NITROGEN MANAGEMENT IN POULTRY INDUSTRY FROM CIRCULAR ECONOMY PERSPECTIVE

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Chemical Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"NITROGEN MANAGEMENT IN POULTRY INDUSTRY FROM CIRCULAR ECONOMY PERSPECTIVE"** was prepared by **CHIA PEI WEN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Chemical Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

The intensive production and linear economy (LE) model utilisation in Malaysian poultry industry potentially lead to climate change. The negative impacts of climate change on poultry farming have attracted the attention of the government because it induces the need to have a transition from a LE model to a circular economy (CE) model. Determining the degree of circularity in an industry is fundamental for identifying the barriers and stimulating strategic planning to implement the CE model. This research measured the degree of circularity in the poultry industry with nitrogen life cycle assessment (LCA). The outline of the nitrogen flows in the Sankey Diagram showed that the industry operates in a combination of a LE model and a CE model. 42.34% of nitrogen was lost to the environment and 28.06% of nitrogen was recovered to generate electricity and produce animal feed meal and organic fertilisers. The nitrogen materials were mostly lost through ammonia emission, nitrate runoff as well as waste disposal and wastewater discharge without treatment. Issues with respect to ineffective implementation and governance mechanism, imbalanced industrial development, limited financial capacity from local financial institutions and lack of a supportive enabling environment have limited the progress of circularity improvement. In return, the recommendations such as the introduction of an appropriate governance structure and regulatory framework, closing the industrial development gap, budget reinforcement and enabling environment strengthening were proposed to solve the identified barriers and facilitate the poultry farmers in the economy model transition. Besides, the smart farming activities, namely feed ingredients substitution with palm kernel cake, by-products recycling in rendering plant, alum addition in beddings, Amolgera addition in litter pile and microalgae cultivation in wastewater and sludge treatment are revealed as the potential approaches to reduce the nitrogen loss as well as embracing a CE model in the poultry industry.

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LIST OF SYMBOLS / ABBREVIATIONS

CE	circular economy
CLFID	Crop, Livestock and Fishery Industries Division
DVS	Department of Veterinary Services
EM	effective microorganisms
GHGs	greenhouse gasses
KEDA	Kedah Regional Development Authority
KEJORA	Lembaga Kemajuan Johor Tenggara
LCA	life cycle assessment
LE	linear economy
MADA	Muda Agricultural Development Authority
MARDI	Malaysian Agricultural Research and Development Institute
MAQIS	Malaysian Quarantine Research and Inspection Services
MEQR	Malaysia Environmental Quality Regulation
PS	parent stock
R&D	research and development
SDGs	sustainable development goals
SMEs	small and medium scale poultry farmers
WWTPs	wastewater treatment plants

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CHAPTER 1

INTRODUCTION

1.1 Introduction

With the consumption per capita of poultry meat and eggs of 47.4 kg and 20.7 kg, poultry products are primary protein sources for the majority of Malaysian population (Department of Statistic Malaysia, 2021). Malaysian poultry industry is evolving throughout the years in meeting the increasing national demand for poultry products and became one of the most successful livestock segments in Malaysia.

Despite its role in supplying protein sources and promoting economic growth, the concentrated distribution of the industry engenders local and regional environmental disturbances. The environmental impacts are mainly caused by waste generation and material lost during farm operations. High concentrations of nitrogen compounds can be found in the generated waste and wastewater, threatening biodiversity with various degrees of nitrogen pollution. In addition, the high intensity of nitrogen inputs in the plantation and production of poultry feed has resulted in greenhouse gas emissions and climate change. In return, climate change reduces industrial productivity and increases the operation costs in poultry farming. The negative impacts on the poultry production chain have attracted the attention of the government because it appears the need to have appropriate nitrogen management systems and to compete for limited resources such as land and energy.

To tackle these problems, the government established the National Agriculture Policy to encourage poultry farmers to employ smart farming practices and technologies in their production chain. Besides, the integrated farming companies prepare sustainability statements in their annual reports as the initiatives for moving forward to sustainable production. The initiatives aim to increase the productivity of the industry and at the same time, balance the social and economic well-being of poultry communities and reduce the environmental impacts. Apart from that, the establishment of Twelfth

Malaysia Plan (2021 – 2025) has included the CE embracement as one of the initiatives to achieve long term sustainability.

The transition from a LE model to a CE model is a new trend due to the capitalisation of sustainable development concepts for business activities (Rocchi et al., 2021). The mechanism of the CE model in reducing resource dependency and balancing renewable resources is engaging in terms of natural capital preservation. High nitrogen content in poultry waste enables them to be recycled and converted into a new form of raw materials or products of higher value. The aspect is significant for the transition to a CE model from the economic and environmental perspectives. The government is launching and working towards the CE action plans in dealing with nitrogen waste management issues in the poultry industry. However, the current poultry productions in Malaysia are utilising a LE model. The farming operations consume high resources input. In return, it produces high waste outputs instead of being fully utilised. Determining the degree of circularity in the poultry industry is fundamental for identifying the barriers to embrace the CE model. Following this, the related parties could stimulate strategic planning and issue the countermeasures on the related matters.

1.2 Importance of the Study

The embracement of a CE model provides opportunities for the sector in solving the concerning material loss and environmental issues as well as achieving sustainable production. This study serves as guidance in measuring the industrial circularity and discovering the obstacles to embracing the CE in the industry. Based on this study, strategic planning could secure the potential strategies for circularity enhancement in terms of nitrogen management and improve industrial productivity through the transition from a LE model to a CE model. This study may be a clear direction for the Malaysian government and future works on the circularity of the poultry industry.

1.3 Problem Statement

The intensive poultry farming activities create wastes with high concentrations of nitrogen compounds. The improper management of poultry waste releases an excessive amount of nitrogen into the environment, causing diverse effects on the environment, public health and the economy. From the perspective of the CE, the nitrogen content in poultry waste can be recovered or transformed into new forms of materials such as fertilisers. The CE model reduces the dependency on non-renewable resources with the recirculation of the generated waste. Besides handling environmental issues, the concept can induce sustainable operations in the industry. The Malaysian government is working towards the CE action plans with the introduction of the Twelfth Malaysia Plan (2021 – 2025). However, without an appropriate methodology for assessing the degree of circularity, it will be difficult to formulate holistic solutions as the factors that contribute to a LE process are hard to be distinguished. Therefore, it is important to evaluate the extent of circularity of an industry in order to secure the potential strategies for circularity enhancement.

1.4 Aim and Objectives

This project aimed to enhance the circularity embracement in Malaysian poultry industry. The objectives of this project are listed as follows:

a. To evaluate the current degree of circularity in the poultry industry.
b. To identify the difficulties of embracing the circular economy in the poultry industry.
c. To propose recommendations for circularity improvement in the poultry industry.

1.5 Scope and Limitation of the Study

The scope of this project was to study the circularity of Malaysian poultry industry. This study accessed the degree of circularity and discovered the factors that limit the transition to a CE model. The limitations of the study are listed as follows:

1. The study focused on the nitrogen management of the chicken farming industry only.
2. The nitrogen assessment performed does not cover the farming practices of every poultry farm in Malaysia.
3. Some of the data for the nitrogen flows were not assessable through the local government’s statistical data.

4. The strategies and recommendations discussed are subjected to the economic and social development of the country.

1.6 Contribution of the Study

The methodology used in this project could serve as a guide for the Malaysian government to work towards the CE action plans. The government could form a board of CE committees to overview the circularity embracement with the assessment conducted in this project. The overview could make efficient decisions in formulating befitting settlements to strengthen the circularity in the country.

1.7 Outline of the Report

Chapter 1 introduces the general information about this project. The body of this report consists of Chapter 2, 3 and 4 where the chapters describe the approach and findings of this project. Chapter 2 covers the current status of the Malaysian poultry industry and a general introduction to the CE's concept. The industry's overview, namely farming activities, environmental problems and environmental control are included in the background studies in Chapter 2. Chapter 3 elaborates on the methodology used for the circularity evaluation. In the next place, the findings of the assessment are discussed in Chapter 4, along with the insights on this project. The conclusion and recommendations for this project are described in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Poultry Industry in Malaysia

The poultry industry in Malaysia has been expanding rapidly throughout the years. The industry produces 98.2% of the national demand for poultry meat and 113.5% for eggs (Department of Statistic Malaysia, 2021). Efforts have been taken by the government to emphasise the development of the industry by encouraging the usage of modern technology as well as the adherence to good farming practices (MAFI, 2011). The industrial activities are further strengthened by the launching of National Agrofood Policy 2.0 (2021-2030). According to the Ministry of Agriculture and Food Industries (2021), the policy aims to encourage greater adoption of sustainable consumption and production. As illustrated in Figure 2.1, the population of chickens and ducks has been increasing gradually to cope with the high demand for poultry products by local and foreign markets. As listed in Table 2.1, different poultry animal species are bred across the country as well.

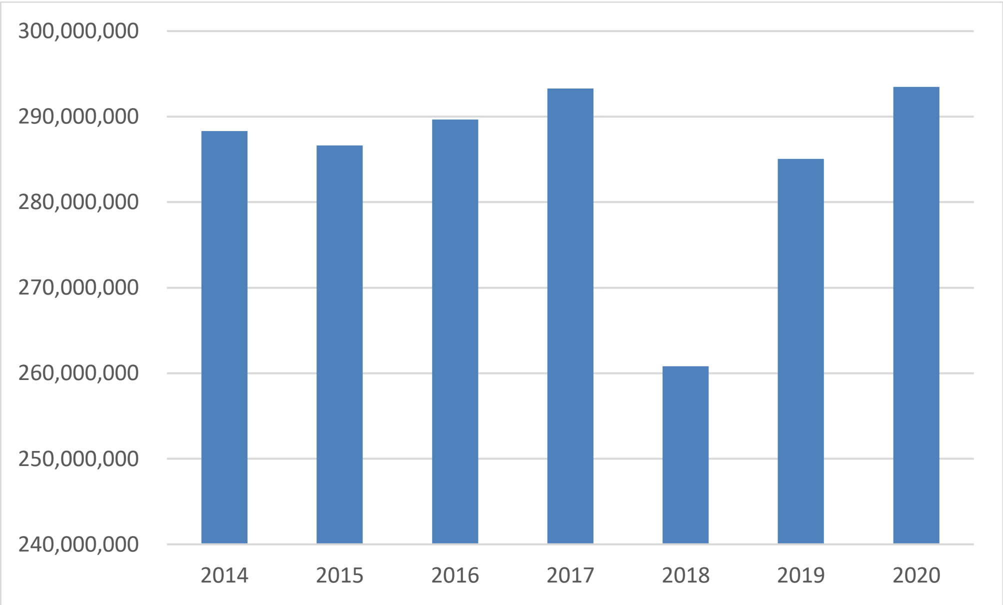


Figure 2.1: Chicken Population in Malaysia, 2014 – 2020 (Ministry of Agriculture and Food Industries Malaysia, 2020).

Table 2.1: Poultry Animals Population in Malaysia in 2019 (Department of Veterinary Services Malaysia, 2019).

Region	P. Malaysia	Sabah	Sarawak
Chicken	242 926 679	6 858 731	53 550
Duck	9 143 034	35 287 926	179 872
Goose	2 568	-	-
Quali	2 299 900	18 289	91 375
Pigeon	4 909	-	-
Silkies	286	-	-
Turkey	8 245	-	-
Ostrich	111	62	-
Guinea Fowl	332	-	-
Others	40	-	-

2.2 The Supply Chain of Poultry Industry

The poultry industry has several stages in the production chain. Figure 2.2 sums up the involvement of feed milling, animal breeding, animal farming and food processing in the production chain.

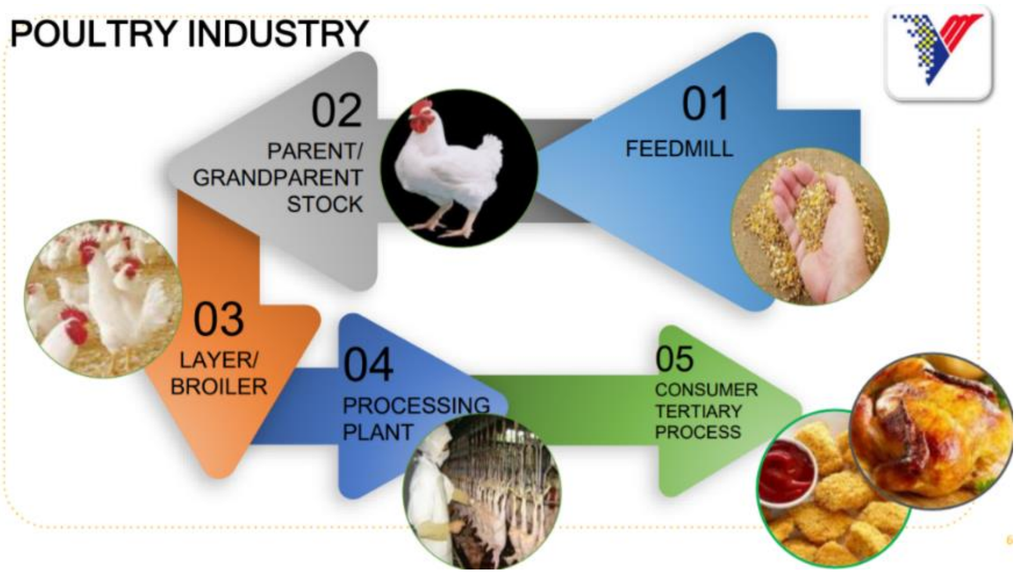


Figure 2.2: Poultry Industry Production Chain (Department of Veterinary Services Malaysia, 2019).

2.2.1 Feed Milling

Most integrated industry players have facilities to manufacture poultry feed with customised formulations. Feeds are specifically produced based on the needs and formulas of each rearing stage. In general, the ingredients such as corn, soybean meal and cereal grains are used in poultry feed's production. According to the Malaysian Feedmillers Association (2017), 85% of the ingredients are imported, while the rest is supplied by local agricultural products, including rice bran and palm kernel cake. Figure 2.3 illustrates a feed mill facility that is used for poultry feed production.

Figure 2.3: Feed Mill in Penang (Kami Farming Sdn Bhd, n.d.).

2.2.2 Breeder and Broiler Farming

Breeder farms produce fertilised eggs for broiler and layer breeding and supply. The eggs are collected and graded daily for uniform quality. After grading, the eggs are stored in trays located in a controlled environment for a period of days. The eggs are transferred to incubators with controlled temperature and humidity suitable for embryonic development (Let's Talk Chicken, n.d.). The hatching process takes around 21 days. The hatched chicks are vaccinated to be protected from common poultry diseases. The chicks are graded to ensure a uniform quality and distributed to rearing farms. The broilers are ready to be marketed at about 30 to 42 days when they weigh around 2.3 kilograms. The broilers are transported to the abattoirs and processing plants for further processing.

There are 10 grandparent stock farms in Malaysia supplying the parent stock (PS) chicks to the 106 PS farms across Peninsular Malaysia (Federation of Livestock Farmers' Associations of Malaysia, 2020). The male and female PS chicks are raised separately due to the difference in their growth rates and nutritional requirements. The PS hens and roosters will be moved to the breeding barns as illustrated in Figure 2.4 once they have reached the mating requirements to breed the commercial broilers for the market. Cobb and Ross' breeds are widely used in Malaysian broiler farms as the breeds are highly profitable. Table 2.2 sums up the population of broiler and breeder in 2019.

Figure 2.4: Broiler Breeder Farm in Perak, Malaysia (Dingdings Poultry, n.d.).

Table 2.2: Population of Broiler and Breeder in 2019 (Department of Veterinary Services Malaysia, 2019).

Region	Chicken		
	Broiler	Breeder	Local Fowl
P. Malaysia	145 049 672	13 353 781	10 633 513
Sabah	3 935 600	470 231	-
Sarawak	30 907 933	858 316	750 647
Total	179 893 205	14 682 328	11 384 160

2.2.3 Layer Farming

The operation of layer farm is similar to broiler farm. The only differences are the breed of the chicken and the commercial product. Lohman Brown and Hisex Brown are the main breeds for eggs production (Federation of Livestock Farmers' Associations of Malaysia, 2020). The layers are raised in cages to lay eggs at the weeks of age of 18-78.

There are 11 layer PS farm companies and 204 layer farms in Malaysia. Their population and production are tabulated in Table 2.3. The eggs produced in the farms are collected and marketed through wholesalers as fresh in-shell eggs. On the other hand, a relatively small amount of the eggs is sent to the processing plants to produce different forms of liquid eggs based on the requirements of the industries.

Table 2.3: Layer Farm Production in 2019 (Department of Veterinary Services Malaysia and Ministry of Agriculture and Food Industries Malaysia, 2019).

Region	Layer	Eggs (million)
P. Malaysia	73 880 013	10 908
Sabah	2 452 900	
Sarawak	2 771 030	
Total	79 103 943	

2.2.4 Animal Slaughtering and Food Processing

Primary food processing starts with animal stunning and slaughtering. Feathers, offal and blood are collected for material recovery or disposal. The carcasses are cleaned to remove the residues and packed for the market or sent for further processing. In the secondary food processing, the poultry carcasses are separated into parts or separated from bones. The operations can be carried out with mechanically separation and deboning (Kiepper, 2003). The tertiary food processing processes the deboned meat into value-added food products for consumers' convenience. It involves smoking, marination and the production of ready-to-eat and ready-to-cook products.

Additional ingredients and flavours are added to the raw meat to enhance the taste of the products and reduce consumer' food preparation time.

2.3 Environmental Impacts of Poultry Industry

The poultry industry has given a rise to environmental concerns at regional and global scales. Different concentrations of pollutants are emitted throughout the poultry supply chain. Intensive production of feed ingredients and poor waste management in poultry farming and food processing are the main sources of environmental problems.

2.3.1 Local and Regional Environment

The environmental problems observed at the poultry farms, abattoirs and the region around the production site tend to have larger impacts. The impacts are directly imposed on poultry production workers and neighbouring area residents.

