Environmental Impact Evaluation Using Green Value Stream Mapping (Green-VSM) and Life Cycle Assessment (LCA)

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***Abstract*—PT. AI is an industry that moves their business in the agro-industrial sector. One of their products is insecticide that has cypermethrin (hazardous material) and xylene (flammable material) as the main materials in a formulation process. Moreover, PT. AI also use aluminum and corrugated box as the packaging materials. By utilizing Green-VSM (process visualization) and LCA (environmental impact assessment), this study is intended to assess each production process of the insecticide and the environmental impact that is caused by process, material and waste that occurs within each process. Furthermore, the identification of improvement opportunities for reducing environmental impact will be done. Based on this study, the existing condition of the process causes environmental impact towards human health of 0.01 DALY (714 points), ecosystem quality of 361.45 PDF*m2y (20.528 Points) and resources of 5.9 MJ (0.8 points). By analyzing the existing condition there are four improvement opportunities that are identified. The first opportunity is redesigning the current corrugated box design, which reduces the environmental impact for 8.675 points from material use reduction. The second opportunity is having a sorting activity towards the cap of the bottle which reduce environmental impact for 3.548 points. The third opportunity is changing into a new procedure towards the box sealing process which reduces environmental impact for 0.0008 points. The fourth improvement is substituting material towards bottle material (from supplier) packaging into the duplex board which reduces environmental impact for 2.915 points. Those improvements opportunities in total are expected to reduce the environmental impact for 15.138 points.**

***Keywords*—Environmental Impact Assessment, Formulation Processs, Green-VSM, Life Cycle Assessment.**

I. PENDAHULUAN

ENVIRONMENT has become the main concern nowadays. The growing population and consumption become the main cause of the environmental problem such as the depleted natural resources and non-renewable energy in a very alarming way [1]. Furthermore, waste generated during an industrial process also causes environmental problem such as health problem and the destruction towards environmental component [2]. So that, the industry and government must pay attention to the development that has concern toward the environment.

Indonesia is a developing country that is currently focusing on the development toward the industrial sector [3]. However, this development also requires big attention towards industrial waste, where industrial activity mostly creates waste that harmful towards the health and components of the environment. Until today, the government of Indonesia has established various regulation that is intended to control the environmental impact caused by various activity within the country, including industrial activity.

PT. Agro-Industry (PT. AI) is one of the industries in Indonesia that moves in the sector of agro-industry which the main process in this industry is a formulation process. One of the formulation processes is the formulation of *cypermethrin* and *Para-xylene* to create an insecticide. *cypermethrin* is a chemical that can cause health issues and toxicity towards animal and underwater or aquatic organism [4]. Para-xylene is a hazardous material that can affect human health and has flammability characteristics, moreover it very corrosive towards plastics, rubbers, and coating [5]. PT. AI also utilize aluminum and corrugated box as the main packaging material for insecticide. Those materials for formulation and packaging can cause environmental impact within the extraction process (upstream process before went into PT. AI), furthermore, environmental impact will be also generated during the process and waste occurred within PT. AI.

By looking at the stated condition, it is necessary to conduct evaluations towards the process or system that is applied to the planning activities, production activities, and waste treatment activities. This study proposed the use of Green Value Stream Mapping (Green-VSM) as the extents of conventional value stream mapping and Life Cycle Assessment (LCA) Approach to identify the environmental impact that generated in each process and materials. These two approaches are intended to create a visualization towards the formulation process flow, by using Green-VSM, which is equipped with environmental impact assessment value, from LCA, within each process that occurs within the process. Then, the opportunity of improvement to reduce environmental impact will be analyzed and identified which then will be used to develop future Green-VSM as the proposed condition that has a less environmental impact.
This study evaluates the environmental impact that occurs within the planning activity, production or formulation activity, and waste treatment activity of PT. AI. This study observes environmental impact generation in each batch of the production process. Moreover, this study will neglect the machinery life and the use of surfactant which is a secret material of PT. AI.

II. RESEARCH METODOLOGY

A. Observation and Data Collection

In this stage, observation of the existing system will be executed. The purpose of this stage is to collect data and information of the insecticide formulation processes. Data and information are derived from direct observation, interview with the stakeholder of the process, and secondary data of the production process, such as the historical data. Data and information that will be collected are production process flow (planning, production, and waste treatment), input and output in each process, including waste generation.

