung Priok, Jakarta Utara, Indonesia
- Purpose: Calculate environmental impacts and compare impacts based on 2020 and 2022 operating reports.
- Functional Unit: 1 kWh
- Scope : Gate to Gate
- Product : Electricity (100%)

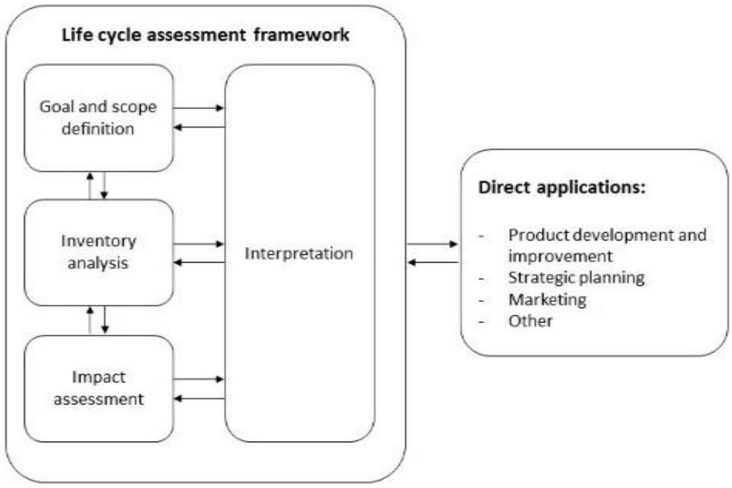

Figure. 1. Life Cycle Assessment Framework based on ISO 14040

B. Data Collection

The data used is data sourced from operational report documents, interviews, field observations with a time span of January-December 2020 for the 2020 report and January- December 2022 for the 2022 report. The data used is data for input and output for each process unit in each generating unit. The power plant in Priok PGU consists of 3 (three) units, PLTGU Unit 1-2, each unit consists of 3 Gas Turbine Generator unit and 1 Steam Turbine unit, and PLTGU Units 3 and 4 each consist of 2 Gas Turbine Generator units and 1 Steam Turbine unit.

C. Inventory and Impact Assessment

The data use is raw materials and emissions released by CCPP, where it has ten thermal generators, namely gas turbines, and can be combined with steam turbines. The electricity production process at the Priok CCPP includes the Gas Turbine Generator, HRSG, Steam Turbine Generator, Condenser, Transformer, WTP, desalination plant, H2 Generator and WWTP process units to distribution transformers. The functional unit used in this LCA study is 1 kWh of electricity in the transformer, which will be distributed to the 150 kV distribution network. The emissions obtained are internal data taken periodically and reported to the Indonesian government authority, namely the environmental service. The production process only produces a single final product, namely 100% electricity, distributed on the 150 kV network.

Then evaluate the possible environmental impacts caused by the production process using the LCIA model that is already in the SimaPro software so that the midpoint impact of the input-output material will be obtained. All impacts of the use of resources and the resulting emissions are grouped and quantified into certain impact categories that are then weighted according to their contribution level. The analytical method chosen is CML IA and ReCipe; this is because this method has been commonly used so that it is easier to compare with the results of previous studies.

3. RESULT AND DISCUSSION

The results of this study describe the LCI measures, impact assessment, and interpretation. Results for each stage of the life cycle are presented separately.

A. Life Cycle Inventory

In this study, input and output information was collected directly from the research location. Some data, such as emissions and waste at Priok PGU, were obtained from environmental performance reports, while material and product yields were obtained from plant operational data. Basically, in Unit 1-4 system has a similar process unit conFigureuration. However, Units 3 and 4 do not use HSD in the operation process. Appendix A provides a detailed flow diagram that illustrates the movement of materials between interconnected process units, creating a continuous system. Each process unit within this system is characterized by mass flows, which serve both as inputs and outputs. The output from one unit becomes the input for the next, ensuring a smooth progression of material through the various stages of the process. This interconnected flow highlights the importance of tracking and managing both inputs and outputs to optimize overall system efficiency. For more details result of live cycle inventory will explained in Table Appendix B.