2.3.1.1 Soil Pollution

Pollution of soil is mainly caused by the addition of nutrients in poultry feed, excessive application of manure, and poor manure management and storage. The addition of nutrients and heavy metals in poultry feed could increase the productivity of poultry production by preventing disease, increasing egg production and improving the weight gain and feed conversion (Yu and Fang, 2019). However, the poultry animals could only absorb up to 15 per cent of the nutrients they ingest (Gerber, Opio and Steinfeld, 2007). The indigested nutrients are therefore excreted in manure, one of the potential materials to produce organic fertiliser. Even so, when it is applied more than the capacity of the soil, it becomes a source of emissions. The direct application of high nutrient content manure on soil without pre-treatment leads to the accumulation of nitrate, phosphate and heavy metals content in soil (Li, 2017). In return, the acidification of soil affects its properties, leading to the declination of soil quality and disrupting agricultural production. Besides, leaching and runoff of the contaminated soil give rise to contamination of surface water and groundwater resources.

2.3.1.2 Water Pollution

The operations of food processing plants and improper disposal of poultry manure and carcasses contribute to water quality problems. The hygiene and quality control in daily operations of food processing plants require high water usage. Conversely, the processes such as slaughtering, de-feathering, disinfecting and cooling discharge a large amount of wastewater into the environment, polluting the surface water (Juliza Abu Bakar et al., 2019). The wastewater contains large quantities of biodegradable organic materials, including blood and faeces (Maheshwari, 2013). These materials can decrease the dissolved oxygen in surface water significantly. In addition, the enrichment of macronutrients such as nitrogen, phosphorus and potassium in wastewater causes the eutrophication of water bodies (Li, 2017). Excessive algae bloom on surface water would induce the death of aquatic life due to oxygen deficiency. Table 2.4 exhibits the nutrient composition of the effluent discharged from a poultry processing plant in Malaysia.

Table 2.4: Nutrient Composition of Poultry Processing Plant Effluent and Malaysia Environmental Quality Regulation (MEQR) (Nik Norsyahariati and Sandra Chinenyenwa, 2018).

Parameters	Plant Effluent	MEQR (2000)
pH	6.74 – 7.62	5.5 – 9.0
Temperature (°C)	23.8 – 28.7	40
Colour (PtCo)	10 200 – 19 440	300
Turbidity (NTU)	319 – 810	5
TSS (mg/L)	254 – 850	100
TDS (mg/L)	495 – 1563	1 000
COD (mg/L)	2 080 – 8 345	100
BOD (mg/L)	727 – 2 960	50
NH_3-N (mg/L)	58 – 122	1.5
Microbes (CFU/1000 ml)	1.2×10^8	5 000

2.3.1.3 Air Pollution

The processes in feed milling, namely feed cleaning, scattering, storage and transportation produce lots of dust. Dust pollution is dependent on the climate, including humidity, wind speed and wind direction. Dust pollution leads to the formation of smoke, fog and acid rain, which could cause a significant decrease in atmospheric visibility and soil corrosion. During migration, dust can also adsorb harmful substances in the atmosphere, such as heavy metals, organic wastes and pathogens that could threaten animals' health (Wang, 2018).

The pollution of the atmospheric environment around the poultry farms or abattoirs mainly comes from the decomposition of waste products such as bedding materials, feathers, manure and animal carcasses. The emission of odours depends on the frequency of poultry farm cleaning and manure storage and management. The odorous gas contains high concentrations of toxic and harmful compounds such as ammonia, nitrogen oxides, volatile organic compounds, sulphide and methane. The gases will adversely affect the life of the surrounding population when they accumulate to a certain level (Yu and Fang, 2019). Other than that, the odour from the facilities attracts pests like flies, mosquitoes and rodents that can transmit diseases including cholera, malaria and dengue fever (Maheshwari, 2013). The emission sources of the air pollutants in the poultry industry are listed in Table 2.5.

Table 2.5: Emission Sources of Air Pollutants in Poultry Industry (Mitroi et al., 2021).

Air Pollutants	Source of Emission
Ammonia	Manure storage and Poultry farms
Methane	Manure storage and Poultry farms
Nitrous Oxide	Manure storage and Poultry farms
Nitrogen Oxide	Farm heating system
Carbon Dioxide	Poultry farms, Transportation, Combustion
Hydrogen Sulphide	Poultry farms, Manure storage and Manure application on soil
Dust	Feed production and Feed storage
Carbon Monoxide	Combustion

2.3.2 Global Environment

The high energy input in the poultry industry has resulted in greenhouse gas (GHG) emissions and climate change. The GHGs are emitted from the burning of fossil fuels, poultry farming, animal slaughtering and poultry feed production. The augmentation of feed consumption and production has changed the global land use by expanding the cropland and intruding the natural habitats with deforestation (Gerber, Opio and Steinfeld, 2007). The changes in land use increase the emission of GHGs and lead to climate change. To some extent, deforestation in natural habitats has caused alterations in the water cycle and soil erosion. Aside from fossil fuels combustion and feed production, manure handling and storage induce the emission of nitrous oxide and methane as well. Nitrous oxide is formed through the decomposition and the oxidisation of ammonia from manure deposited in soil (Tabler, Wells and Moon, 2021). Table 2.6 compiles the GHGs emission factors in the poultry industry.

Table 2.6: GHGs Emission Factors in Poultry Industry (Syakira Afiqah Suffian et al., 2018).

Sources	Carbon Dioxide Emission	Methane Emission	Nitrous Oxide Emission
Transportation	2.65 kg CO_2/liter	0.0333 g CH_4/miles	0.0134 g N_2O/miles
Water	0.8 kg CO_2/m^3	1.25 g CH_4/m^3	0.125 N_2O/m^3
Feed Production	3.2 kg CO_2/kg	264 g CH_4/ton	35 g N_2O/ton
Electricity	1.0 kg CO_2/kWh	0.0109 kg CH_4/MWh	0.0083 kg N_2O/MWh
Manure	4.2 kg CO_2/kg	318 g CH_4/ton	42 g N_2O/ton
Beddings	1.64 kg CO_2/kg	126 g CH_4/ton	63 N_2O/ton

2.4 Environmental Control in Malaysian Poultry Industry

As the wastes generated in the poultry industry are the main constituents in causing pollution and turning the surroundings of the poultry farms into breeding grounds for pests. Irregular waste management results in the depletion of life qualities of the residents around that area. Hence, appropriate waste management systems in poultry farms are very important. The Agrofood policy encourages the usage of green technology as a step towards environmental friendly farming. The well-being of society and the environment can be accomplished by fulfilling pollution prevention measures in livestock systems. The method of waste treatment is dependent on the type of waste obtained. Table 2.7 shows the waste treatment mechanism based on the form of the waste.

Table 2.7: Waste Treatment Mechanism based on the Form of the Waste (Department of Veterinary Services Malaysia, 2019).

Form of Waste	Waste Source	Waste Handling Method
Solid	• Food spills • Livestock manure	• Extraction • Composting
Wastewater	Waste water from cleaning activities that contains • Food • Livestock manure	• Solid separator • Composting • Sediment pond • Pool system • Biological treatment

2.4.1 Effective Microorganisms (EM)

Effective microorganisms (EM) are a mixture of 125 species of microbial inoculums in a solution of lactic acid bacteria that maintains a pH of 3.0 to 3.5 (Nurzillah, Norfadzrin and Haryani, 2018). EM application speeds up the decomposition of organic matter in wastewater treatment, composting and smell reduction by inducing a high metabolic capacity. After over a decade of application, the method is claimed to have no adverse effects on plants, animals, humans and the environment. Usually, the microbes are mixed in the poultry food, drink or waste processing pond. As a result, livestock waste can be turned into non-toxic products as well as reducing the rate of water pollution and odours released into the environment. The active microbes can be genetically modified effortlessly to survive in various mediums and grow without being affected by climatic conditions. Its growth is easily controlled as the biochemical reactions are managed by the microbes' enzymes. Yet, the application of EM requires constant maintenance. Figure 2.5 illustrates the EM that is used in the poultry industry.

Figure 2.5: Effective Microorganisms (Casuncad, 2013).

2.4.2 Dietary Formulation Methods in Poultry Feed

With the nutrient absorption of 35%, the rest of the ingested nutrients went into waste and excreted in manure. A proper dietary formulation for poultry animals is an effective way in lowering the rate of ammonia emissions to the environment. As discussed by Sheikh et al. (2018), a reduction in 3 – 5% of dietary protein could reduce more than 60% of total nitrogen excretion from poultry animals. The reduction of nutrients uptake and the poultry animals' needs fulfilment are made at the same time to reduce the wastage of nutrient sources and maintain the poultry animals' growth rates (Zaini and Lukman, 2015). Balanced nutrition with the formulation of a proper diet produces a good digestive rate and a higher feed conversion ratio.

2.4.3 Composting

Poultry manure is one of the raw materials in composting. Compost is widely used as an organic fertiliser in the agriculture field due to its durability. The decomposition of the manure facilitates the crops to absorb nutrients. It provides ventilation to the roots by improving the sandy soil condition. Earnings from poultry waste compost can generate additional income for the poultry farm operators and maintain a pollution-free environment simultaneously.

Composting is influenced by moisture content, carbon-nitrogen ratio and aeration. Therefore, composting needs to be carried out in the right way to produce good quality compost as shown in Figure 2.6. The suitable moisture content for composting is between 40 – 60%. If the litter pile is too dry, water shall be added. If it is too wet, the occurrence of anaerobic conditions with a sour smell is possible. The duration of composting can be shortened by 2 to 4 weeks using EM. Besides EM, the vermicomposting method using worms is also useful in making compost. The lower the carbon-nitrogen ratio of the poultry waste material, the shorter the time required for composting. Ventilation is necessary to supply oxygen to aerobic microorganisms. The ventilation can be made by periodically turning the compost pile and pumping air into it with mechanical machinery.

Figure 2.6: Poultry Manure Compost (Zen Xin Agriculture Sdn Bhd, 2021).

2.4.4 Biogas System

Poultry waste applies the biogas system as its pollution control. A biogas system is an anaerobic decomposition of organic matter in a digestive tank. The method is mitigation in dealing with greenhouse gases emissions that causes global warming. The main components in the biogas are methane (60%) and carbon dioxide (40%). Methane gas emissions to the environment can be controlled by turning them into renewable energy sources such as fuel and electricity (Nurul Aini et al., 2018). It could reduce electricity utility cost and generate side income for the poultry farmers. However, the raw biogas produced contains hydrogen sulphide compound that is corrosive. It tends to reduce the lifetime of the combustion engine. Moreover, the effluent coming out of the biogas system does not reach the water quality level set by the Department of Environment. The effluent and raw biogas produced must undergo treatment before being used for other purposes or discharged into public drainage. Sediment deposited in the anaerobic tank can be removed and dried to conceive fertiliser for agricultural use.

Malaysia has a biogas plant with a capacity of 22,000 m^3 located in Johor specialised in handling poultry waste from a population of 1.2 million laying hens (Nurul Aini et al., 2019). The plant generates electricity for domestic use, such as ventilation and heating that operate 24 hours per day. The biogas plant has a covered lagoon made of high-density polyethylene plastic sheet used as a gas holder as shown in Figure 2.7.

Figure 2.7: Poultry Farm Biogas Plant in Johor (Environmech Sdn Bhd, 2017).

2.5 Nitrogen Chemistry

Nitrogen appears as a colourless, odourless, non-combustible and non-toxic inert gas at standard conditions. It is an abundant element on Earth, composing 78.09 per cent of the atmosphere by volume (Lumen Learning, n.d.). It could be found in all living things and fossil fuels. In poultry industry, the nitrogen compounds of poultry manure are in the form of ammonium, nitrate and organic nitrogen (Chastain, Camberato and Skews, 2003). The improper management of the poultry manure will eventually release the compounds into the environment.

2.5.1 Properties of Nitrogen

Nitrogen is a trivalent compound with 5 electrons in its outer shell. It has an atomic mass of 14.007 g/mol (Lenntech, n.d.). The nitrogen molecules have a strong triple bond between atoms that contains 226 kcal/mol of energy. The triple bond energy will be released and shown explosive properties when nitrogen gas is formed in numerous reactions (Lumen Learning, n.d.). The strong bond between nitrogen atoms causing difficulties for the compound to react with other compounds.

Ammonia is a thermodynamically stable nitrogen hydride in which it consists of nitrogen and hydrogen with the formula of NH_3. Generally, it exists in the form of colourless gas with a pungent smell. Ammonia is soluble in water as it forms hydrogen bonds with water molecules to give a weak basic solution. Ammonia is synthesised via the reaction between nitrogen gas and hydrogen gas in the Haber-Bosch process. It can serve as starting materials for producing various nitrogen compounds such as nitrogen oxides, nitric acid and nitrates (Sanderson, 2020). Ammonia can be naturally found in soil, air and vegetation. It came from the human body and excreted as urea after breaking down protein into amino acids (New York State Department of Health, 2011). In nature, ammonia is produced in the bacterial processes in soil during the decay of the dead plants, animals and animal wastes. In poultry industry, poultry manure consists of ammonium and ammonia. The volatilisation of ammonia occurs on the surface of manure whenever the manure exposed to air (Chastain, Camberato and Skews, 2003). It could happen even while in the barn, in storage and after land application.

2.5.2 Nitrogen Content in Poultry Waste

Poultry waste consists of manure, feather, bedding material and spilt feed. Within 30 to 42 days of the feeding period, a total of 3.5 kg/head of manure is produced. The nutrient content of poultry waste varies with the nutrient digestibility, animal age, beddings materials and facility cleaning frequency.

In general, poultry waste contains the following compounds listed in Table 2.8.

Table 2.8: Nutrient Content of Poultry Waste (Department of Veterinary Services Malaysia, 2019).

Type of Waste	Fresh	Dried
Nitrogen, N (%)	0.9	4.5
Phosphorus, P_2O_5 (%)	0.5	2.7
Potassium, K_2O (%)	0.8	1.4
Organic Matter Content (%)	30.7	58.6
Moisture Content (%)	64.8	9.2

Nitrogen compound is one of the pollutants that causes some environmental concerns, such as climate change. Four forms of nitrogen are identified in poultry waste, including complex organic nitrogen, labile organic nitrogen, ammonium and nitrate. The complex forms of organic nitrogen have the constituents of feathers, bedding materials, spilt and undigested feed. The uric acid and urea in the poultry waste are labelled as labile organic nitrogen. Uric acid in the fresh manure hydrolyses rapidly to urea by the uricase enzyme, while urea is subsequently hydrolysed to ammonium by the urease enzyme (Bolan et al., 2010).

$$2C_5H_4O_3 + 2H_2O + O_2 \xrightarrow{uricase} 2C_4N_2H_2O_4 + 2CH_4N_2O$$

$$CH_4N_2O + H_2O \xrightarrow{urease} 2NH_3 + CO_2$$

$$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$$

Nitrate is formed through the oxidation of ammonium ions during aerobic composting. Besides, the emission of nitrous oxide (N_2O), which is a type of greenhouse gas that can be produced through the nitrification and denitrification of the nitrogen compounds in the poultry manure (Dunkley, 2014).

2.5.3 Negative Effects of Excessive Nitrogen

Transcended emission of nitrogen to the environment for the past several decades has diverse and far-reaching issues on the public health, environment and economy. The challenges posed by climate change are affecting the poultry industry with the loss of productivity and increased operating costs. Regarding productivity, high concentrations of ammonia in poultry farms have adverse effects on growth rate and health of poultry animals. Exposure to excessively high levels of ammonia concentrations causes discomfort for the animals. Trials have proven that high concentrations of ammonia could influence animals' immunity by altering their organ functions (Karimi, 2019). Following this, stocking density in the farms may need to be reduced. Figure 2.8 portrays the negative effects of high ammonia concentration on poultry animals.

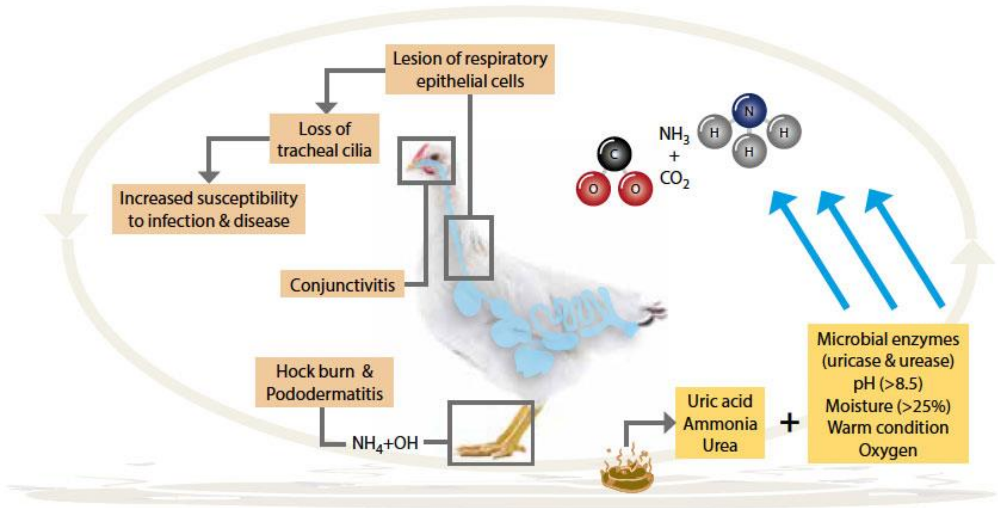


Figure 2.8: Negative Effects of High Ammonia Concentration on Poultry Animals (Karimi, 2019).

In addition, the operating costs in poultry farming activities are likely to increase for the need to reduce the risk of heat stress on birds and maintain optimum building temperatures (The Poultry Site, 2009). Increasing investment is required in ventilation, cooling and humidity control. Building infrastructure and maintenance plans have to be more sustainable, with greater investment to accommodate the extreme weathers.