B. Life Cycle Inventory and Impact Assessment

The collected data then will be identified based on each process, which the input and output will be identified as the life cycle inventory (LC Inventory) of the process. LC inventory is used to describe the material and energy flow in the process, including waste [6]. The framework of the LC Inventory will consist of four inventory flow of intermediate flow (inventory bought from another party), elementary flow (extracted inventory from the environment), elementary input (output that impacts environment), and reference flow (desired output). Furthermore, generated waste will be classified based on 7 Green waste [7].

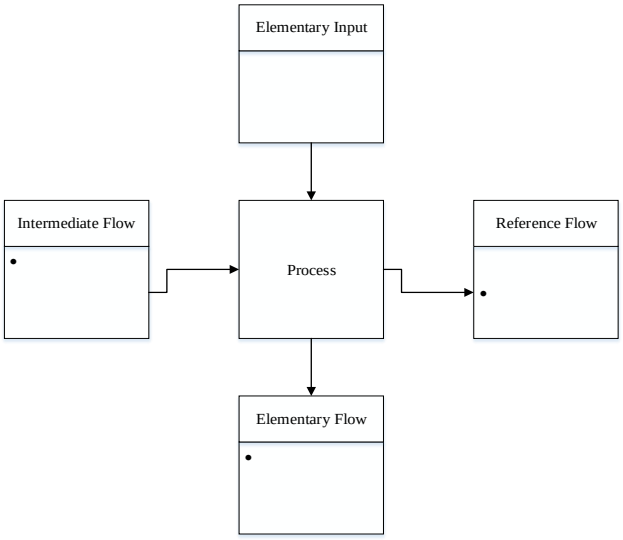

Figure 1. Life Cycle Inventory Framework

After the process, waste, and the environmental impact is identified, then the information of insecticide formulation processes will be used as the input in the development of GVSM. The development of GVSM is intended to give a better visualization of the current process. The visualization will give information on what kind of process that is occurred, the input and output of the process and the environmental impact that is generated by each process. Furthermore, it can be used to trace each processing activity.

C. Life Cycle Impact Analysis

In this step, an overall analysis of the current condition of insecticide product creation which consists of planning, production, and waste treatment activity will be done. The current condition will be analyzed based on the characteristic of the environmental impact that is generated by the processes and what kind of damage that will occur toward human health, ecosystem, and resource availability.

After the environmental impact is identified, then it is analyzed using Root Cause Analysis, in order to get the core issue that generating the impact occurring within the process. After the cause or source of waste and environmental impact is identified, then the opportunity of improvement will be proposed. The opportunity of improvement will be generated based on the root cause analysis results so that the generated alternatives have the contribution in reducing the problem that causing environmental impact within the process.

As the alternatives are generated, and the environmental impact of the process is minimized, then the future Green Value Stream Mapping is made. This future Green-VSM will visualize the future of the process value stream which will become the target of improvement in environmental concerns. The use of GVSM will give a better visualization toward the industry to understand where the alternatives of improvements are placed. Furthermore, the environmental impact can also be used to monitor the execution of improvements.

D. Conclusion

This chapter will explain the conclusion from the results of the whole study. The conclusion will be focused on how this study has impacts on the environmental assessment and improvements towards the firm. In this chapter, recommendations will also be proposed for the PT. AI and future study.

III. PROCESS IDENTIFICATION AND GREEN VSM DEVELOPMENT

A. Production Process and LC Inventory Identification

PT. AI is an industry that moves in the agro-industrial product which produces ten types of product consist of insecticide, herbicide, terrain herbicide, fungicide, ZPT, moluskcide, bio, fertilizer, fitrice and chemical substance. The main production process that is done in PT. AI production plan is called formulation process, which is a process that mixes various type of chemical into the desired product. Insecticide Production Unit produces various types of insecticide which also vary in the product volume. One of Insecticide Production Unit product is 400ml Cypermethrin based insecticide which becomes the observed product in this study. Over the period of January to April 2019, 319330 liters of 400ml cypermethrin based insecticide was produced.

There are three activities that are observed in this study, the first one is the planning activity that consists of production planning and weekly meeting.