However, it is important to note that while the diagram captures the general flow of materials, not all emissions from the process units are fully accounted for. This limitation arises due to the constraints of field conditions and the availability of information, which may prevent the complete identification and quantification of emissions. As a result, there may be unreported or undetected environmental impacts associated with certain stages of the process. This underscores the need for more comprehensive data collection and monitoring efforts to improve the accuracy of emission assessments and better inform environmental management strategies. By addressing these gaps, future studies and operational improvements can ensure a more complete understanding of the system's environmental footprint.

Table I. Life Cycle Impact Assessment (Characterization)

Impact category	In Year 2020	In Year 2022	Unit
GHG	3,85E+02	1,72E-01	kg CO2 eq/kWh
ODP	8,90E-10	3,54E-10	kg CFC11 eq/kWh
AP	1,90E-04	7,74E-05	kg SO2 eq/kWh
EP	3,58E-05	1,25E-05	kg PO4--- eq/kWh
POP	5,75E-05	4,95E-06	kg C2H4 eq/kWh
ADPF	0	0	MJ/kWh
ADP	0	0	kg Sb eq/kWh
TETP	2,95E-23	1,03E-23	kg 1,4-DCB/kWh
FETP	4,79E-07	1,66E-07	kg 1,4-DCB/kWh
METP	6,34E-07	2,19E-07	kg 1,4-DCB/kWh
CP	0	0	kg 1,4-DCB/kWh
T	3,35E-04	1,17E-04	kg 1,4-DB eq/kWh
WF	1,02E-05	1,19E-05	m3/kWh
LUC	2,95E-01	1,93E-05	m2a crop eq/kWh

In this study, the LCIA stage was processed using SimaPro software and produced impact category output along with characterization values. The methods used in the LCA assessment process are ReCiPe 2016 Midpoint (H) V1.06, CML-IA Baseline V3.05. Table I. shows the LCIA results of simaPro calculations.

Table I presents the data, for comparison of the changes in each impact category across two different operating periods. The results are visually represented in Figure. 2, which illustrates the trends in environmental impacts between 2020 and 2022. As shown in the graph, there is a notable reduction in impact for most categories, with the exception of the Water Footprint (WF) impact category, where an increase was observed.

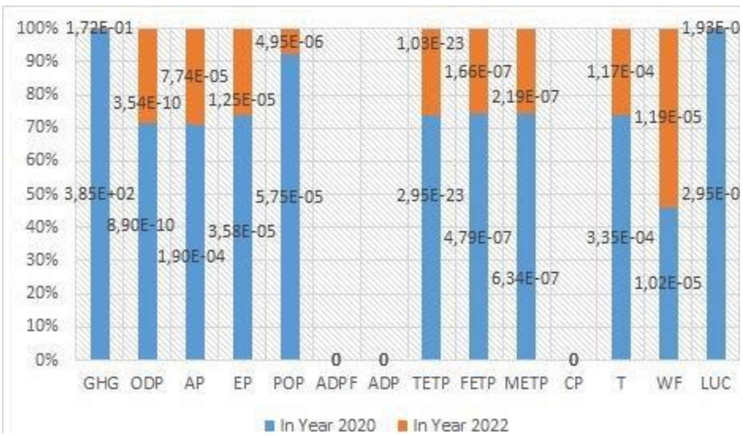

Figure. 2. Comparison of 2020 and 2022 impact categories

Additionally, the categories of Abiotic Depletion of Fossil Fuels (ADPF), Abiotic Depletion Potential (ADP), and Climate Protection (CP) showed no measurable impact based on the calculations performed using the SimaPro software. Despite these exceptions, the overall reduction in environmental impact is significant, with the average percentage change across all categories being 47.3%. Particularly noteworthy are the reductions in the Greenhouse Gas (GHG) and Land Use Change (LUC) impact categories, which both exhibited decreases of over 90%. These substantial reductions suggest that specific environmental management interventions and policies have been highly effective in addressing these key areas.

However, the increase in the Water Footprint highlights the need for targeted efforts to address water resource management in future operations. Overall, the data underscores the varying degrees of success in reducing environmental impacts across different categories, emphasizing the importance of continuous monitoring and adaptive management strategies. Changes in the value of the impact category indicate that the intervention carried out by the company in the form of environmental management policies has a significant influence. So, there could be a reduction in impacts in most impact categories, however there is still an impact category whose value is increasing, namely WF.