Natural nitrogen proportion on Earth is changing drastically due to human activities such as the application of nitrate manures and large-scale discharge from industries. The alterations are influencing the movement of the compounds in the nitrogen cycle and gradually increase the nitrate concentrations in the environment. The abundant amount of nitrogen in the atmosphere produces pollutants such as ammonia and ozone, damaging the ability to breathe, limiting visibility and harming the health of plants, soils and waterways (United States Environmental Protection Agency, 2019). Besides, combustion processes can also enhance the nitrate and nitrite supplies due to the reactivity of nitrogen oxides (USGS, n.d.). Figure 2.9 outlines the transitions of the nitrogen compounds and the major processes involved in the nitrogen cycle.

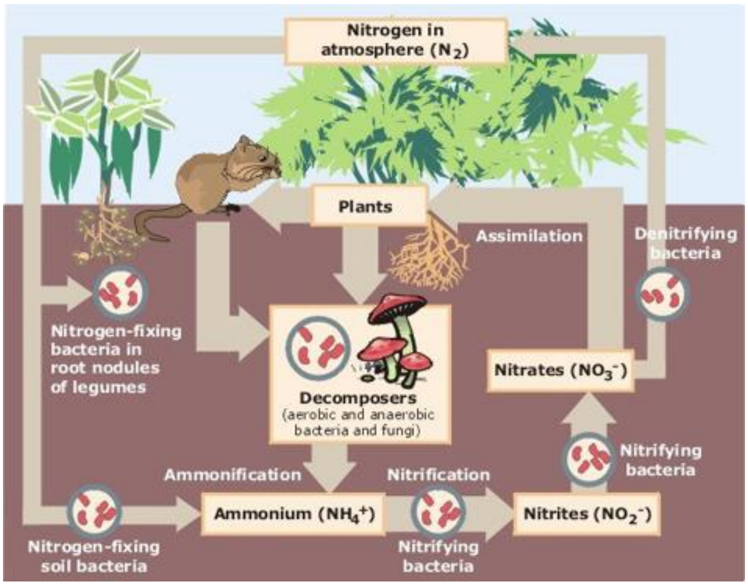


Figure 2.9: The Nitrogen Cycle (Lumen Leraning, n.d.).

Excessive nitrogen-containing nutrients in water bodies induce a faster algae growth than the ecosystems can handle. The overgrowth of algae could harm the water quality, food resources and habitats by reducing the concentration of oxygen in the water, leading to the death of aquatic lives. Algae blooms compose toxins and bacterial growth that are harmful to human and animal species. The consumption of contaminated water and aquatic foods gives rise to various health effects on humans and animals. For instance, the reduction of oxygen transport in blood, problems in the thyroid gland and

Vitamin A shortages (Lenntech, n.d.). Besides, the inhalation of high concentration ammonia will result in respiratory distress or respiratory failure.

Nitrogen pollution affects the global economy indirectly by impacting property values, tourism and recreational businesses and the sectors that depend on clean water bodies (United States Environmental Protection Agency, 2019). Nitrates and algae blooms in drinking water sources require high treatment costs to clean up the polluted water bodies. Moreover, the tourism industry loses income from recreational activities as the water bodies have been affected by pollution and algae blooms. The pollution can also impair the fishing and shellfish industries as it contaminates or kills aquatic lives. Waterfront property values have declined drastically because of unpleasant sight and odour of algae blooms.

2.6 Sustainability through Poultry Industry

Achieving sustainability in poultry industry requires poultry production systems that focus on the management and conservation of resources to satisfy the current human needs without affecting the chances for future generations to meet their needs (Jayaraman et al., 2014). Sustainability encourages businesses to balance their environmental, economic and social interests for long-term gains. With the increasing awareness of the environmental issues, business firms have developed sustainability goals by reducing emissions and energy usage, sourcing fair-trade products and ensuring the waste produced is disposed of in an adequate way (Grant, 2020).

2.6.1 Sustainable Development Goals

The United Nations Member States have adopted a plan for improving lives and achieving a better future for all. There is a collection of 17 interlinked Sustainable Development Goals (SDGs) applied to all nations. The SDGs have been very inclusive with the involvement of governments, businesses and societies as the fulfilment of these ambitions will take exceptional efforts by all sectors. The global meat industry is one of the major contributors to environmental concerns and climate change due to its intensive production. However, many are experiencing hunger, malnutrition, poverty and are unable to access sufficient protein sources. The governments have agreed to achieve the SDGs as an effort to handle the global problems, at the same time, driving forward economic prosperity for all (Johnson, 2018). In 2019, the International Poultry Council (IPC) in partnership with the United Nations Food and Agriculture Organization (FAO) has validated its commitment to transforming the environmental and sustainable practices of the global poultry industry to deliver benefits for both the planet and people globally (International Poultry Council, 2019). The poultry industry is prioritising five of the SDGs shown in Figure 2.10 which include Zero Hunger (SDG 2), Good Health and Well-Being (SDG 3), Quality Education (SDG 4), Industry, Innovation and Infrastructure (SDG 9) and Climate Action (SDG 13). The global poultry industry's targets and actions tabulated in Table 2.9 are set to work towards meeting the SDGs.

Figure 2.10: Poultry Industry SDGs Commitment.

Table 2.9: Poultry Industry's Actions and Targets in Achieving SDGs (International Poultry Council, 2019).

SDGs	Actions/Targets
SDG 2: Zero Hunger	**Building Capacity for High Quality and Sustainable Production:** Poultry industry can reduce hunger by providing sustainable, nutritious and healthy food. The stakeholders are focusing on the improvement of nutritional strategies and balanced breeding to maximise feed utilisation considering consumer and producer demands.
SDG 3: Good Health and Well-Being	**Promoting Poultry Products as a Healthy Choice and Sharing Good Production Practices:** The products of the poultry industry contribute to good human health by adopting biosecurity technologies and precision livestock farming across the entire production chain to manage health issues and reduce disease risks.
SDG 4: Quality Education	**Sharing Good Practices and Promoting Sustainable Production:** High quality education is beneficial in sustainable poultry production chain and consumption of poultry products through the regional associations in developing and sharing the best poultry management and manufacturing practices to avoid food waste and health related concerns.
SDG 9: Industry, Innovation and Infrastructure	**Supporting Innovative and Sustainable Industrialisation:** Poultry industry is growing through innovation and sustainable industrialisation. The stakeholders are prioritising the improvement in infrastructure that delivers higher efficiency and sustainability.
SDG 13: Climate Action	**Reducing Greenhouse Gas and Other Emissions:** Poultry industry is combating climate change by reducing greenhouse gases emissions and addressing climate impacts through the stakeholders' support on the latest innovations such as low-emission technologies.

2.6.2 Aspects of Sustainability in Poultry Industry

It is challenging to tackle every sustainability aspect of poultry industry because they are interlinked with each other and the developments of other sectors. Sustainability is not just environmentalism, issues such as social equity and economic development are emphasised as well. The principle of sustainable development aims at increasing poultry productivity to meet future demands at the same time, balancing the social and economic well-being of poultry communities and the reduction of environmental impacts. Since 2016, a narrative sustainability statement that includes the risks and opportunities of the aspects of sustainability is mandatory in the annual report of all public listed companies in Bursa Malaysia (Chong, Dayana Jalaludin and Lian, 2019). The sustainability statements exhibit poultry farms' initiatives moving forward to sustainable production in terms of the aspects of sustainability.

2.7 Circular Economy

The waste disposal issues have been labelled as global problems. In a LE model, unusable products and by-products are viewed as wastes and immediately disposed of. The disposal of wastes without utilising them as another form of resource might cause economic loss due to the necessity of purchasing new resources for the production of new products (Ruth Nattassha et al., 2020). Sustainable development needs innovative changes in the traditional economic model adopted in societies and businesses. The introduction of a CE model is important to improve supply chain process efficiency and waste management performance.

2.7.1 Introduction of Circular Economy

A CE model is an economic system designed for the model of production and consumption to rebuild overall system health (Het Groene Brein, n.d.). Every layer in the economy is interlinked with each other in which the consequences must be taken into account before making choices as the actions made are influencing the value chain. CE is recognised as a concept that is benefiting businesses, society and the environment at all scales. The concept emphasises the preservation of resources values in the form of energy, labour and materials. Products are enhanced with good quality materials for their durability as well as maintenance and repair to circulate them in the economy and remove the need to produce new products (Youmatter, 2020). The utmost goal of CE is to preserve the natural capital by decreasing resource dependence and balancing renewable resource flows. The wastes and unusable products are regenerated into their original form or a new form of resources as much as possible to retain their values and prolong their life cycle. By following this, the number of wastes disposed to the environment can be minimised and lead to a more sustainable system. The product cycles that employ the CE model are different from disposal and recycling where embedded energy and labour are lost during the recycling process (Youmatter, 2020). Recycling reduces the products back to their origin materials allowing them to be remade into new products. While recycling is certainly important in actualising CE, it requires costs to remake the products entirely and it is inevitable to material losses due to the lower value process (Ellen MacArthur Foundation, 2017). Despite the positive impact of CE, the application of the model in the supply chain increases the operating cost. The cost may be reasonable based on the effectiveness of improving the environmental performance from case to case.

2.7.2 Circular Economy and Linear Economy Comparison

As demonstrated in Figure 2.11, a CE model works differently from a LE model in the way on how the value of the materials is created or maintained. In LE, the raw materials are refined into products and discarded as wastes when they are unusable (Ward et al., 2016). LE's value is emphasising mass production and marketing (Youmatter, 2020). In terms of sustainability, the focus of LE is sought in eco-efficiency that minimises the ecological impact and gets a satisfactory output at the same time. In CE, there are closed loops in the cycles of raw materials. CE applies Reduce, Reuse and Recycle (3R) approaches through minimising the usage of resources and maximising the reuse of products and raw materials (Het Groene Brein, n.d.). The value of CE is created based on the preservation of resources and sustainable production. The sustainability within CE is focusing on increasing the ecoeffectiveness of the system where it strengthens the ecological, economical and societal systems.

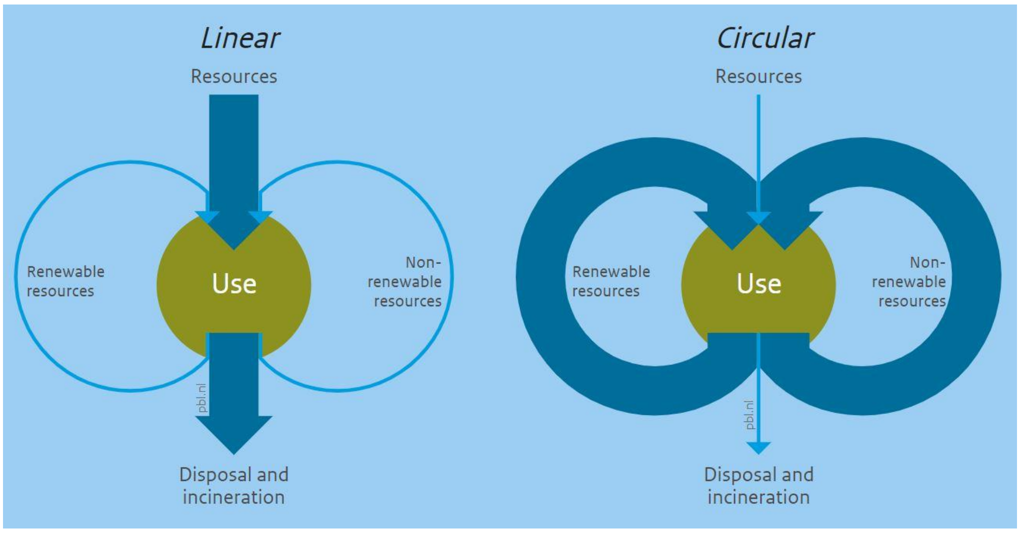


Figure 2.11: Linear and Circular Economy Raw Materials Preservation (PBL Netherlands Environmental Assessment Agency, 2019).

2.7.3 Circular Economy Cycles

In general, material cycles produce minimal waste in which the materials can be reused repeatedly in a high-quality way. Producers collect unusable products and repair them for new purposes. If a material goes through lesser processing steps for reuse, the higher the quality of the processed material will be (Het Groene Brein, n.d.). Figure 2.12 displays that the CE has two cycles in materials circulation, a bio-cycle and a techno-cycle. Due to their difference in the material process, it is crucial to separate the organic and technical materials after using them. Organic materials are consumable and can safely re-enter the ecosystem. Consumption happens only in the bio-cycle. The organic materials are intended to go through one or more cycles where the materials biodegrade over time through biological processes such as anaerobic digestion and composting to regenerate renewable organic raw materials and restore the embedded nutrients to the environment (Youmatter, 2020).

In comparison, technical materials are synthetic materials that cannot re-enter the environment. Instead of being consumed, the materials are used and recovered. In the techno-cycle, proper management of the technical materials is essential as the materials have limited availability and cannot easily be regenerated (Het Groene Brein, n.d.). Technical materials are continuously cycled through the system to recapture their values through the recovery of the products, components and materials by repairing, remanufacturing or recycling (Ellen MacArthur Foundation, 2017).

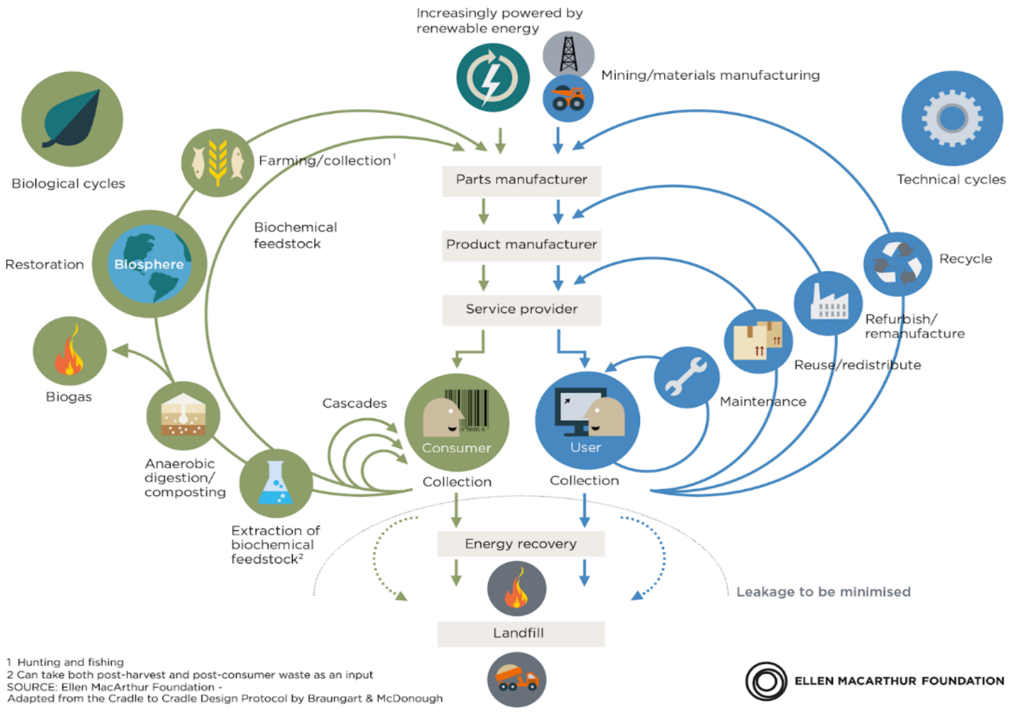


Figure 2.12: Bio-cycle and Techno-cycle (Ellen MacArthur Foundation, 2017).

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Project Flow

As illustrated in Figure 3.1, the research started with background studies to determine research objectives and select appropriate study methods. The project was schemed to:

a. Perform analysis on the current degree of circularity in Malaysian poultry industry.
b. Describe the shortcomings and barriers to embracing CE in Malaysian poultry industry.
c. Propose suggestions for improving the circularity in Malaysian poultry industry.

With the aim of measuring the current degree of circularity in Malaysian poultry industry, a life cycle assessment (LCA) of nitrogen was carried out by computing the nitrogen flows in a Sankey Diagram. The inventory analysis collected the data needed for the quantification of nitrogen flows. Nitrogen flows of the supply chain activities were composed into a Sankey Diagram to evaluate the extent of circularity in the industry. Outcomes such as the linear economy factors and CE embracement barriers were further discussed in the report along with the proposal of holistic solutions.

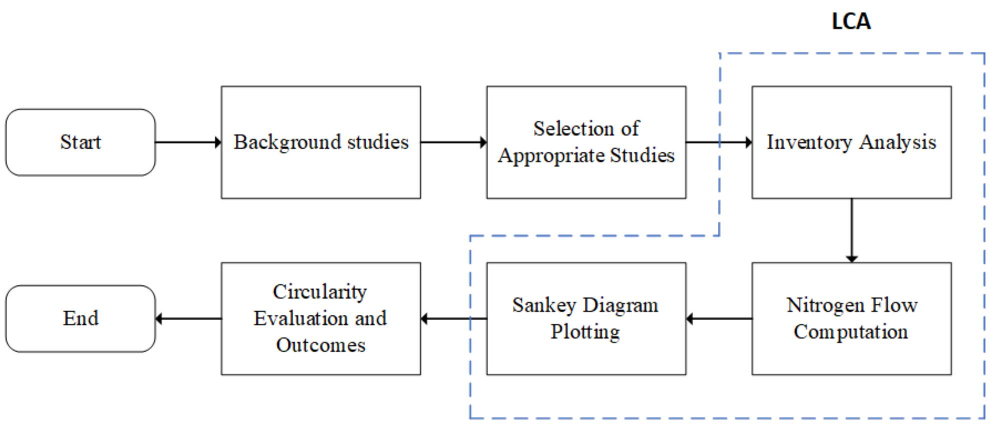


Figure 3.1: Project Flow Chart.

3.2 Background Studies

Background studies were carried out to ascertain the current status of Malaysian poultry industry and the government's plan to embrace a CE model. As shown in Figure 3.2, the components of the poultry industry's overview, including supply chain, environmental issues and pollution control measures were studied as well. By going through the background studies of the industry, the scope of the project was determined based on the exposure to the industry's matters.