Table 1.
Life Cycle Inventory Identification

LC Inventory	Planning	Production	Waste Treat.
Energy (kWh)	22.587	52.092	0.123
Paper (Kg)	0.109	-	-
Aluminum can (Kg)	-	625.126	0.314
Corrugated board (Kg)	-	236.6	1.4
Cypermethrin (Kg)	-	150	-
Para-xylene (Kg)	-	2664.4	-
Garbage (Kg)	-	-	77.5

Table 1 shows the inventory that occurs within planning, production, and waste treatment activity. Energy is used in each activity in order to execute their equipment. Planning activity will need the energy to run personal computers,

printer, laptop, and a projector including other supporting equipment such as air conditioner and refrigerator. On the other hand, production and waste treatment activity will utilize energy to run machinery within the plant which ranged from the electric pump, mixer, automatic filler and capper, packing machine, and forklift. The inventories that occurs are energy, material, and garbage which later these inventories will be assessed from 7 green waste classification and environmental impact value.

Table 2.
7 Green Waste

7 Green Waste	Source	Amount
Material (Kg)	Bottle & cap	0.314
	Corrugated board	1.4
Garbage (Kg)	Non-hazard waste	77.5
	Open burning (ash)	$475*10^{-6}$
Emission (kWh)	Electricity	57.92
	Waste treatment	0.123
Transport (kWh)	Forklift	16.76
Energy (kWh)	Wasted Electricity	0.487

Table 2 shows the occurrence of 7 green waste within planning, production, and waste treatment activities. Only five out of seven green wastes that are identified in this study, since the other two green waste is not occurred (water) and beyond the scope of this study (biodiversity). Emission, transport, and energy will share the same unit since the source of this waste is the same (electricity use). Later these wastes will lead to the same environmental impact of emission.

B. Life Cycle Impact Assessment

After the life cycle inventory is identified, then it will be assessed based on environmental impact. In this study, the assessment will utilize the impact category and damage category aspects. Impact category is a classification based on characteristic of the impact (carcinogen, respiratory, climate change, radiation, ozone layer, ecotoxicity, acidification, land use, and minerals) in the other hand damage category is a group of impact category that share the same damage toward environment aspect that consists of human health (carcinogens, respiratory, climate change, radiation, and ozone layer), ecosystem quality (ecotoxicity, acidification, and land use), and resources (minerals) [8].

Table 3.
Life Cycle Impact (Each Inventory)

Activity	Human health	Eco quality	Resources
Energy (kWh)	0.319	0.016	0.787
Paper (Kg)	0.075	0.115	0.002
Aluminum can (Kg)	447.939	11.325	0.000
Corrugated board (Kg)	25.62	0.698	0.000
Cypermethrin (Kg)	123.289	3.533	0.398
Para-xylene (Kg)	97.207	4.015	0.275
Garbage	6.734	0.233	0.011
Total	714.068	20.258	0.800

Table 4.
Life Cycle Impact (Activities)

Activity	Human health	Eco quality	Resources
Planning	0.122	0.117	0.111
Production	706.715	19.897	0.678
Waste Treatment	7.2312	0.2441	0.0112
Total	714.068	20.258	0.800

Table 3 shows the environmental impact that is caused by each inventory flow within all activities. On the other hand, Table 4 shows the comparison of environmental impact within each activity in points to get more understanding in which process generates the biggest impact. On the other hand, environmental impact that is caused by 7 green waste is shown in Table 5.

Table 5.
Life Cycle Inventory Identification

7 Green Waste	Human health	Eco quality	Resources
Material	0.232	0.006	0.000
Garbage	6.998	0.238	0.011
Emission	0.168	0.008	0.113
Transportation	0.100	0.003	0.001
Energy	0.002	0.000	0.000

IV. DISCUSSION & ANALYSIS

The following analysis will analyze the existing condition which will be based on the impact category and damage category, then the opportunity of improvement will be identified and analyzed to estimate how much environmental impact can be reduced.

A. Life Cycle Impact Analysis

There are three damage categories that represents damage towards the environmental aspect that is generated from the observed study. The first is human health. The human health impact is one of the damage categories that assess how the damage of a product lifecycle may damage the health of any human individuals which includes present or future generations [8]. By looking at Table 3 and Table 4 human health is the most impacted environmental aspect based on this study results covering for 97% (714.068 points) from overall impact or equal to 0.01 DALY (Disability Adjusted Life Years). The main contributor to human health impact itself is the use of material within the production activity, which is sourced from the production of aluminum can, cypermethrin, and Para-xylene. The use of energy that occurs in the production process of those materials causes emission that mostly create impact toward respiratory system (65.59 %) and climate change (29.08%).