The increase in the water footprint of the power generation industry, particularly in thermoelectric and hydroelectric plants, presents significant environmental, economic, and social challenges. Thermoelectric plants, which rely heavily on blue water for cooling and steam generation, face heightened risks of resource competition and aquatic ecosystem disruption, particularly in water-scarce regions. Increases in green water use, particularly in biofuel production, raise concerns over sustainability and competition with food crops. The rise in the grey water footprint, associated with pollution, poses risks to water quality and public health. Economically, higher water use may lead to operational risks, including plant inefficiencies and higher costs due to regulatory pressures or the need for technological upgrades. Socially, the competition for freshwater between power generation and community needs could exacerbate water scarcity issues, especially in vulnerable regions. Consequently, the industry is moving toward more sustainable practices, such as adopting renewable energy technologies with lower water demands, closed-loop cooling systems, and the use of treated wastewater for cooling to mitigate these impacts.

The decrease or increase in environmental impacts within each category is directly influenced by the operational strategies employed by the power plant. By identifying potential areas for improvement, particularly by pinpointing the "hot spots" or critical points in the life cycle that contribute significantly to the total environmental impact, companies can optimize their operations more effectively (Pieragostini *et al.,* 2012). Understanding these critical points allows for targeted interventions that can yield substantial environmental benefits.

These findings provide valuable insights for policymakers within the company, enabling them to make informed decisions about which operating strategies to adopt or modify. By integrating Life Cycle Assessment (LCA) evaluations into the decision-making process and conducting them periodically, companies can continuously monitor and refine their operational practices. This approach not only ensures compliance with environmental standards but also enhances sustainability efforts, leading to more efficient resource use, reduced emissions, and overall improved environmental performance. Periodic LCA evaluations thus serve as a crucial tool for guiding the company toward more sustainable and responsible operations, making it easier to adapt to evolving environmental regulations and stakeholder expectations.

4. CONCLUSION

The conclusion of this study indicates that significant changes have occurred in the results of the environmental impact assessment across all impact categories. The intervention of environmental management policies has proven to influence the outcome of various categories within the Life Cycle Impact Assessment (LCIA). Notably, the categories of Greenhouse Gases (GHG) and Land Use Change (LUC) experienced the most significant reductions, with both showing reductions of over 90%. This suggests that targeted environmental policies can effectively mitigate these types of impacts. However, the study also highlights an exception: water footprints. Unlike other categories that saw reductions, the water footprint experienced an increase in environmental impact between the 2020 and 2022 operating periods. This increase suggests that while policies were effective in reducing GHG emissions and land use changes, further attention and tailored strategies are required to address water usage and its associated environmental impacts in future environmental management efforts. Overall, the findings underscore the importance of continually adjusting and refining environmental policies to address specific areas where progress may be slower or where new challenges arise.