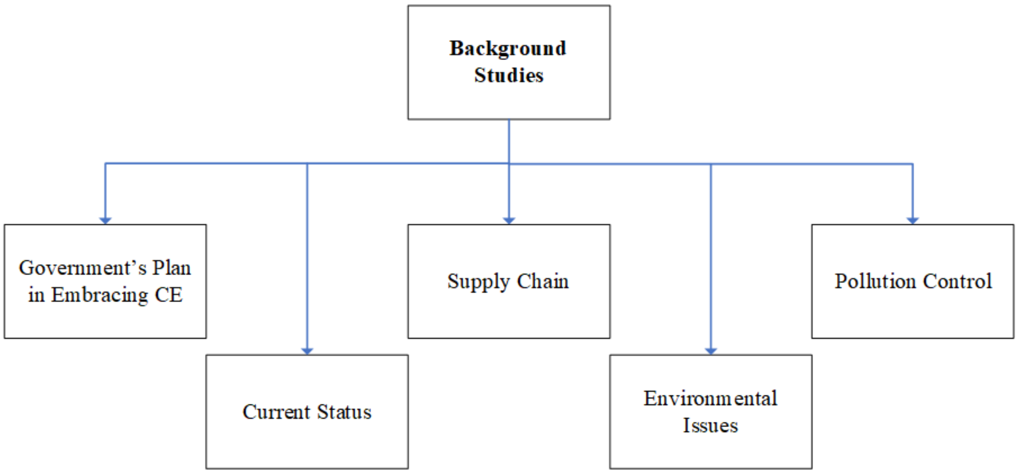


Figure 3.2: The Components in Background Studies.

3.3 Selection of Appropriate Studies

The LCA of nitrogen was selected as the methodology to study the degree of circularity in the poultry industry. The study started with an inventory analysis by performing a farm operations survey and literature review of sustainability statements and research papers. The nitrogen flows were quantified and plotted in a Sankey Diagram.

3.4 Life Cycle Assessment of Nitrogen

The terminology of nitrogen LCA involved inventory analysis, nitrogen flow computation and Sankey Diagram plotting. The terminology is further elaborated in Sections 3.4.1 to 3.4.3.

3.4.1 Inventory Analysis

The data necessary to quantify the nitrogen flows in the poultry industry's supply chain was collected and analysed. As portrayed in Figure 3.3, the supply chain was divided into 4 divisions. Each division has its own set of nitrogen flow nodes, including inputs, outputs and intermediate process as shown in Figure 3.4. The nitrogen flow nodes were connected based on the practices adopted by the poultry farmers. Their practices were assessed through their sustainability statements. Besides, an additional survey on their daily farm operations was conducted by sending enquiry e-mails to reduce the error of nitrogen flow nodes.

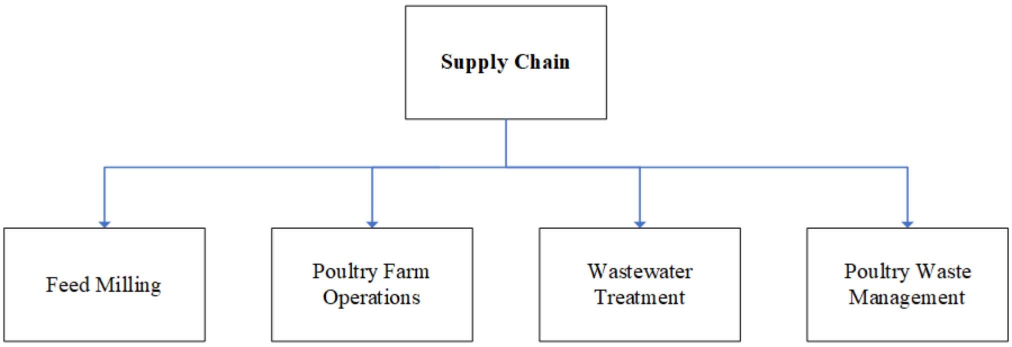


Figure 3.3: Poultry Industry Supply Chain Divisions.

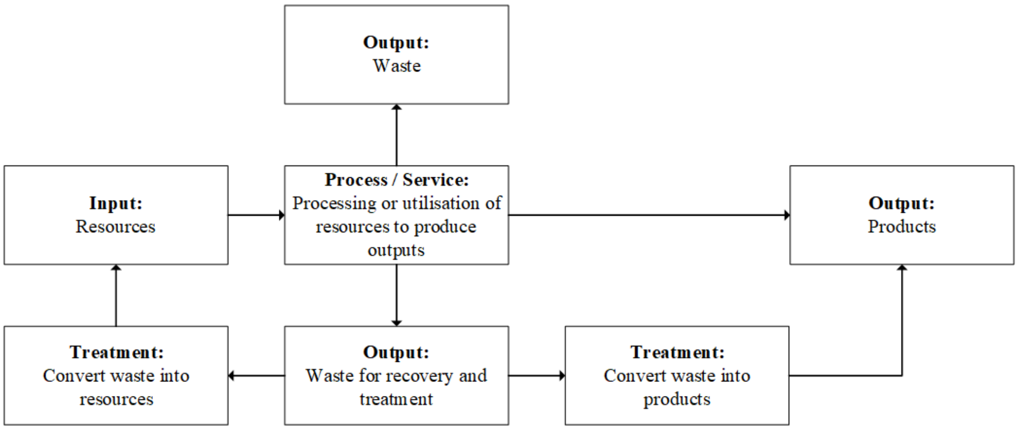


Figure 3.4: Connection of Nitrogen Flow Nodes.

In the next place, the figure of each nitrogen flow node was sourced accordingly. The figures were sourced from government agencies' livestock statistical data in 2019. Alternatively, the figures were obtained or calculated from research papers when the figure required is not accessible in the government's statistical data. Table 3.1 tabulates the sources of data for nitrogen flow computation.

Table 3.1: Data Sources for Nitrogen Flow Quantification.

Data	Sources
Nitrogen Flow in Feed Milling	• Malaysian Feedmillers Association • Poultry farms' sustainability statement • Farm operations survey
Nitrogen Flow in Poultry Farm Operations	• Poultry farms' sustainability statement • Farm operations survey • Department of Veterinary Services Malaysia
Nitrogen Flow in Waste Management Systems	• Poultry farms' sustainability statement • Farm operations survey • Department of Veterinary Services Malaysia • Research papers
Nitrogen Emission and Disposal	• Poultry farms' sustainability statement • Farm operations survey • Research papers

3.4.2 Nitrogen Flow Quantification

With the data obtained from inventory analysis, the nitrogen flows were quantified. The quantification of nitrogen flows was based on the following formula:

$$\text{Input} = \text{Output} \tag{3.1}$$

The nitrogen flow calculation was carried out with the poultry animals' populations and the production of poultry meat and eggs in 2019 as the starting basis. In addition, several assumptions were made during the quantification of the nitrogen flows. The assumptions made are as follows:

1. All forms of protein have 16% of nitrogen content.
2. Nitrogen is derived from protein only.
3. Half of the breeders and local fowls are male.
4. Male breeders and local fowls have the same feed intake rate as broilers.
5. Female breeders and local fowls have the same feed intake rate as layers.
6. All of the broilers and half of the local fowls reared in 2019 were slaughtered for the market.

The complete quantification of the nitrogen flows was computed in Appendix A.

3.4.3 Sankey Diagram Plotting

For the ease of circularity evaluation, the computed nitrogen flows were compiled in a Sankey Diagram. The Sankey Diagram was plotted on an online Sankey Diagram builder, SankeyMATIC as portrayed in Figure 3.5.

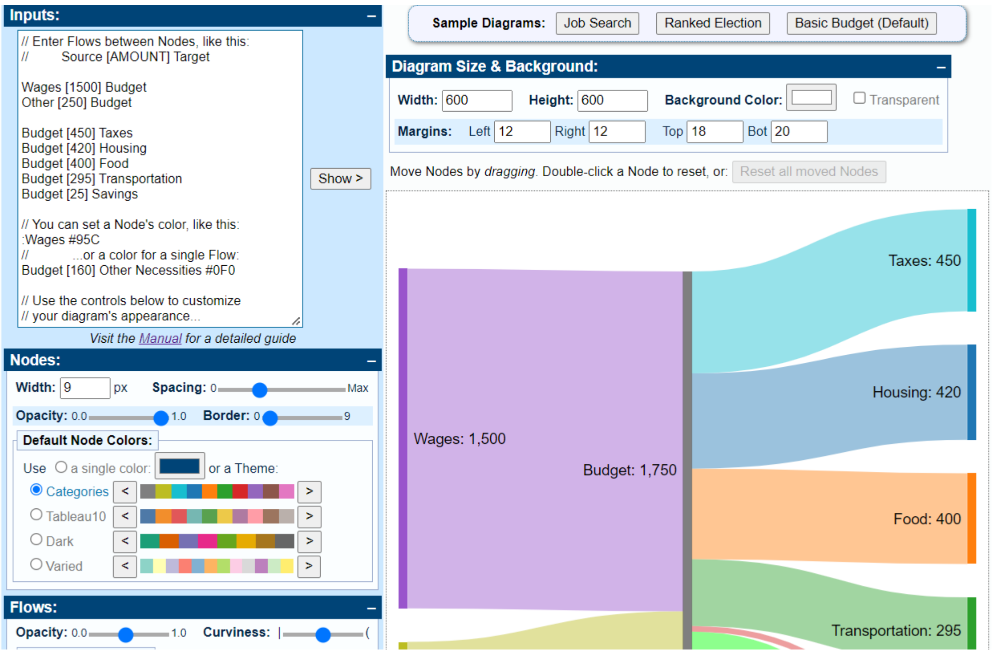


Figure 3.5: SankeyMATIC.

The plotting of a Sankey Diagram was based on the input data of each nitrogen flow. The format of the input data in SankeyMATIC was as follows:

$$\text{Source [AMOUNT] Target \#Colour} \tag{3.2}$$

The input data in SankeyMATIC was shown in Appendix B.

3.5 Circularity Evaluation and Outcomes

The computation of the linear and circular economy flows in the Sankey Diagram concluded the degree of circularity in Malaysian poultry industry with the rate of nitrogen recovery and nitrogen loss. Following this, the linear economy factors and barriers to a CE were identified. Holistic solutions of circularity embracement were proposed according to the evaluated findings. Figure 3.6 demonstrates the flowchart of circularity evaluation and outcomes.

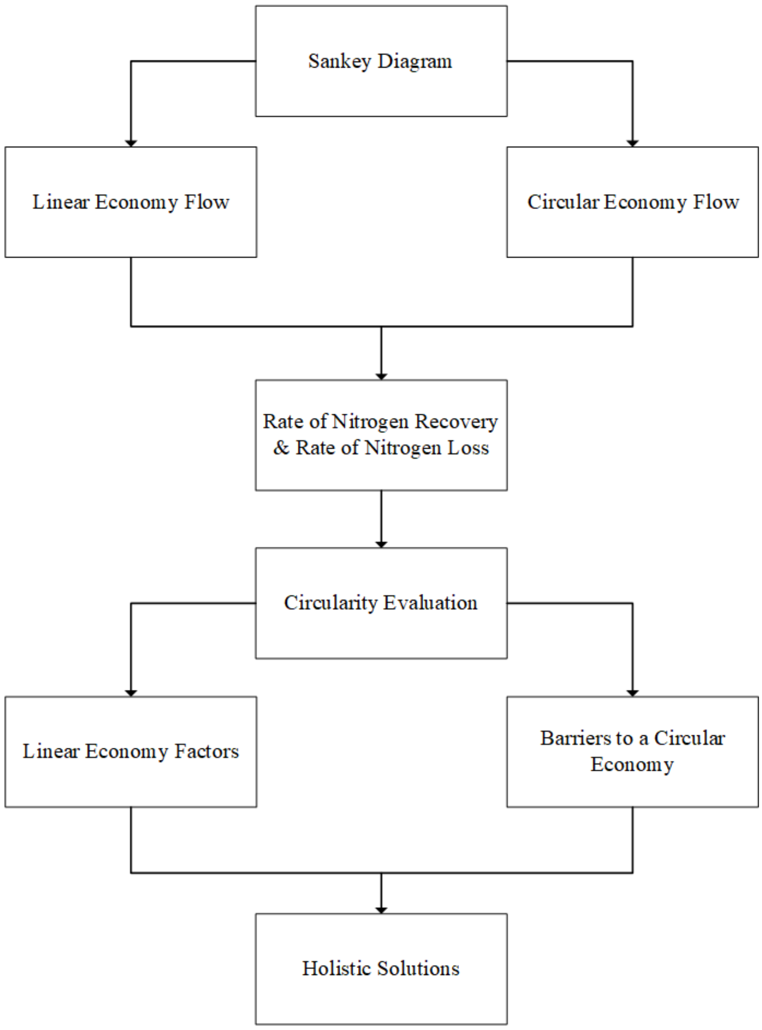


Figure 3.6: Flowchart in Circularity Evaluation and Outcomes.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Nitrogen Flows in Malaysian Poultry Industry

The nitrogen flow in each poultry farming stage were evaluated to compute a Sankey Diagram and determine the degree of circularity in the industry. The nitrogen flows in feed milling, poultry farming and waste management are further discussed in Sections 4.1.1 to 4.1.4.

4.1.1 Nitrogen Flow in Feed Milling

The nitrogenous material input in the poultry industry is the raw materials for feed milling. As shown in Figure 4.1, 15% of the raw materials were supplied by the domestic agriculture industry, while the rest was imported (Malaysian Feedmillers Association, 2017). With a total of 276,536.34 tonnes of nitrogen from the feed materials, 276,536.32 tonnes of nitrogen were supplied to the poultry farms as animal feed. The feed mill wastes such as unused and contaminated raw materials were disposed of according to industrial solid waste disposal regulations or recycled through reselling and used in the production of organic fertiliser.

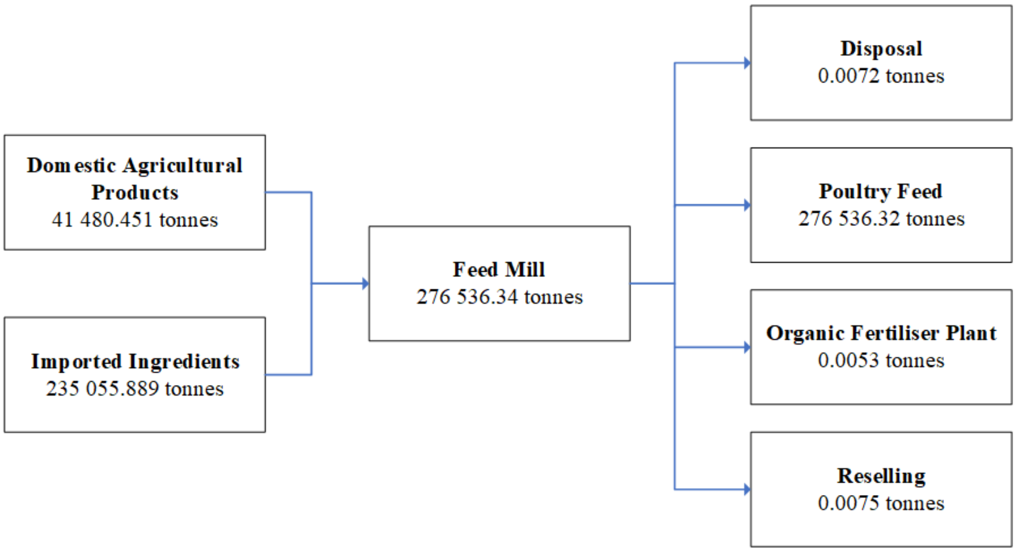


Figure 4.1: Nitrogen Flow in Feed Milling.

4.1.2 Nitrogen Flow in Poultry Farm Operations

According to Ferket et al. (2002), 35% of the nitrogen consumed is retained within the animals, while the rest is excreted as manure (45%) and ammonia (20%). In Figure 4.2, 96,787.71 out of the 276,536.32 tonnes of nitrogen feed supply were retained; 124,441.34 tonnes of nitrogen were excreted as manure and 55,307.26 tonnes were emitted as ammonia. The excreted nitrogen materials were further distributed for disposal and material recovery.

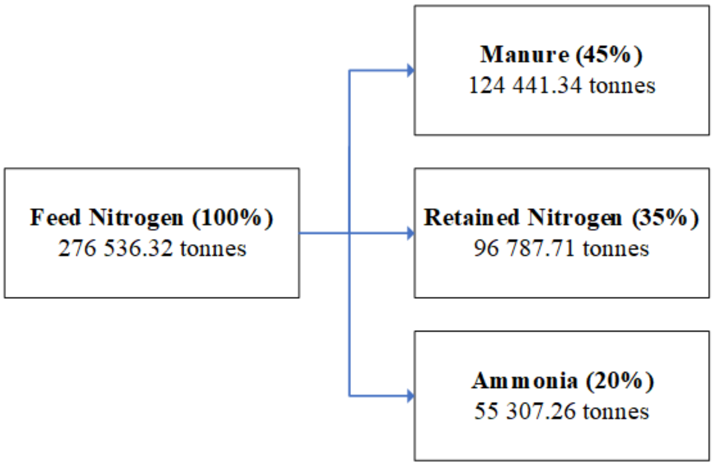


Figure 4.2: Nitrogen Flow in Poultry Feeding.

In 2019, a total of 654,000 tonnes of eggs and 1,589,081 tonnes of poultry meat were produced for local and international markets (Ministry of Agriculture and Food Industries Malaysia, 2019). The eggs and meat contained 81,832.94 tonnes of retained nitrogen. Following this, there were 13,178.14 tonnes of retained nitrogen within the poultry by-products. The poultry by-products, including organs, feathers and blood were collected in food processing plants for disposal or material recovery. Some of the by-products were sent to rendering plants to process offal and feather meal as aqua feed. Figure 4.3 summarises the material flow of the retained nitrogen in poultry products.