The second impact is ecosystem quality. Ecosystem quality will be expressed in the percentage of threatened or disappeared species from a given area during a certain time [8]. The ecosystem will be impacted by 20.258 points which equal to 361.45 PDF*m2y (area i\n m^2 that will be threatened yearly) by each batch of insecticide produced. The use of aluminum and cypermethrin are the major source of ecosystem quality impact, which comes from the area that is used for energy generation to produce aluminum can and cypermethrin.

The third impact is resources. The resource concentration depletion is the result of mineral extraction processes. As the concentration of resources becomes smaller, the energy that is needed to extract the resources in the future will increase. To create one batch of insecticide the resources will be impacted by 0.800 Points or equal to 0.64 MJ surplus energy. Resource impact that is caused by production activity is generated by the production process of Para-xylene and cypermethrin. The impact is caused by the material or minerals that are used to generate the energy to extract the material. On the other hand, planning activity gives the impact from the use of electronics equipment, such as personal computer, laptop, and printer.

B. Existing Condition Analysis

There are three activities executed in the production of insecticide, planning, production, and waste treatment activity. Planning activity has the least environmental impact compared to other activities having a total of 0.349 points of environmental impact. Life cycle inventories that occur in this activity are mostly the energy use for electrical office equipment such as PC, laptop and printer. The inventories of planning activity consist of electricity that is used by the equipment and paper that is used as the material. The use of paper (55.5%), computer (26.2%), and printer (14.3%) are the main contributor to environmental impact from the planning activity.

Production activity is the major contributor compared to other activities in terms of the environmental impact generated by each activity. Production activity environmental impact covers 98.92% of overall activities environmental impact which is ranged from planning, production, and waste treatment activity. LC Inventories that occur in production activities consist of energy for transportation, energy for machining, material for insecticide, and packaging material. Materials give the biggest environmental impact (99.966%) followed by machining energy (0.0188%) and transportation energy (0.015%).

The third is waste treatment activity and the 7 green wastes. Waste treatment activity has the second biggest environmental impact compared to other having a total impact of 7.487 points on the other hand 7 green wastes have an impact of 7.881 points since it includes the waste treatment activity and the energy use in both planning and production activity. There are five identified green wastes in this study which are energy (from waiting and producing rework product), emission (the use of energy), garbage (raw material packaging and PPE), material (defect material), and transportation (energy used).

C. Opportunity of Improvement Analysis

To reduce the environmental impact within the activities this study tries to identify and analyze the core issues of where the environmental impact occurs and why those impacts are occurred, including why there is waste that is generated and cause environmental impact also. By considering the condition in PT. AI this study able to identify four opportunities of improvements that are expected to reduce the environmental impact. Material is the identified main contributor to the environmental impact during this study. However, some material such as aluminum, para-xylene, and cypermethrin (even considered as the biggest contributor), during this study, cannot be identified their improvement opportunity since there is some condition that beyond the scope of this study. So, the following opportunity that can be identified are,

1. Cardboard box redesigning. This improvement will redesign the current cardboard box by considering the center of gravity of the product, which then will reduce the material used to 66% (0.7 Kg to 0.46 Kg) for each cardboard box. This improvement reduces the material used in the bottle divider inside the box. This opportunity of improvement is expected to reduce the environmental impact for 8.675 points since the material is reduced.
2. Boxing and sealing procedure improvement. Waiting occurs in the sealing process, which covers about 84.375% of the time. The procedure improvement is intended to reduce the waiting time by balancing the time between loading and sealing process. This improvement is expected to reduce the waiting and make the energy use more efficient (sealing process) and reduce the environmental impact of 0.0008 points.
3. Sorting process. Rework that occurs, in this case, is caused by a problematic cap dimension. To minimize the problem from it, it is proposed to have a sorting process toward the cap. This opportunity is proposed to reduce the environmental impact of 3.549 points which include the environmental impact from energy and material use.
4. Material substitution for bottle packaging (from supplier). By considering the character and the requirements for the bottle handling, the duplex board is proposed to substitute the corrugated box that is used to separates bottles layer. This improvement is expected to reduce the environmental impact of 2.915 points.