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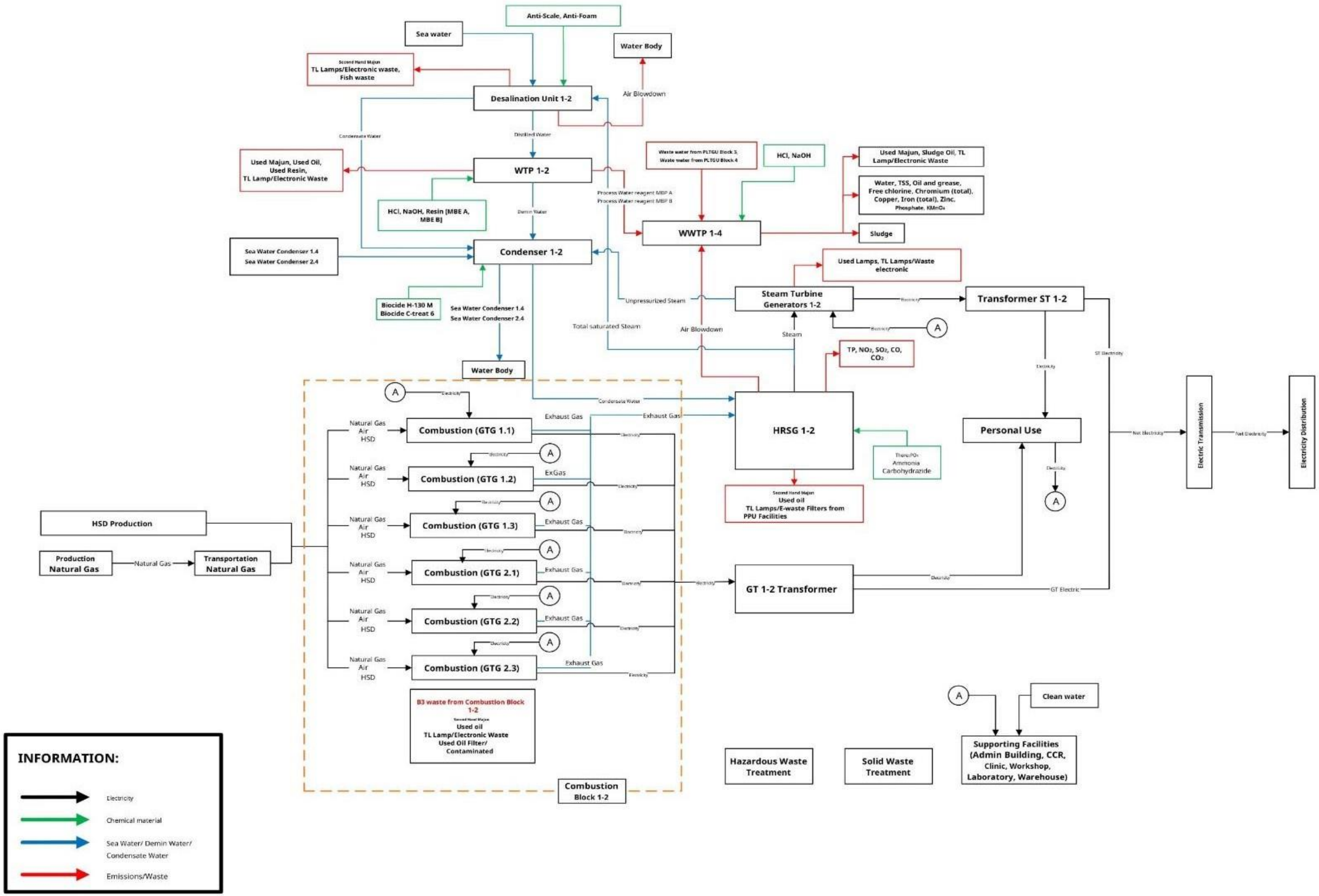
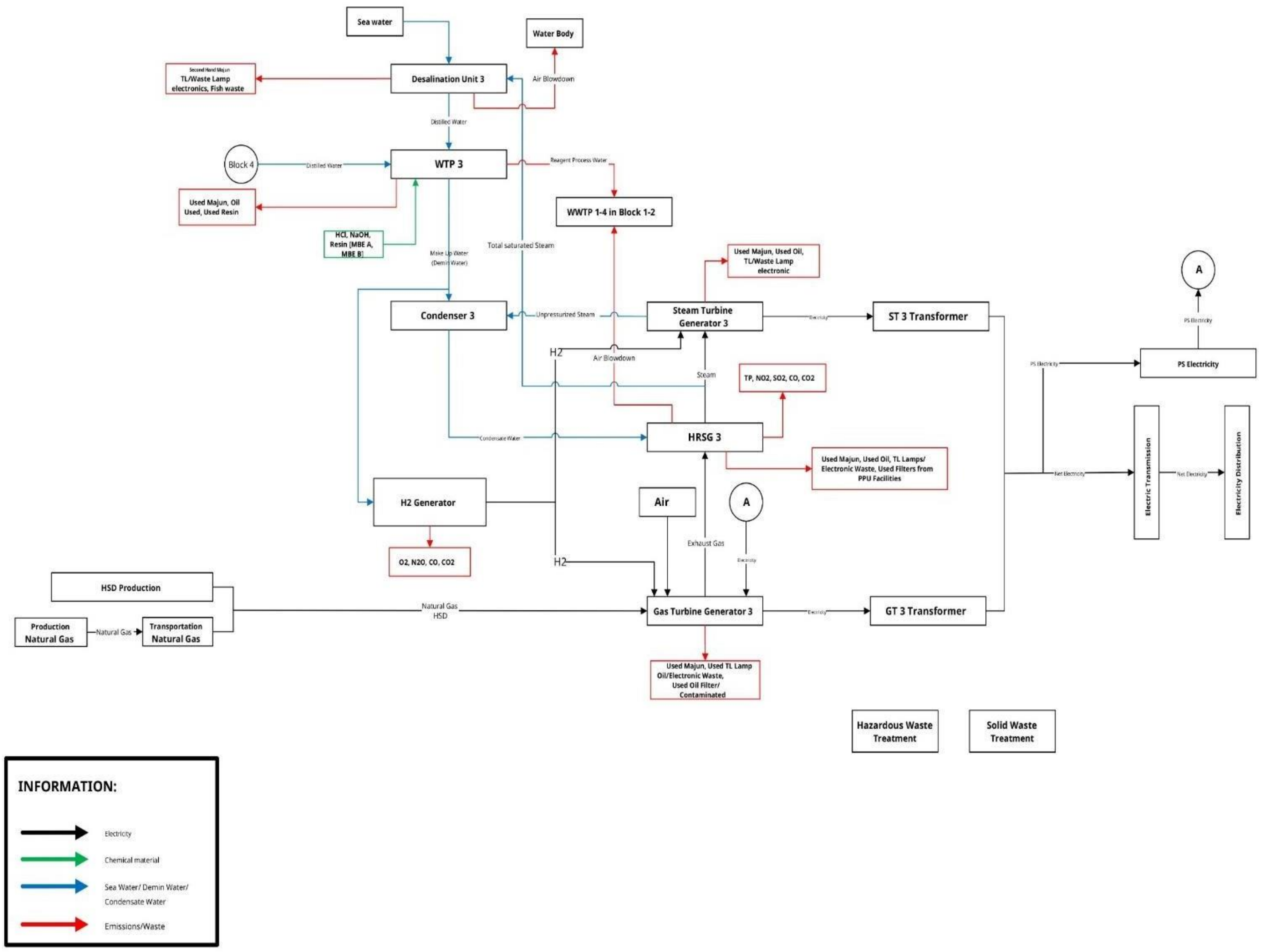
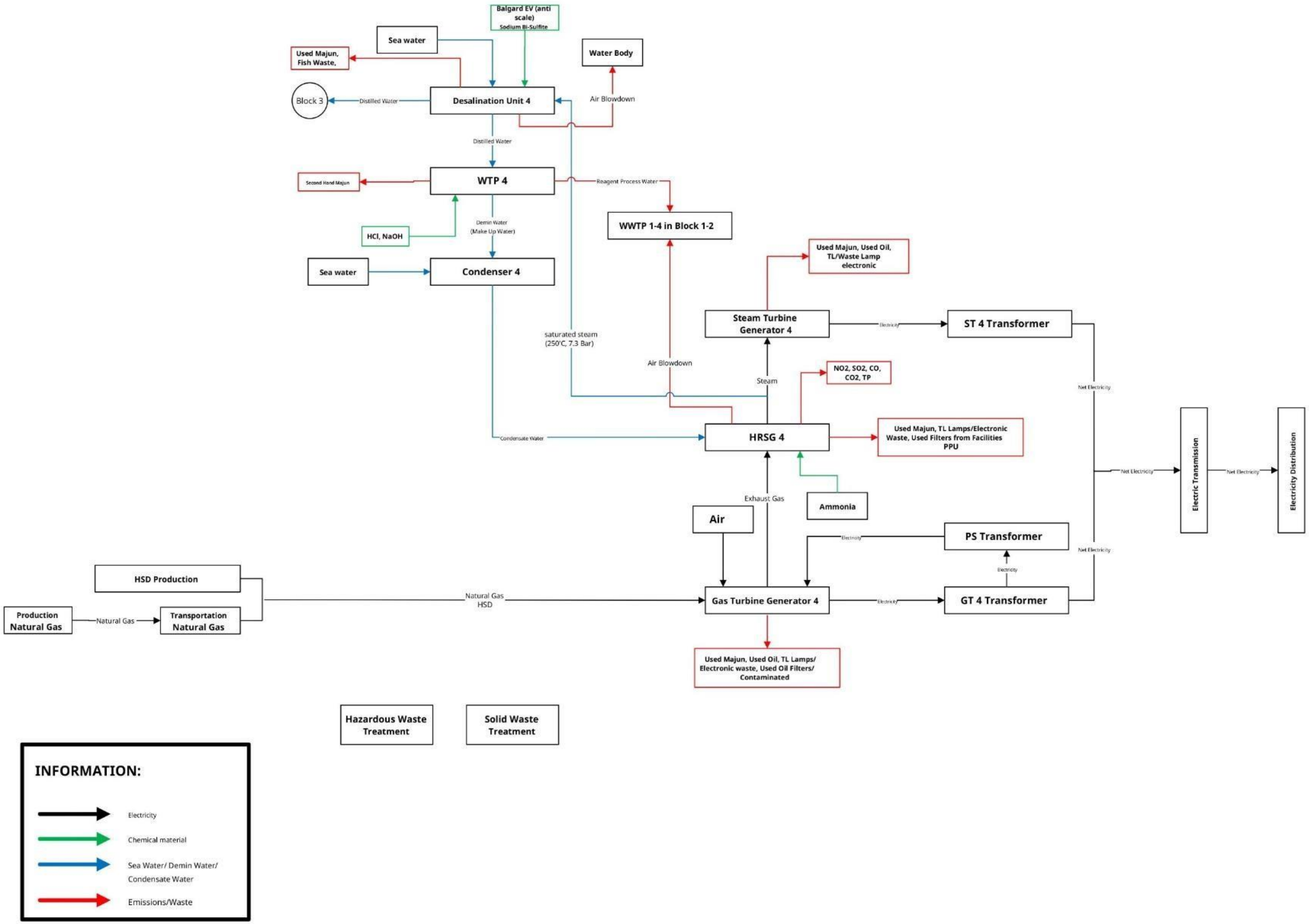
APPENDIX A