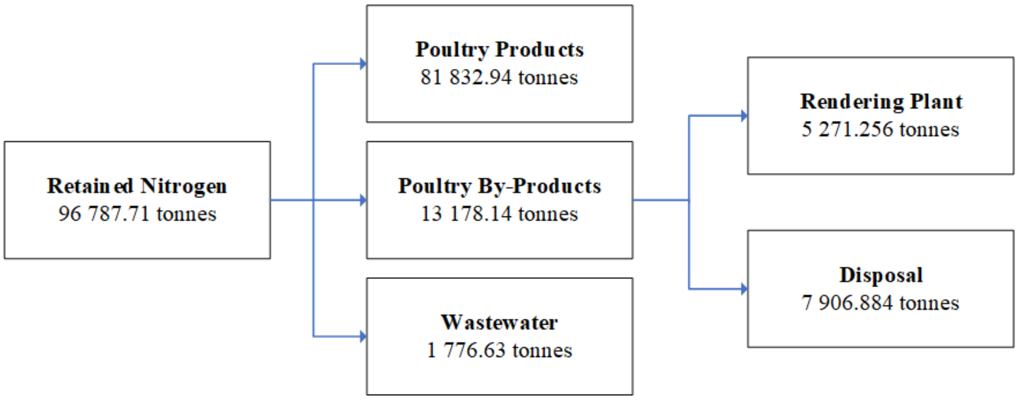


Figure 4.3: Material Flow of the Retained Nitrogen.

4.1.3 Nitrogen Flow in Wastewater Treatment

A portion of the retained nitrogen in poultry by-products was lost during the hygiene control of the food processing plants. The loss of nitrogen in the cleaning and operating utility leads to nitrogenous wastewater generation. The wastewater produced was either channelled to rivers without treatment or to wastewater treatment plants for nitrification and denitrification processes. Research conducted by Avula, Nelson and Rakesh K. Singh (2009) showed that primary and secondary processing of live birds generated 26.5 L/bird of wastewater. The 185,585,285 slaughtered birds in 2019 had generated 4,918,010,053 L of wastewater with a mean concentration of 361.25 mg/L total nitrogen (Maizatul Azrina Yaakob et al., 2018). Consequently, the generated wastewater was composed of 1,776.63 tonnes of nitrogen. The nitrogen was distributed to rivers and wastewater treatment plants. The nitrogen removal efficiency in the wastewater treatment plant is 86% (S. Al-Shididi, M. Henze and Z. Ujang, 2003). Hence, 916.74.123 tonnes of nitrogen compounds in the wastewater were converted into nitrogen gas, while the rest was discharged into rivers as shown in Figure 4.4.

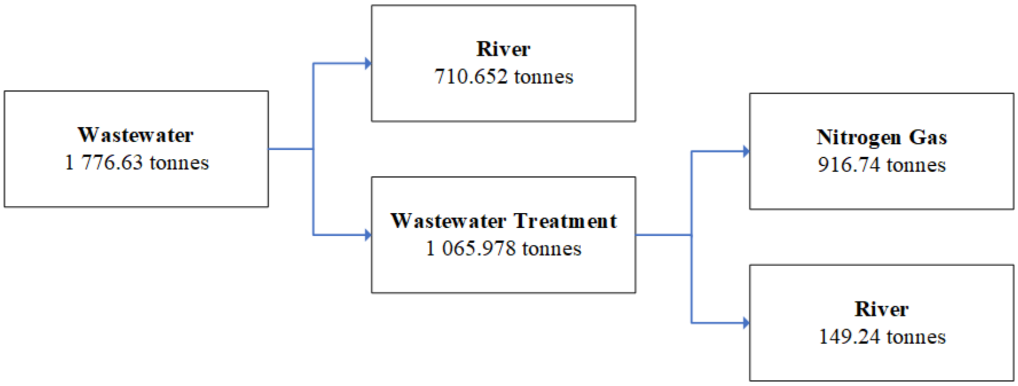


Figure 4.4: Nitrogen Flows in Poultry Wastewater.

4.1.4 Nitrogen Flow in Poultry Waste Management

124,441.34 tonnes of excreted nitrogen manure were collected during poultry farm operations for land application, biogas and organic fertiliser production, while 55,307.26 tonnes of nitrogen in ammonia were emitted to the environment. A biogas plant located in Johor with a capacity of 22,000 m^3 is specialised in handling poultry waste from a population of 1.2 million laying hens. Each bird is estimated to excrete 3.5 kg of manure that has 0.9% of nitrogen within 30 to 42 days of the feeding period (Department of Veterinary Services Malaysia, 2019). As demonstrated in Figure 4.5, 37,800 from the 124,441.34 tonnes of manure nitrogen were sent to the biogas plant to yield methane for generating electricity for the layer farm's usage. For the remaining 86,641.34 tonnes of manure nitrogen, they were either used in the production of organic fertiliser or used in land application without prior treatment.

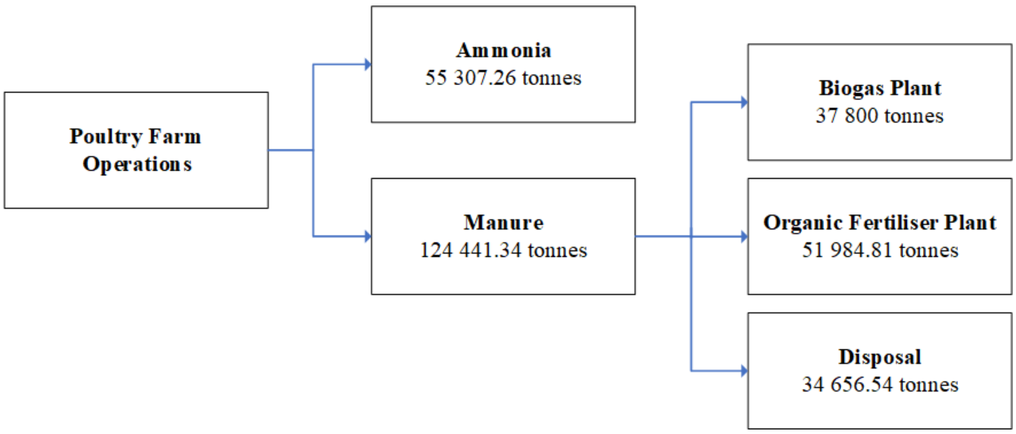


Figure 4.5: Material Flow of the Excreted Nitrogen.

The anaerobic digestion in the biogas plant has a solid waste weight reduction of 60% after each cycle (Mes et al., n.d.). The yielded solid waste from the biogas plant is stabilised and suitable for the production of organic fertiliser. The 15,120 tonnes of undigested nitrogen in the biogas plant were sent to the organic fertiliser plant and the total nitrogen in the organic fertiliser plants was 67,104.82 tonnes. A study conducted by Chastain, Camberato and Skewes (2003) stated that the composting activity resulted in an approximately 26% nitrogen loss in the forms of nitrate and ammonia. In organic fertiliser plants, 17,447.25 tonnes of nitrogen were lost to the environment due to the manure storage method and there were 49,657.56 tonnes of nitrogen used to produce organic fertiliser for the organic farms. Figure 4.6 summarises the nitrogen flow in organic fertiliser plants.

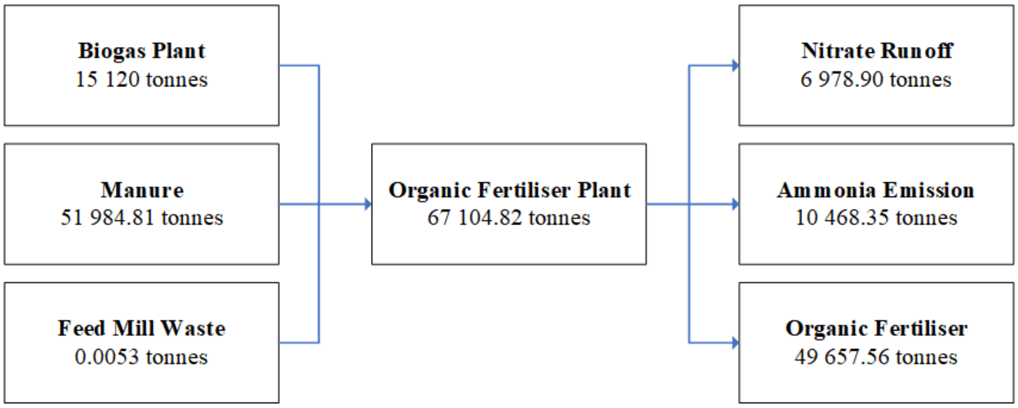


Figure 4.6: Nitrogen Flow in Organic Fertiliser Plant.

Land application and disposal were grouped into a node as both procedures possess the same risk to the environment such as nitrate runoff and ammonia emission. The summation of the nitrogen from the feed mill waste, poultry by-products and soil-applied manure gave a total of 42,563.43 tonnes of nitrogen loss through disposal and land application. Besides, the summation of the ammonia emission from the poultry farms and organic fertiliser plants gave a total loss of 65,775.61 tonnes of nitrogen to the environment. Figures 4.7 and 4.8 sums up the total nitrogen loss in disposal and ammonia emission.

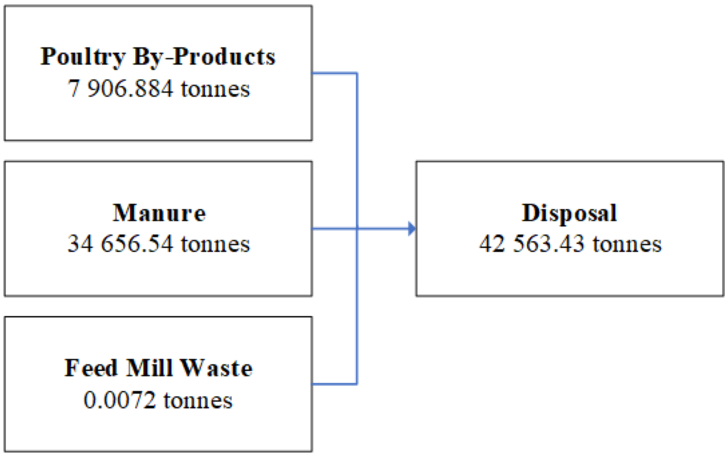


Figure 4.7: Total Nitrogen Loss in Disposal.

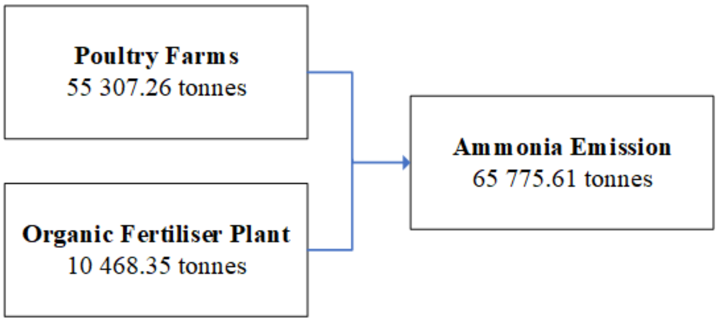


Figure 4.8: Total Nitrogen Loss in Ammonia Emission.

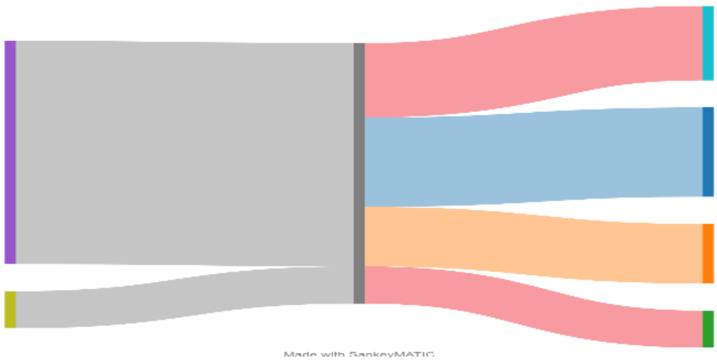
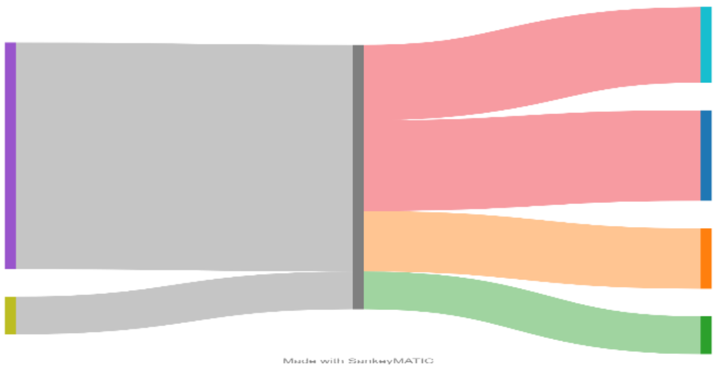
4.2 Circularity in Malaysian Poultry Industry

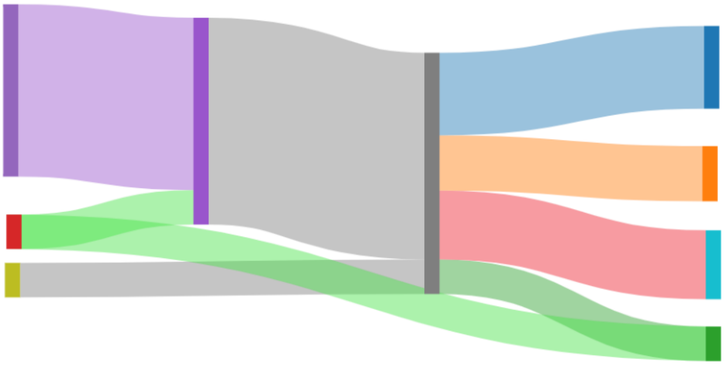
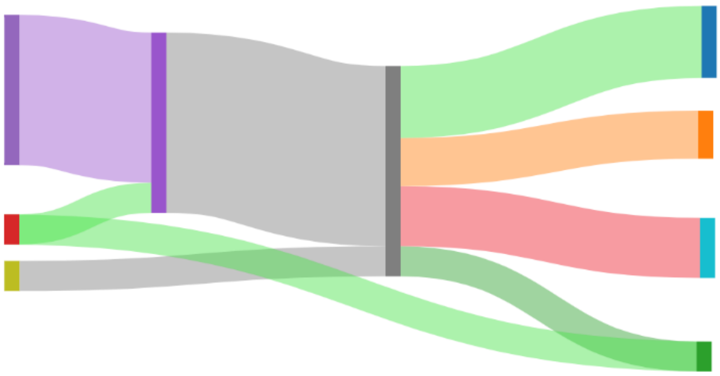
The composing of nitrogen flows in a Sankey Diagram could determine the degree of circularity in an industry. The circularity findings of the plotted Sankey Diagram are further elaborated in Sections 4.2.1 and 4.2.2.

4.2.1 Sankey Diagram

Sankey Diagram is a flow diagram that visualises the transfer of material of a system. The amount of material transfer is represented by the width of the arrows to locate the major flow contributions. Sankey Diagram is often used in monitoring the input, output and wastage of energy and material flow. In the circular economy context, Sankey Diagram is used for the circularity evaluation by observing the flows and loops in the diagram. As listed in Table 4.1, the outcome of the circularity evaluation comes in two forms, a LE model and the combination of a CE model with a LE model. A system with a CE model can be identified with the presence of an open loop, closed loop or both in a Sankey Diagram. Generally, the combination of a CE model and a LE model is found in most circularity evaluations. With this circularity evaluation method, the material lost in the system can be pinpointed easily. In addition, appropriate actions can be taken accordingly to minimise the material lost and implement the CE model at the same time.

Table 4.1: The Description of Circularity Evaluation Outcome.

Circularity Evaluation Outcome	Description
*LE model	• The waste generated is disposed without material recovery. 
*Combination of a LE model and a CE model	**LE model with open circular loop/ loops** • The waste generated is disposed without material recovery. • The waste is collected and processed into another form of material as the input of the other systems. 

Circularity Evaluation Outcome	Description
	LE model with closed circular loop/ loops • The waste generated is disposed without material recovery. • The waste is collected and processed into another form of material as the input of the system. 
	LE model with open and closed circular loops • The waste generated is disposed without material recovery. • The waste is collected and processed into another form of material as the input of the system and other systems. 

**Red flow = LE flow; Green flow = CE flow*

The compilation of the nitrogen flows in Malaysian poultry industry has constructed a Sankey Diagram as illustrated in Figure 4.9. The green flows in Figure 4.9, including 'Reselling', 'Rendering Plant', 'Biogas' and 'Organic

Fertiliser' were labelled as CE flows; whereas the red flows such as 'Disposal', 'Ammonia Emission', 'Nitrate Runoff', 'Nitrogen Gas' and 'River' were labelled as LE flows. 'Poultry Products' is neither a linear nor a circular flow in this case as the products were consumed. As portrayed in Figure 4.9, the poultry industry is in a LE model with open circular loops. In fact, there is a closed circular loop not shown in Figure 4.9. 'Biogas' is considered as a closed circular loop since it was used to generate electricity for poultry farms' usage. Since Figure 4.9 takes into account of nitrogen flows only, 'Biogas' is not circulated to 'Poultry Farm Operations' in Figure 4.9. On the whole, Malaysian poultry industry operates in a combination of a LE model and a CE model. The produced poultry waste was disposed and recycled for for self-use and general use.