V. CONCLUSION

This study identifies three activities of producing one batch of insecticide. This study identifies that about 735.126 points of environmental impact are generated which consists of human health (97.14%), ecosystem quality (2.76%), and resources (0.11%). The biggest contributor to environmental impact is the materials (727.054 points) for the production activity which consists of the aluminum can (64.2%), cypermethrin (17.3%), Para-xylene (13.8%), and insecticide box (3.6%).

This study also identifies four opportunities of improvements that are expected to reduce the environmental impact in a total of 15.138 points. Those opportunities are redesigning packaging box material in production activity (8.675 points reduction), minimize wasted energy by procedure change in sealing process (0.00083 points), minimize material waste by sorting station for capping process (3.548 points), and minimize garbage environmental impact by changing the layer material for bottles packaging (2.915 points). However, improvements toward redesigning box and material substitution towards bottle packaging will need coordination between PT. AI and the supplier.

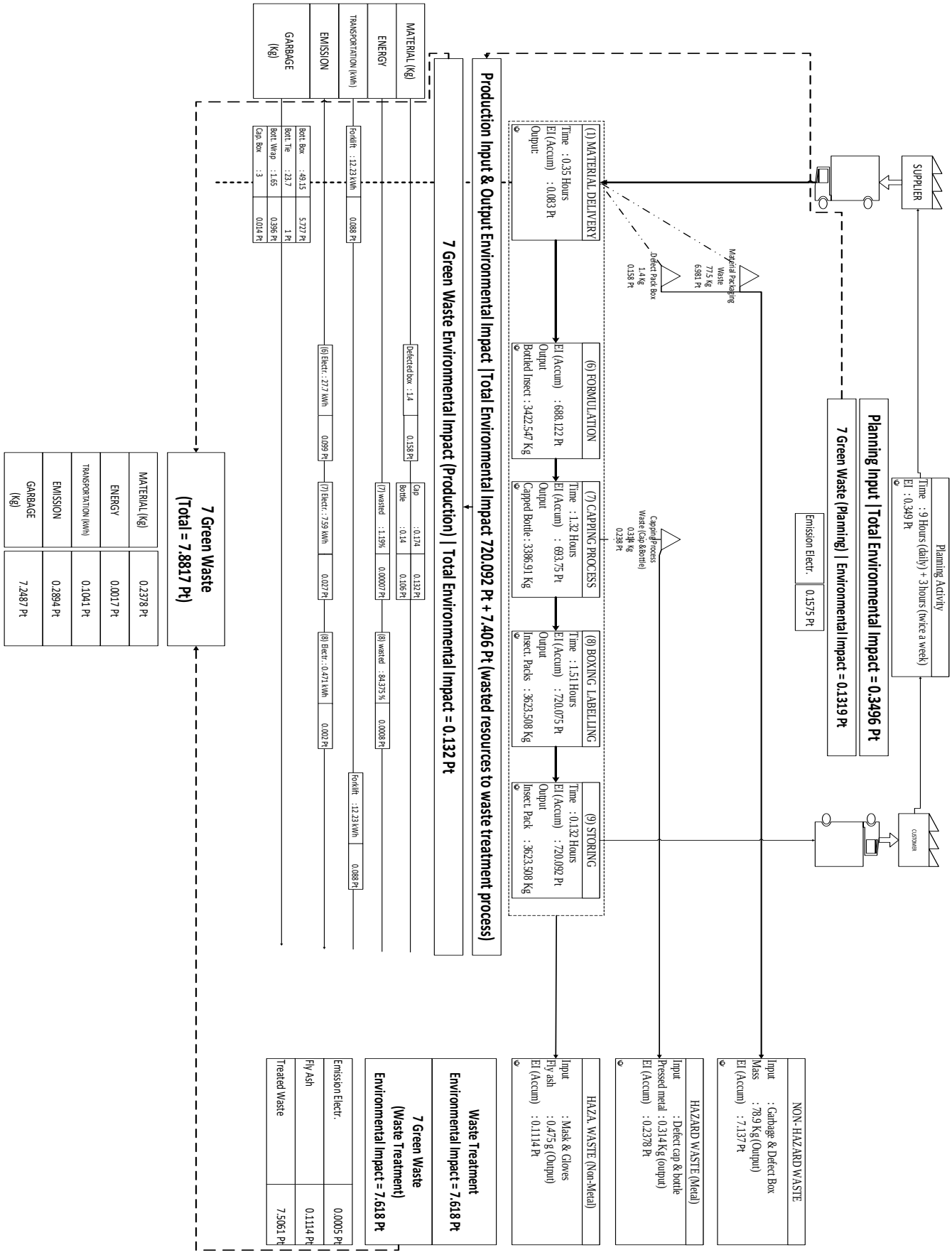

Figure 2. Current State Green-VSM

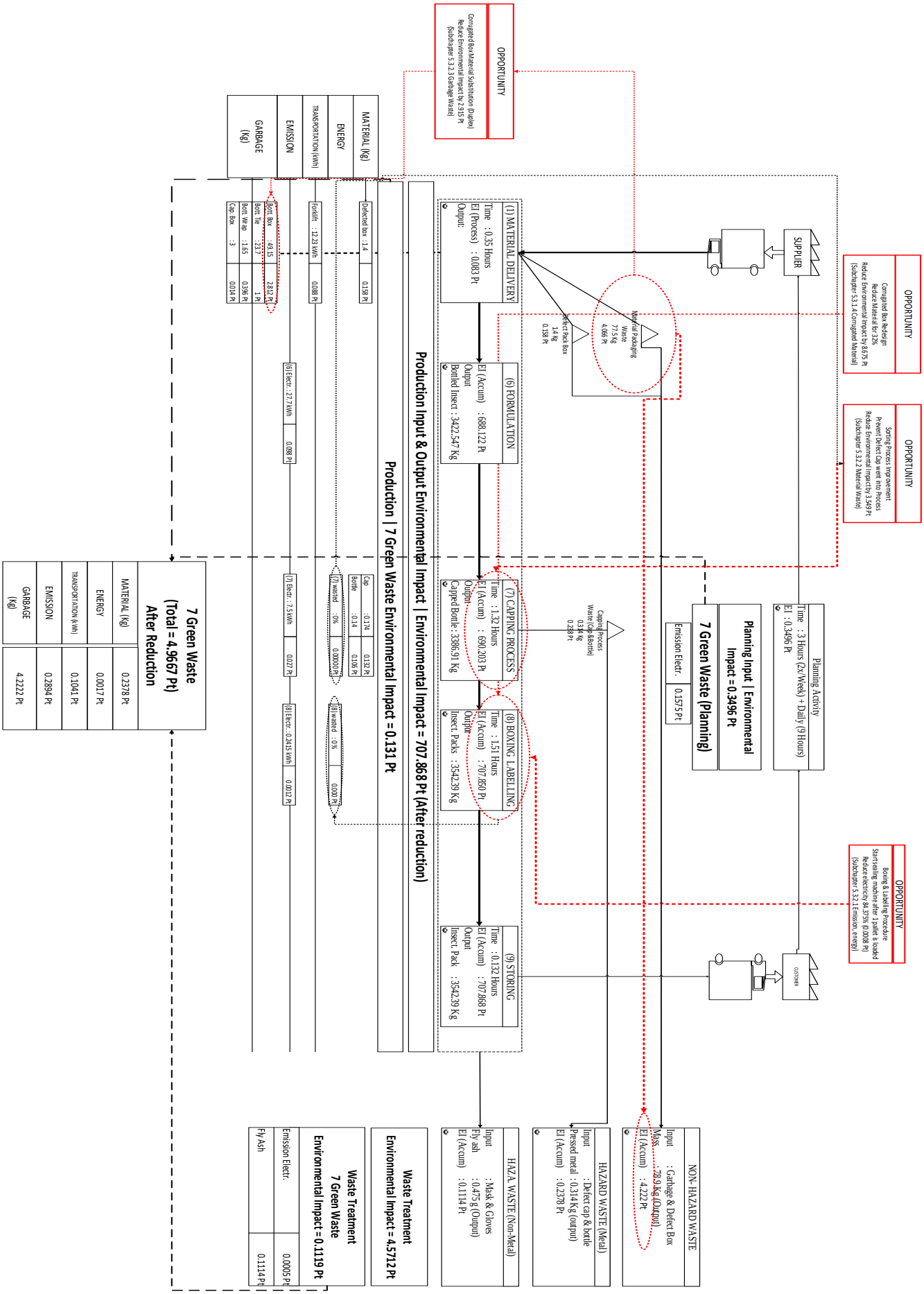

Figure 3. Future Green-VSM

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