Sea water
Water Body
Desalination Unit 3
TL/Waste Lamp electronics, Fish waste
Air Blowdown
Distilled Water
Block 4
Distilled Water
WTP 3
Reagent Process Water
Used Majun, Oil Used, Used Resin
WWTP 1-4 in Block 1-2
HCl, NaOH, Resin (MBE A, MBE B)
Make Up Water (Demin Water)
Total saturated Steam
Used Majun, Used Oil, TL/Waste Lamp electronic
A
Condenser 3
Unpressurized Steam
Steam Turbine Generator 3
ST 3 Transformer
PS Electricity
PS Electricity
H2
Air Blowdown
Steam
TP, NO2, SO2, CO, CO2
Condensate Water
HRSG 3
Used Majun, Used Oil, TL Lamps/ Electronic Waste, Used Filters from PPU Facilities
Net Electricity
Electric Transmission
Net Electricity
Electricity Distribution
H2 Generator
Air
A
Exhaust Gas
O2, N2O, CO, CO2
H2
HSD Production
Natural Gas HSD
Gas Turbine Generator 3
GT 3 Transformer
Production Natural Gas
Natural Gas
Transportation Natural Gas
Used Majun, Used TL Lamp Oil/Electronic Waste, Used Oil Filter/ Contaminated
Hazardous Waste Treatment
Solid Waste Treatment
INFORMATION:
Electricity
Chemical material
Sea Water/ Demin Water/ Condensate Water
Emissions/Waste