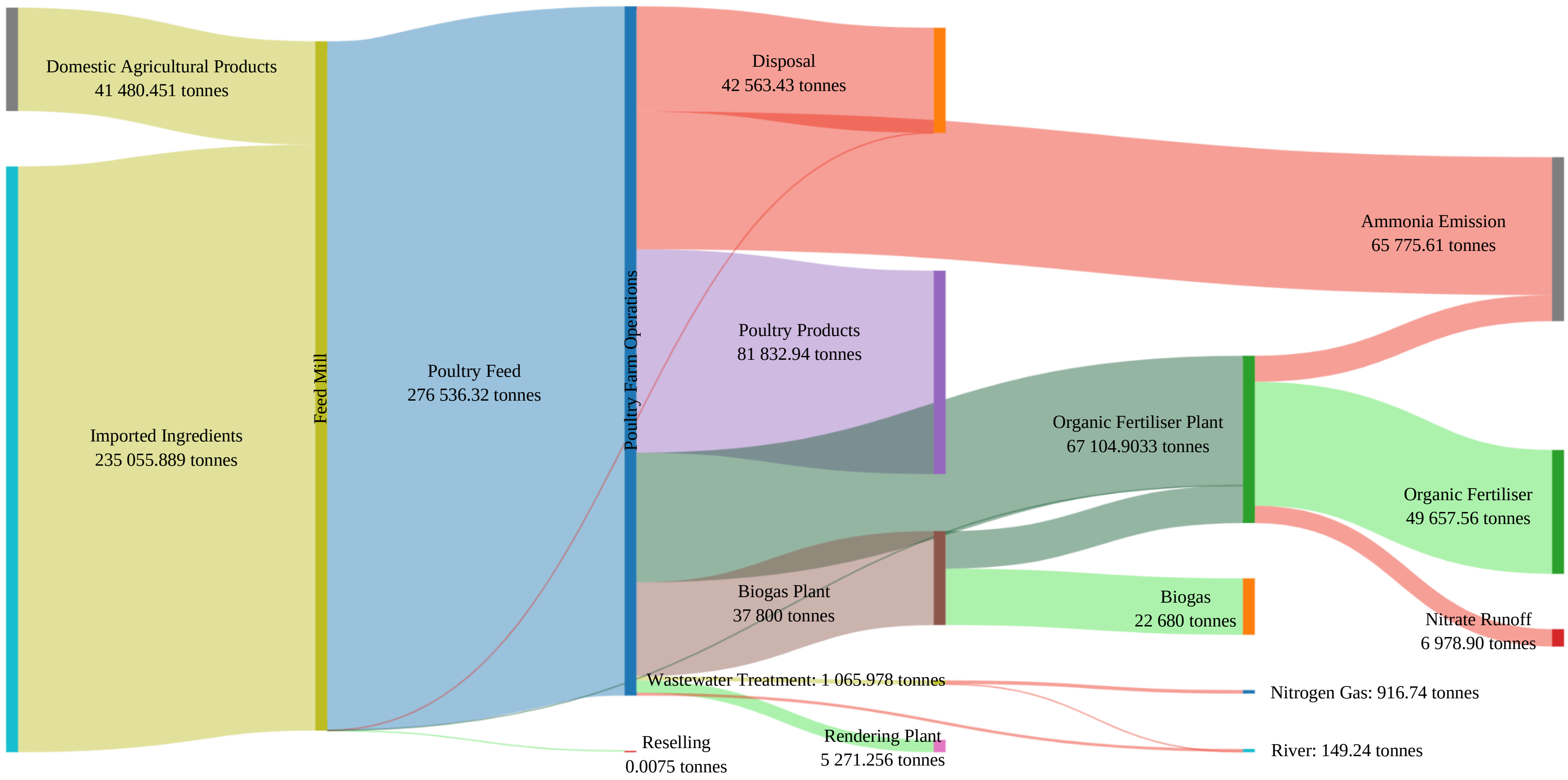


Figure 4.9: Sankey Diagram of the Nitrogen Flow in Malaysian Poultry Industry.

4.2.2 Circularity Evaluation

The total nitrogen weight of the linear and circular economy flows was summed up and tabulated in Tables 4.2 and 4.3 to evaluate the circularity extent of the poultry industry. As compared to 42.54% of nitrogen loss, the nitrogen recycling rate of 27.94% is insufficient for the circularity development in Malaysian poultry industry. The nitrogen materials were lost through ammonia emission, nitrate runoff as well as waste disposal and wastewater discharge without treatment. As for the nitrogen intake, it is fully dependent on agricultural products such as maize and soybean imported from Argentina and Brazil. Poultry feed costs constitute about 70% of the production costs of the poultry industry (Supriya Surendran, 2022). Poultry farming practices such as open-house systems and outdated waste management systems, poor manure storage and handling, infrequent manure removal and overfeeding are the main contributors to nitrogen loss. Among 117,966.7138 tonnes of lost nitrogen, 116,558.5908 tonnes were harmful to the environment and the industry. The compounds could influence the movement of the nitrogen compounds in the nitrogen cycle leading to environmental issues such as climate change and pollution. Furthermore, it affects the productivity of the poultry industry due to the poor growth rate of poultry animals in a high atmospheric concentration of ammonia. It is undeniable that the reduction of nitrogen loss and feed ingredients import is necessary to improve the degree of circularity in the industry. Measures should be pursued on the factors of nitrogen loss.

Alternatively, 77,480.7376 tonnes of nitrogen were recovered through reselling and the production of organic fertiliser, feather meal, offal meal and biogas. These nitrogen recovery methods could lessen the farms' energy dependency, generate side income for the poultry farmers and strengthen the industry circularity at the same time. More nitrogen waste should be channelled to these material recovery options instead of disposal. Aside from the material recovery options utilised in Malaysian poultry industry, there are lots of advanced technologies and smart farming practices that shall be adopted by the poultry farmers.

Table 4.2: The Total Nitrogen Weight and Percentage of Linear Economy Flow.

Flow Name	Linear Flow Weight (Tonnes)	Percentage (%)
Disposal	42 563.43	15.39
Ammonia Emission	65 775.61	23.79
Nitrate Runoff	6 978.90	2.52
Nitrogen Gas	916.74	0.33
River	859.89	0.31
Total	117 094.57	42.34

Table 4.3: The Total Nitrogen Weight and Percentage of Circular Economy Flow.

Flow Name	Circular Flow Weight (Tonnes)	Percentage (%)
Organic Fertiliser	49 657.5600	17.96
Biogas	22 680.0000	8.20
Rendering Plant	5 271.2560	1.91
Reselling	0.0075	< 1
Total	77 608.8235	28.06

4.3 Difficulties in the Implementation of the Circular Economy in Malaysian Poultry Industry

Malaysian poultry industry continues to face issues and challenges in CE implementation. In return, it affects competitiveness and hinders the industry from achieving its full potential. Issues with respect to ineffective implementation and governance mechanism, imbalanced industrial development, limited financial capacity from local financial institutions and the lack of a supportive enabling environment for the poultry farmers especially small-scale poultry farms have suppressed the industry circularity.

4.3.1 Ineffective Implementation and Governance Mechanism

The enforcement of policies remains an issue in addressing the circularity improvement in Malaysian poultry industry. There are no specific policies and legislation to encourage the shift towards a circular economy. Currently, the government is focusing on the waste minimisation initiatives such as reducing carbon emissions and the usage of plastics. Waste minimisation is beneficial to the environment by reducing the amount and toxicity of hazardous waste generated, but it does not reduce the dependency on the raw material input. The absence of effective legislation detrimentally affects the participation of stakeholders to adopt the practices as an alternative to improve industrial circularity. Regulatory frameworks formulate the government's commitment and action plans in dealing with concerning issues to achieve the desired outcome. The absence of an effective regulatory framework could prevent proper and legal action from being taken as they are relying on regulatory negotiations as the default mechanism (KeTTHA, 2009).

The current regulations and action plans are administered by multiple ministries, departments and agencies, resulting in the lack of a unified approach and the overlapping of the roles, functions and the target groups. In addition, the collaboration among divisions has not been fully leveraged, leading to limited data sharing among the divisions and fragmented coordination and monitoring. As shown in Table 4.4, multiple agencies are responsible for developing the livestock industry in Malaysia. For example, a federal department under the Ministry of Agriculture and Food Industries (MAFI), the Department of Veterinary Services (DVS) has a similar involvement as the other departments or agencies in the development of the livestock industry in their respective areas. Eventually, the lack of sensible responsibility assignment among the management units from the central to local levels affects the overall development planning and implementation (Yap, 2019). The consequence is that there is no oversight body performing their oversight roles due to the lack of efficiency among divisions and laborious administrative procedures. Without the administration from an oversight body, the policy targets are hard to meet. At the same time, it reduces the effectiveness of the governance framework and contributes to the limited success of circularity development in the industry.

Table 4.4: Description of Function of the Livestock Agencies in Malaysia (Yap, 2019).

Agencies	Description of Function
Ministry of Agriculture and Food Industries (MAFI)	
DVS	Livestock industry development; provide and implement commodity development programmes for livestock.
MAQIS	Quarantine, inspection services and enforcement of relevant regulations; issuance of permits, licences and certificates for imports and exports of animals.
CLFID	Develop livestock industry consistent with the government's policies.
MARDI	Research and development on livestock production.
MADA	Establish agro-based industrial zones for livestock.
Ministry of Rural Rehabilitation and Development (MRRD)	
KEJORA	Development of animal livestock projects in KEJORA.
KEDA	Plan, implement and monitor livestock projects for the target groups.

4.3.2 Imbalanced Industrial Development

Malaysian poultry industry has huge industrial development gaps in which the small and medium scale poultry farmers (SMEs) are lagging in terms of technical proficiency and productivity. SMEs lack the drive to adopt modern technologies as they are not aware that the endorsement is beneficial to the environment, society and even themselves. The lack of capital to invest in strategic planning, low levels of collaboration in research and limited access to skilled workers have hindered the involvement of the SMEs (Economic Planning Unit, 2021). Generally, SMEs have concerns about the high initial capital cost for the facility building and construction. The facilities require operating and maintenance costs for long-run operations. The majority of them have difficulties in attracting investment to update their farm facilities and technologies. Productivity growth of the SMEs remains low due to the slow progress in automation and mechanisation and their dependency on low-skilled labour. The unsustainable practices have affected the capability of SMEs, resulting in low yields. Stemming from low value-added activities and the slow technologies adoption among the SMEs, the industrial circularity enhancement is hard to achieve. It can be seen in their waste management procedures, such as wastewater effluent discharge. Several researchers have investigated the properties of the effluent discharged from small scale abattoirs and food processing plants. The results indicated that the effluent has high pollutant levels. It is unsafe to discharge the effluent into rivers without pre-treatment.

In comparison, the large-scale poultry farms and food processing plants of the integrated farmers are equipped with wastewater treatment plants for water recycling or effluent discharge. Not only that, they install manure belts in layer farms; their poultry farms are in a closed-house system; they recover wastes into various materials, including organic fertiliser, feather meal and offal meal; and the poultry farms are getting ahead in energy independence with a biogas plant. The integrated poultry farmers place great emphasis on their commitments to the environment's well-being, economy and social aspects. The integrated farmers are open to innovative solutions as they have the capability to invest. They believe that the investments are beneficial to them. Moreover, they have broad opportunities to access the technologies available in the market by attending the industry conferences such as Malaysian International Feed, Livestock & Meat Industry Show organised annually by Livestock Malaysia. The conference gathers innovators, industry leaders and experts to share their insights on the industry development and challenges. Eventually, it generates ideas for the farmers to improve their practices and switch to a circular economy model (Livestock Malaysia, n.d.). It was undeniable that the imbalanced industrial development within the poultry industry is not ideal for the circularity enhancement as there are unsustainable consumption and production practices within the industry.

4.3.3 Limited Financing Capacity

Technology adoption is capital intensive and highly dependent on funding from the government and private sectors. Imported advanced technologies could be costly and subjected to significant costs, such as royalty payments for the intellectual property. Such costs could increase poultry farmers' capital burden if they wish to upgrade their farming practices. Besides, the immobilisation of alternative financial resources is caused by the lack of innovative financing mechanisms and expertise to evaluate the smart farming projects that seek funding. As a result, most financially unsustainable poultry farmers experience difficulties in securing funding. At the same time, it obstructs the ideas of acquiring modern technologies and leads to the inefficiency of the waste management system. Most poultry farmers are SMEs that do not have the capacity and resources to negotiate acceptable terms and conditions with local financial institutions. In addition, the incentives for smart farming projects are subject to unfavourable conditions where the farmers have to implement the project with limited resources and time. The existence of different market choices creates competing incentives in which the financial institutions tend to choose the options that could produce benefits for them (KeTTHA, 2009). Such a competitive environment increases the pressures on the poultry farmers to capitulate and agree to unfavourable terms. Besides, the cost of strengthening and technology maintenance is to be borne by the poultry farmers, increasing their capital costs burden. It was undeniable that the approach to technology adoption relies on private capital. It occurs from the inflicting of terms and conditions that treat the funding for technology adoption as a conventional loan. As a result, the capital available to fund smart farming activities is very much lacking. It adds a disincentive to the SMEs from adopting modern waste management technologies. Consequently, only those with better access to capital have the capability to overcome the financial difficulties to participate in technology adoption. This could significantly exclude the involvement of SMEs in the CE implementation.

4.3.4 Lack of a Supportive Enabling Environment

A supportive environment enables the poultry farms to develop substantially in terms of environmental, economic and social aspects. However, many elements have contributed to the deprivation of developmental opportunities. The involvement of various authorities with different legislation in Malaysian poultry industry poses serious challenges to governance-related issues, such as inadequate monitoring, reporting and evaluation, limited enforcement capacity, as well as insufficient research and development. As revealed by the research conducted by MARDI on the idea of using local agricultural products and wastes such as broken rice, sorghum, tapioca and sago in poultry diets (Zahari and Wong, 2009). The idea is not fully utilised due to the deficiency of xanthophylls that affects the skin and shank pigmentation of birds as well as the pale colour of egg yolks (Zahari and Wong, 2009). The idea of using the local agricultural products in poultry diets has been studied by many institutions and researchers. The recommended levels of inclusion in poultry diets are uncertain as the value studied varies from one study to another. Despite everything, there is no further update on this field research and the poultry farmers continue to stick to the usage of conventional maize-soybean meal for poultry diets these days. The poultry farmers tend to rely on their perceptions to make decisions when they could not access to the information they need. They are clueless about the prospects, market potential, benefits and risks of the available smart farming activities. It affects their decision-making processes as they are confronted with several issues in technology adoption, including limited financing, the lack of technical knowledge and poor network connectivity to support modern technologies. In the end, it hampers the idea of switching from a LE model to a CE model in the poultry industry.

Various causes such as lack of private sector investments, high dependency on low or semi-skilled labour and lack of integrated efforts to encourage smart poultry farming have contributed to the low modern technology adoption rate in the poultry industry. Apart from that, the technologies require high capital expenditure and a long lead time in order to claim the result. As a result, these industry players substitute the modern technologies with the outdated and low productivity technologies, making the industry less sustainable as well as depleting the circularity development. For instance, out of the 3 biogas plants that specialised in handling the poultry waste in Malaysia, only 1 of them is functional. This is due to the factors such as improper planning and monitoring as well as weak technical support and knowledge in maintaining and running the system consistently (Nurul Aini et al., 2019). Besides, the lack of logistical support in the poultry supply chain hinders the collection of biogas feedstock from various locations for centralised processing, leading to insufficient poultry waste to continuously produce biogas. The absence of an effective business model and the lack of comprehensive action plans to direct the smart poultry farming activities have led to the disorganised implementation of the initiatives to promote the smart farming practices. In brief, the lack of shared responsibility among stakeholders to manage sustainability practices effectively is due to the deficiency of a supportive enabling environment for them to grow.

4.4 Measures of the Circularity Improvement in Malaysian Poultry Industry

As identified in the previous section, actions have to be taken to overcome the issues with respect to material loss and poor implementing mechanisms in order to improve the circularity in the poultry industry. In return, it involves the cooperation between stakeholders to achieve the goal at its highest potential. The responsibilities of government agencies and poultry farmers in the industry's circularity enhancement are further introduced in Sections 4.4.1 and 4.4.2.

4.4.1 Government Initiatives

The existing difficulties of embracing CE in poultry industry has to be addressed in appropriate ways. Effective and efficient initiatives enable the embracement to be sustainable over the long term. This section proposes Malaysian government initiatives to address the problems identified in Section 4.3. The initiatives are further discussed in Sections 4.4.2.1 to 4.4.2.4.

4.4.1.1 Introduction of Appropriate Governance Structure and Regulatory Framework

Ineffective implementation and governance mechanism requires the introduction of appropriate governance structure and regulatory framework that address the encouragement or mandatory of shifting towards CE. The introduction of the regulatory framework must embed the governance principles accordingly to strengthen the governance structure. These strategies must be specific and be able to take every aspect into account to derive appropriate solutions. The implementation of the CE policy should be systematic. It should have a legally constituted implementing agency from other organisations to act as oversight functions to improve the accountability of the policy. Beyond this, the cooperation between Malaysian government, livestock associations and industry leaders needs to be encouraged. It could act as a catalyst for embracing CE in poultry industry, undertaking the smart farming practices and technology adoption.

The implementation system employed by the Japanese government is a good example to follow. As portrayed in Figure 4.10, the Japanese government formulates the management standards and basic policy, whereas the prefectures formulate specific plans to implement the policy. Prefectures' roles are to perform on-site inspections and provide instruction and advice to farmers on management standards compliance. In return, farmers submit their facility improvement proposals or loan applications for prefectures' approval and prefectures report their implementation progress to the government. By following Japan's implementation system, the roles of the stakeholders in CE policy implementation will be as listed in Table 4.5.

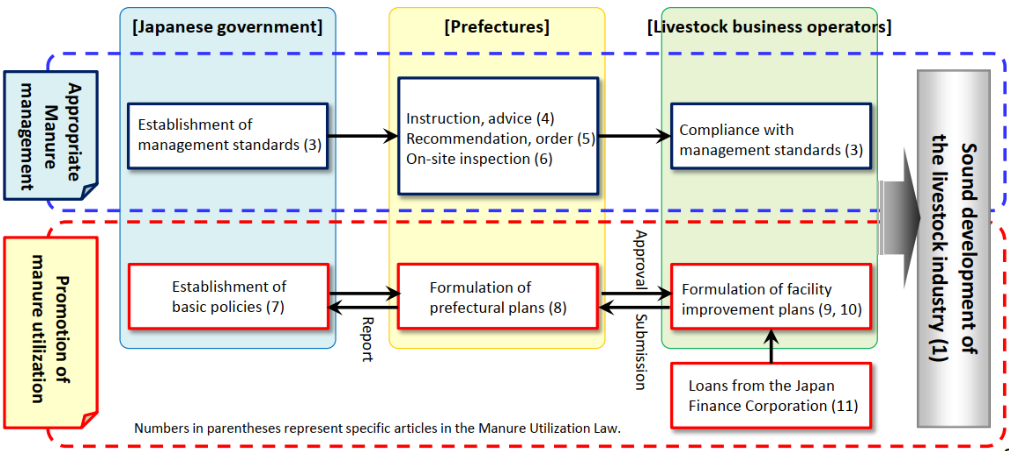


Figure 4.10: The Implementation System in Japan (MAFF Japan, 2018).

Table 4.5: Roles of Stakeholders in CE Policy Implementation.

	Ministry of Agriculture and Food Industries (MAFI)	Department of Veterinary Service (DVS)	Poultry Farmers
Roles in Policy Establishment	Establishment of management standards	Formulation of implementation plans	Compliance with management standards
Implementation Roles	• Review management standards • Secondary proposals reviewal and approval • Review implementation progress	• On-site inspection • Instruction • Advice • Assist poultry farmers • Primary proposals reviewal and approval • Implementation progress update	• Formulation of facility improvement plans • Proposal submission and loan application

4.4.1.2 Close Industrial Development Gap

A huge industrial development gap requires stakeholders' attention and assistance in closing the gap. SMEs should be prioritised in industrial development. Measures such as technical training on smart farming activities and financial aid are important to address their lack of awareness, lack of the capability to attract investment and high dependency on low productivity practices and low-skilled labour. Inclusive programmes, namely industrial conferences are required for SMEs to engage and network with stakeholders and innovators on the latest developments in the industry and market. Eventually, SMEs could generate ideas to make a transformation in their farming practices and switch to a CE model. For example, SMEs can collaborate with other firms to participate in broader production networks. The collaborations allow SMEs to be more resilient in dealing with the disruptions by transforming them to opportunities and taking full advantage of the presented benefits. While minimising the industrial development gap, it is important to ensure the solutions are effective and accessible for SMEs. In addition, the research community and large firms should be more incentivised to collaborate with SMEs.

4.4.1.3 Reinforcement of Budget for Financial and Technical Assistance

The endorsement of smart farming practices and waste management for material recovery and energy generation encounters difficulties because it requires large investment in equipment and technical compliance. For instance, the livestock operators in Japan have high intentions of strengthening livestock production infrastructure as they are eligible to receive attractive subsidies whenever they implement the measures in compliance with the Japanese government's policies. In addition, assistance is provided to improve facilities and machinery in the form of subsidy programs, leasing of facilities and machines, tax benefits and financing. Policies need to be formulated based on the issues of financial and technical assistance to address the embracing of CE in poultry industry. The policies should discuss the budget reinforcement and introduce more grants and funds with broad coverage of allowable expenditures. The government should undertake a comprehensive study on the structure of the existing tax incentive to formulate a more attractive, transparent and competitive tax incentive framework for the farmers to enter into activities that benefit CE embracement. The elements of the incentives available for poultry industry, such as investment tax allowance, incentives to modernise the poultry rearing system, pioneer status, reinvestment allowance, incentives for SMEs, incentives for Halal food production and incentives for training shall be re-evaluated (PwC Malaysia, 2022). Furthermore, financial support and funds from various financial institutions shall be invited to invest in poultry farming improvement plans and environmental protection projects without subjecting the unfavourable conditions.

4.4.1.4 Enhancement of Enabling Environment

Without a robust enabling environment, the advancement of the industry is impacted even if the farmers have the intentions and ability to do so. Hence, the enhancement of enabling environment has to be addressed accordingly. It can be fulfilled by the introduction and popularisation of appropriate technologies, the implementation of a systematic research and development (R&D) programme, human resource development and the execution of a CE advocacy programme.

In terms of the introduction and popularisation of appropriate technologies, the Japanese government has executed a great job. They offer training to on-site farm advisors allowing them to conduct surveys and identify effective examples adopted by the farmers. Annual training sessions are held on different subjects including composting, sewage treatment, odour control, etc. The identified examples are widely publicised to promote their nationwide adoption. Aside from that, the Japanese government sets unit prices for the recovered material and energy generated to ensure that farmers' income from the sale of the recovered products exceeds the cost of improving, operating and maintaining facilities and machinery necessary (MAFF Japan, 2018). The Malaysian government should take these examples as the initiatives to improve the circularity of the industry.

Other than that, assistance shall be provided to national, regional and university research organisations that are developing new technologies and mechanisms to facilitate the problems faced by the poultry farmers. A systemic R&D programme could accelerate the growth of CE in the industry with innovative technologies and services. The innovation in R&D programme enhances the diffusion of technology in the industry by making them cheaper and easier to use. The innovation could strengthen businesses' competitive edge by assisting the poultry farmers' decision-making process in respect to investing in CE technologies and businesses.

In addition, the implementation of advocacy programmes could encourage more stakeholders to embrace a CE model in their daily farm operations. The specific messages of the advocacy programme should be tailored based on its specific audiences and outcomes. For the CE advocacy programme in poultry industry, the industry stakeholders, including industry leaders, investors, large firms and SMEs are the targeted audiences. The programme should be designed to increase their awareness of the benefits and advantages of embracing CE and participation in the CE business in the industry. Having full access to the information in advocacy programme is crucial for any new technology to take root. The conducive environment would provide indirect assistance by reducing the transaction cost for financing. It facilitates investors' decision-making process in capital mobilisation as well as providing assistance to SMEs in embracing the CE model.

4.4.2 Adoption of Smart Farming Activities

It is envisaged that with the increased side income and reduced energy dependencies coming from the CE embracement, the industry players are at the largest benefits. This would mean that the industry players must play their parts by contributing to the circularity development through their daily operations. This section recommends the roles of the poultry farmers in reducing the material loss for circularity embracement. It includes poultry feed ingredients substitution, by-products recycling, reduction of ammonia emission, upgradation of manure storage and handling method and microalgae cultivation in wastewater and sludge treatment.

4.4.2.1 Substitution of Feed Ingredients

The costs spent on poultry feed production account for 70% of total production cost of the industry. It is mainly due to the high dependency on the imported maize and soybean. To reduce the dependency on imported agricultural products, Sime Darby Plantation collaborated with Malaysian Palm Oil Board and developed a palm kernel pre-cleaning system. Palm kernel cake is a by-product produced in palm kernel oil extraction. The development of the pre-cleaning system has further enhanced the value of palm kernel cake by introducing it as the potential animal feed, PURAFEX. According to Sime Darby Plantation (2017), the scientific research has proven that the consumption of feed containing PURAFEX could produce healthier birds with much lower fat content. In addition, it had a better performance than commercial feed in terms of mortality rate. The mortality rate of PURAFEX consumption was shown to be lower than 3%, which was much lower than the 4 – 5% industry standard. As shown in Tables 4.6 and 4.7, PURAFEX can now be used to replace up to 30% of the imported ingredients with comparable nutrient content. The ingredient substitution could save more than 10% of chicken feed cost. Figure 4.11 illustrates the poultry feed substituted by PURAFEX.

Table 4.6: Ingredients Comparison between Commercial Poultry Diets and Diets Containing PURAFEX (Rohaya Halim et al., 2020).

Ingredients	Percentage (%)	
	Commercial Poultry Diets	Diets Containing PURAFEX
PURAFEX (Palm Kernel Cake)	0.0	30.0
Maize	57.0	32.9
Soybean Meal	24.0	21.0
Fish Meal	10.0	11.0
Rice Bran	3.6	2.8
Palm Oil	4.0	0.5
DiCalcium Phosphate	1.5	1.5
Vitamin Premix	0.1	0.1
Mineral	0.1	0.1
Methionine	0.2	0.2
Lysine	0.1	0.1

Table 4.7: Nutrient Content Comparison between Commercial Poultry Diets and Diets Containing PURAFEX (Rohaya Halim et al., 2020).

Nutrient Content	Percentage (%)	
	Commercial Poultry Diets	Diets Containing PURAFEX
Crude Protein	22.0	22.0
Fibre	4.0	6.3
Fat	3.5	6.2
Ash	7.0	8.8
Metabolisable Energy (kcal/kg)	3 850.0	3 850.0

Figure 4.11: PURAFEX (Rohaya Halim et al., 2020).

As illustrated in Figure 4.12, despite the discovery of the ingredients to substitute the commercial poultry diets, some of the integrated poultry farming companies are still utilising the commercial maize and soybean meal as the ingredients in poultry feed milling. The application of imported maize and soybean meal in poultry feed milling is unsustainable where the prices of the ingredients are much higher than sourcing the ingredients locally. Besides, intensive production of feed ingredients puts pressure on land use and drives deforestation, soil degradation and climate change. To solve this problem, the feed millers are suggested to substitute a portion of maize and soybean meal with PURAFEX. The ingredients substitution in every feed mill in Malaysia could reduce 30% of the total poultry feed ingredients import, which is 70,706.4998 tonnes of nitrogen. In return, the nitrogen import drops from 235,688.3327 to 164,981.8329 tonnes. Figures 4.13 and 4.14 compare the nitrogen inputs of the poultry industry before and after PURAFEX substitution.

Figure 4.12: Poultry Feed Specifications (Dindings Poultry Development Centre Sdn Bhd, n.d.).

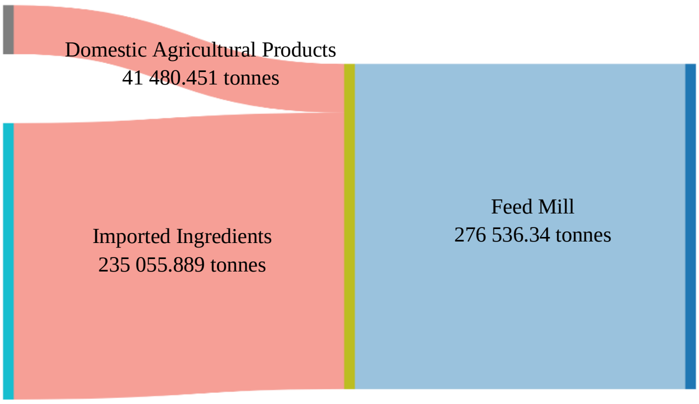


Figure 4.13: Sankey Diagram Before PURAFEX Substitution.

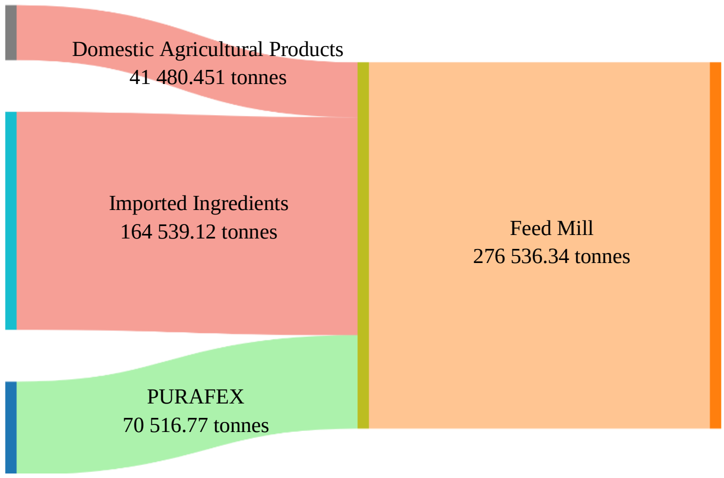


Figure 4.14: Sankey Diagram After PURAFEX Substitution.

Poultry litter has been proven to be three times more valuable as an animal feed than as fertiliser. Trials have documented that the nutrients and energy content in poultry litter can be safely recycled as one of the ingredients of poultry diets after neutralizing the pathogens. However, despite of its documented nutrient value and safety, such waste recycling practices is heavily dependent on public acceptance on the concept of waste material consumption and regional regulations.

4.4.2.2 Recycling of Poultry By-Products

The intensive and large-scale production of Malaysian poultry has generated an enormous number of poultry by-products. The by-products have high nutrient content which can be converted to different materials listed in Table 4.8. Unfortunately, poultry by-products are not fully utilised in Malaysia as most poultry slaughtering processes are performed in wet markets. The wet markets are not equipped with a rendering plant to recover the by-products. As a result, some of the by-products are disposed of with or without following the Department of Veterinary Service's disposal policy. The underutilisation of by-products causes the loss of potential revenues as well as increases the cost of by-products disposal. Hence, the by-products produced during food processing operations must be utilised efficiently. The poultry slaughtering in wet markets should be restricted and carried out in licensed abattoirs equipped with a rendering plant. The concentrated poultry slaughtering operations facilitate the collection of poultry by-products for rendering.

Table 4.8: Poultry By-Products and Their Potential Uses (Sari, Ozdemir and Celebi, 2016).

By-Products	Uses
Hatchery Wastes	High calcium diet
Feathers	Bedding material, fertilisers, biofuel, biodegradable plastics and feather meal
Heads	Poultry meal
Blood	Blood meal
Gizzard and Proventriculus	Chitinolytic enzyme
Feet	Soup and poultry grease
Intestines and Glands	Meat meal and poultry grease

Rendering by-products for animal feed ingredient is the most profitable application in by-products recycling as the by-products have high protein and lipid contents. Rendering produces offal meal and feather meal which can be used as an animal feed, fertiliser or further processed in anaerobic digestion and composting. Apart from animal feed and fertiliser, feather meal can be one of the potential materials to produce biodiesel. Feather meal is boiled in water to extract its primary fat. The extracted fat is then trans esterified into 7 – 11% biodiesel (Sari, Ozdemir and Celebi, 2016). The result of chemical analysis has confirmed that feather meal produced biodiesel has better quality than biodiesel made from other materials. Each rendering product is an excellent source of nutrients that provides cost-effective source of protein. The rendered offal meal can be used to feed house fly larvae, the potential poultry feed ingredients substitution. Fly larvae has 63.1% of protein content and 15.5% of fat content in which it is a better source of quality feed than soybean meal (Pieterse and Pretorius, 2013). Meanwhile, the excrement of fly larvae is perfectly suited as an organic fertiliser for crops such as durian, banana, chili, and pineapple due to its high organic matter and rich in nitrogen, phosphorus and potassium contents (Malaysian Global Innovation and Creative Centre, n.d.). In Tables 4.9 to

4.14, the substituted poultry feed is compared to commercial poultry diet in terms of ingredients composition and nutrient content. The substituted ingredients are feather meal, poultry offal meal and fly larvae.

Table 4.9: Ingredients Comparison between Commercial Poultry Diets and Diets Containing Feather Meal (Ra'fat, 2008).

Ingredients	Percentage (%)	
	Commercial Poultry Diets	Diets Containing Feather Meal
Feather Meal	0.000	5.000
Corn	56.210	63.100
Soybean	34.700	24.100
Oil	4.210	3.120
DiCalcium Phosphate	1.815	1.692
Limestone	1.325	1.401
Salt	0.582	0.497
Methionine	0.339	0.361
Lysine	0.206	0.347
Vitamin Pre-mix	0.600	0.600

Table 4.10: Nutrient Content Comparison between Commercial Poultry Diets and Diets Containing Feather Meal (Ra'fat, 2008).

Nutrient Content	Percentage (%)	
	Commercial Poultry Diets	Diets Containing Feather Meal
Crude Protein	20.00	20.00
Crude Fibre	2.59	2.37
Ether Extract	2.48	2.98
Calcium	1.00	1.00
Phosphorus	0.56	0.53
Metabolisable Energy (kcal/kg)	3100.00	3100.00

Table 4.11: Ingredients Comparison between Commercial Poultry Diets and Diets Containing Poultry Offal Meal (Silva et al., 2013).

Ingredients	Percentage (%)	
	Commercial Poultry Diets	Diets Containing Poultry Offal Meal
Poultry Offal Meal	0.000	6.000
Corn	58.832	63.962
Soybean Meal	30.773	22.171
Poultry Fat	6.330	4.752
DiCalcium Phosphate	1.754	0.877
Limestone	0.860	0.645
Salt	0.471	0.266
Methionine	0.205	0.195
Lysine	0.168	0.231
Vitamin Pre-mix	0.100	0.100

Table 4.12: Nutrient Content Comparison between Commercial Poultry Diets and Diets Containing Poultry Offal Meal (Silva et al., 2013).

Nutrient Content	Percentage (%)	
	Commercial Poultry Diets	Diets Containing Poultry Offal Meal
Crude Protein	19.100	19.100
Crude Fibre	2.683	2.306
Calcium	0.857	0.857
Phosphorus	0.427	0.427
Metabolisable Energy (Mj/kg)	13.600	13.600

Table 4.13: Ingredients Comparison between Commercial Poultry Diets and Diets Containing Fly Larvae (Vilela et al., 2021).

Ingredients	Percentage (%)	
	Commercial Poultry Diets	Diets Containing Fly Larvae
Fly Larvae	0.000	20.00
Wheat Grain	64.10	59.50
Soybean Meal	23.50	16.40
Cottonseed Oil	5.53	0.53
Meat and Bone Meal	2.51	0.47
Limestone	0.88	0.00
Salt	0.14	0.15
Vitamin Pre-mix	0.05	0.05
Mineral Pre-mix	0.08	0.08
Lysine	0.18	0.00
Methionine	0.23	0.13

Table 4.14: Nutrient Content Comparison between Commercial Poultry Diets and Diets Containing Fly Larvae (Vilela et al., 2021).

Nutrient Content	Percentage (%)	
	Commercial Poultry Diets	Diets Containing Fly Larvae
Crude Protein	19.90	22.80
Calcium	0.79	0.80
Phosphorus	0.40	0.44
Metabolisable Energy (kcal/kg)	3 200.00	3 200.00

Besides rendering, pyrolysis is an innovative technology that can be adapted for the disposal of poultry wastes and by-products. Pyrolysis occurs in the absence of oxygen. It produces specific properties of biochar from different substrates which can be used to alleviate ammonia emissions and nitrogen loss in litter pilling and composting, remove contaminants and improve soil properties (Purnima Singh et al., 2018). Furthermore, biochar can be further processed into a liquid biofuel, suitable for storage and transport. The advantage of pyrolysis is its mild operating conditions and short process duration (Sari, Ozdemir and Celebi, 2016). The technology's construction materials can be cheaper than other processes, but it requires a higher capital cost when drying or size reduction of the pyrolysis products is necessary. Besides, the technology design of pyrolysis process could provide additional returns by adding the energy recovery functions that generates heat and electricity.