Balgard EV (anti scale)
Sodium Bi-Sulfite
Sea water
Used Majun, Fish Waste,
Water Body
Block 3
Distilled Water
Desalination Unit 4
Air Blowdown
Distilled Water
Second Hand Majun
WTP 4
Reagent Process Water
WWTP 1-4 in Block 1-2
Demin Water
(Make Up Water)
HCl, NaOH
Sea water
Condenser 4
Used Majun, Used Oil, TL/Waste Lamp electronic
saturated steam
(250'C, 7.3 Bar)
Steam Turbine Generator 4
Electricity
ST 4 Transformer
Air Blowdown
Steam
NO2, SO2, CO, CO2, TP
Net Electricity
Condensate Water
HRSG 4
Used Majun, TL Lamps/Electronic Waste, Used Filters from Facilities PPU
Net Electricity
Electric Transmission
Net Electricity
Electricity Distribution
Exhaust Gas
Ammonia
Air
PS Transformer
Electricity
Net Electricity
Electricity
HSD Production
Natural Gas
HSD
Gas Turbine Generator 4
Electricity
GT 4 Transformer
Production Natural Gas
Natural Gas
Transportation Natural Gas
Used Majun, Used Oil, TL Lamps/ Electronic waste, Used Oil Filters/ Contaminated
Hazardous Waste Treatment
Solid Waste Treatment
INFORMATION:
Electricity
Chemical material
Sea Water/ Demin Water/ Condensate Water
Emissions/Waste