Figures 4.15 to 4.19 compare the nitrogen inputs and outputs of the poultry industry before and after complete poultry by-products recycling. Figure 4.15 was extracted from the Sankey Diagram (Figure 4.9). It shows that 4,994.508 tonnes of nitrogen were sent to rendering plants for material recovery, while 7,491.762 tonnes of nitrogen were disposed of. The complete by-products recycling in Figures 4.16 to 4.19 are described in different scenarios, which are open circular loops, closed circular loops and a combination of both. The rendered by-products in open circular loops are used to produce various products such as fertilisers, animal feed, pet food, biochar, biofuel and biodegradable plastics. For the combination of open and closed circular loops in Figures 4.17 and 4.18, a portion of the rendered by-products is fed to the poultry animals. In comparison, all of the rendered by-products in closed circular loops are fed to the poultry animals. As illustrated in Figure 4.19, the closed circular loops approach is more beneficial for the poultry industry as it reduces the import of 12,486.27 tonnes of nitrogen in maize and soybean meal. Poultry abattoir and food processing plant operators are encouraged to employ closed circular loops approach in poultry by-products recycling. Nonetheless, the application of feather meal and offal meal in poultry feed depends on the public's acceptance because of concerns for meat hygiene, risks of diseases transmission and ethical issues regarding cannibalism. More research shall be conducted to improve the quality of the recycled feed and to prove its credibility to the public.

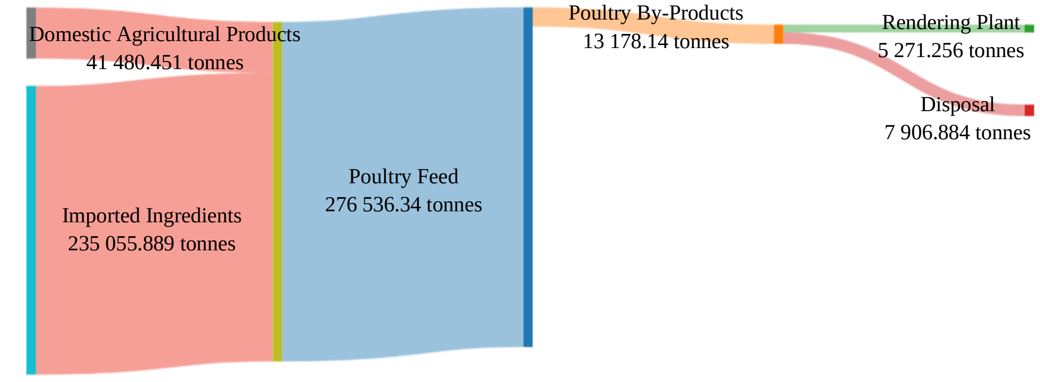


Figure 4.15: Sankey Diagram Before Complete Recycling of Poultry By-Products.

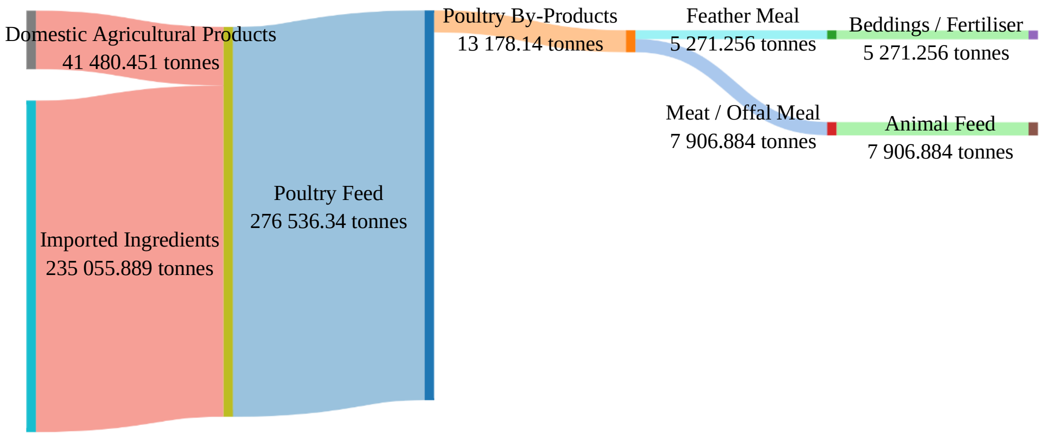


Figure 4.16: Sankey Diagram After Complete Recycling of Poultry By-Products (Open Circular Loops).

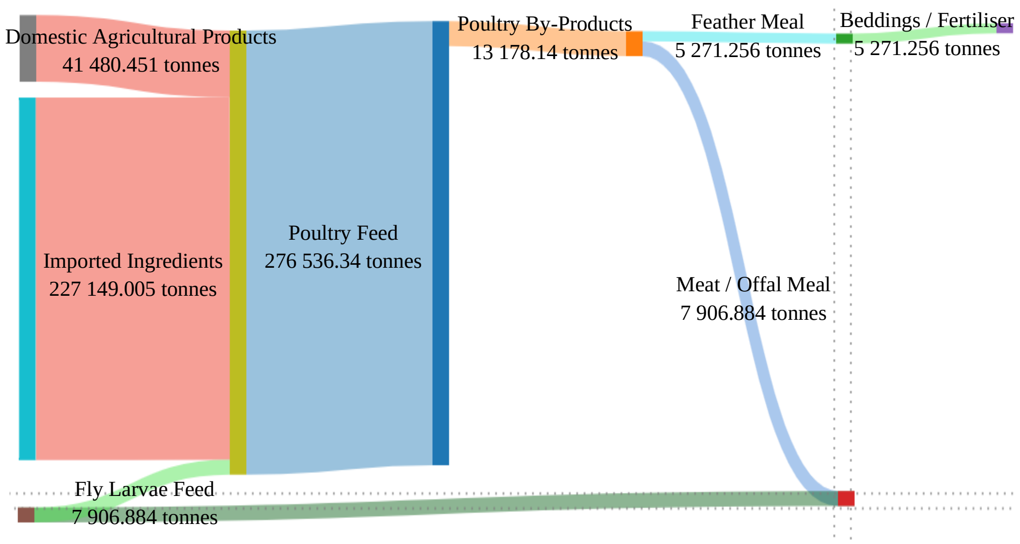


Figure 4.17: Sankey Diagram After Complete Recycling of Poultry By-Products (Open and Closed Circular Loops – Meat/ Offal Meal).

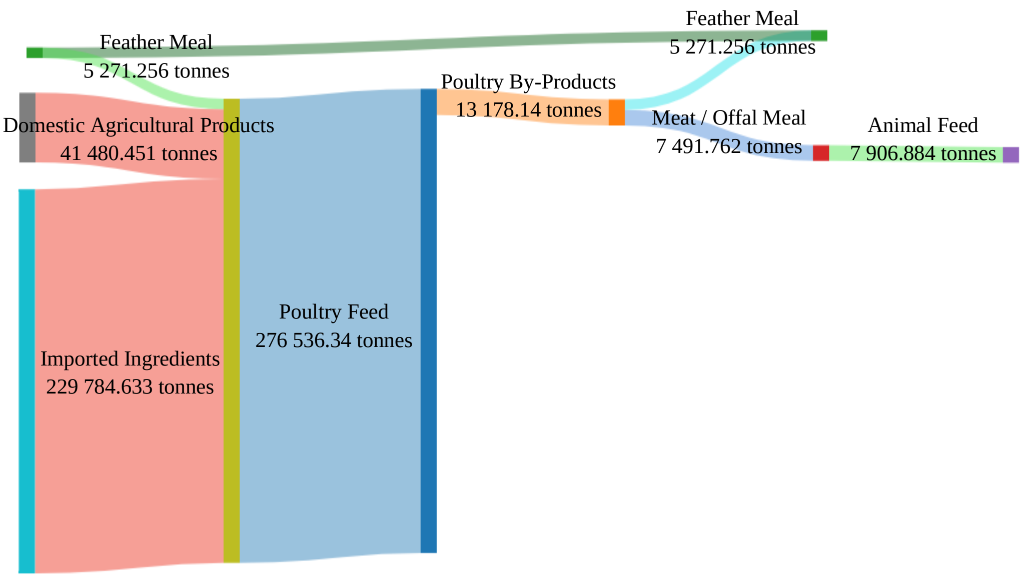


Figure 4.18: Sankey Diagram After Complete Recycling of Poultry By-Products (Open and Closed Circular Loops – Feather Meal).

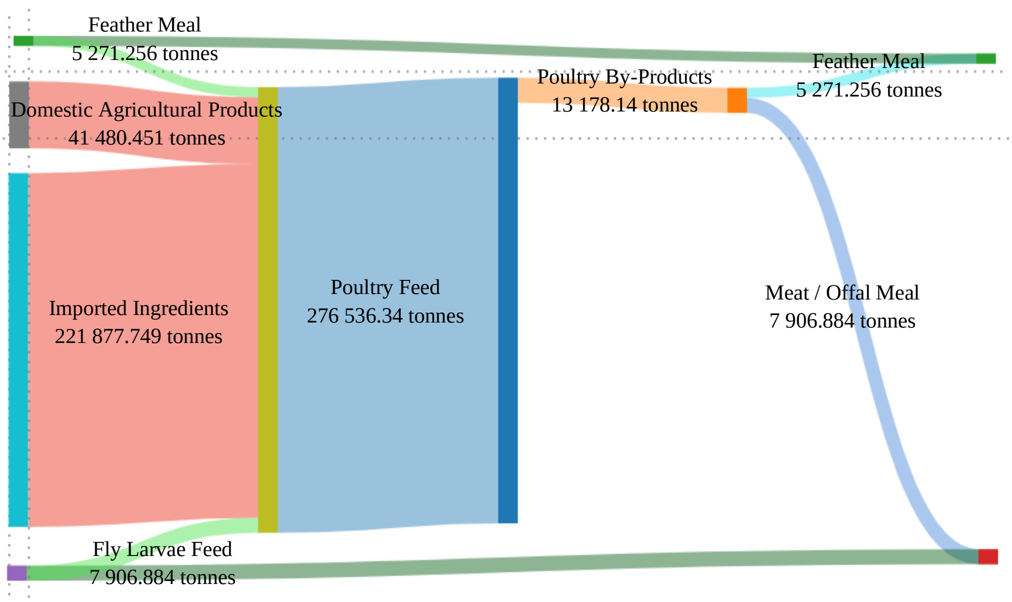


Figure 4.19: Sankey Diagram After Complete Recycling of Poultry By-Products (Closed Circular Loops).

4.4.2.3 Reducing Ammonia Emission

Poultry farmers improve the air quality in poultry houses through ventilation. The increased ventilation rate in poultry farms reduces the ammonia concentration within the facility, but it leads to higher ammonia emission to the atmosphere. The conventional methods of filtering vented air in the closed-house system can be achieved with air cleaning devices, such as biofilters and scrubbers. Unfortunately, the practical application and sizing of such devices in poultry farms are limited by various forms of constraints, namely cost, sizing and technical problem to treat the large volume of air exhausted from poultry farms (Arogo et al., 2002). In addition, the high concentration of dust in poultry farms can affect the performance of air cleaning devices as well. Only mechanically ventilated poultry houses can be equipped with such technologies and they cannot reduce the ammonia concentration in poultry farms. To reduce ammonia emission efficiently, several methods shall be adopted by poultry farmers.

The addition of alum to poultry litter has been proven to reduce ammonia concentration in poultry houses as well as the ammonia emissions to the atmosphere. Alum minimises microbial activity by reducing the pH value of manure or litter and thereby limiting ammonia volatilisation. There are three types of alum available, such as dry, liquid and high acid liquid alum. Since alum loses its effectiveness with time, poultry animals should be placed 2 – 5 days after alum application to bedding materials. After applying alum to beddings, the poultry houses have over 75% of ammonia concentration reduction for the first two weeks (Livestock and Poultry Environmental Learning Community, 2019). The effectiveness slowly reduces to 50% in the third week, and 20-30% thereafter. The exact duration of ammonia level control is dependent on the application rate of alum. The higher the application rate, the better the ammonia control performance. The application of alum can improve bird performance as well as lower the energy usage for poultry house ventilation (Ritz, Fairchild and Lacy, 2004). Aside from that, the usage of alum treated litter as fertilisers increases the crop yields as the nitrogen content is retained within the treated litter. While the addition of alum to litter has been effective in controlling ammonia levels, it is best to utilise this application with adequate ventilation, ration composition and diet management, optimised birds' density in poultry houses and careful litter management (Karimi, 2019). This is to help limit excessive moisture in poultry houses, keeping poultry manure dry by eliminating within-house condensation.

Figures 4.20 and 4.21 compare the nitrogen outputs of the poultry industry before and after the reduction of ammonia emissions in poultry houses. Figure 4.20 was extracted from the Sankey Diagram (Figure 4.9). It shows that 55,456.0743 tonnes of nitrogen were lost to the atmosphere through ammonia emission. Based on the waste management guideline provided by the Department of Veterinary Service (2019), poultry farms with closed-house system needs to be cleaned thoroughly for each production cycle, which is 30 – 42 days. On the other hand, for the open-house system, poultry waste needs to be cleaned regularly for less than 2 weeks. Hence, the ammonia level reduction is assumed to be 70%. As illustrated in Figure 4.19, the nitrogen loss is reduced to 16,636.8223 tones. The rest of the nitrogen is retained in poultry manure for material or energy recovery. To further reduce ammonia emission, poultry houses shall be cleaned frequently. Besides, a manure belt system shall be installed in layer farms to minimise ammonia volatilisation.

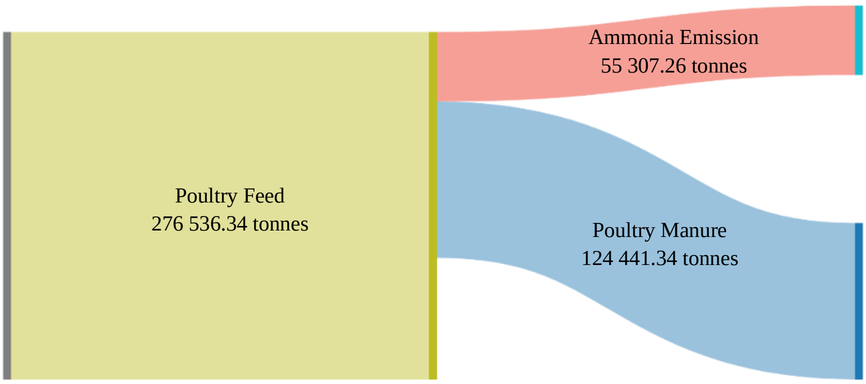


Figure 4.20: Sankey Diagram Before the Reduction of Ammonia Emission.

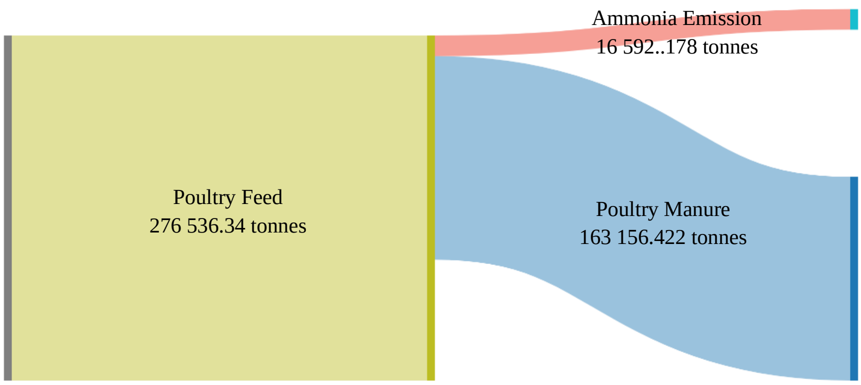


Figure 4.21: Sankey Diagram After the Reduction of Ammonia Emission.

4.4.2.4 Upgrade Manure Storage and Handling Method

Once the litter is removed from poultry farms, the litter is either applied on soil without treatment or piled up for composting. The application of litter on soil without treatment is disadvantageous to the environment and the farmers. For this reason, litter treatment prior to soil application is necessary to minimise the nitrogen loss to the environment through ammonia emission and nitrate runoff. The conventional methods to treat poultry litter are drying and composting as they are the cheapest and most feasible methods in a tropical country. The collected litter is piled up for air drying and aerobic bacterial processes. The methods used to store the litter can reduce the nitrogen content significantly. The result of nitrogen loss is shown in Table 4.15. Based on the results in Table 4.15, the uncovered pile is not suitable for long-duration storage. The litter pile should be covered when the litter is meant to be stockpiled for more than 1 or 2 days. Aside from that, the manure storage area should be designed to keep the litter pile as dry as possible by preventing contact with rainfall or rain runoff. This practice could conserve valuable nitrogen content and reduce nitrogen loss by up to 17%. Besides, it lowers the potential for pollutants runoff and reduces odour and pests.

Table 4.15: Nitrogen Losses from Litter Storage Method (Chastain, Camberato and Skewes, 2003).

Type of Storage	Moisture Content (%)	Nitrogen Lost (%)
Uncovered Pile	39 – 47	30
Covered Pile	16 – 19	17
Stacking Shed	7 – 15	26

Aside from covering the litter pile, a biotechnological agent, Amalgerol can be added to the litter pile to further reduce the nitrogen loss. Amalgerol is a water-soluble thick liquid created by the mixture of specific vegetable oils. Its basic structure can limit ammonia emission up to 40 – 68%. Research conducted by Zemek and Marecek (2005) claimed that Amalgerol addition to litter pile and boiler drinking water along with the fresh bedding material treatment has reduced 41.16% of ammonia emission in broiler litter pile. The results are shown in Table 4.16 and Figure 4.22.

Table 4.16: Decrease in Ammonia Concentrations and Ammonia Emission Rates (Zemek and Marecek, 2005).

Parameters	Values
Mean Ammonia Concentration – Treated Litter Pile (mg/m^3)	5.26
Mean Ammonia Concentration – Untreated Litter Pile (mg/m^3)	8.94
Ammonia Emission Rate from 1 m^2 of Treated Litter Pile (g/h)	1.89
Ammonia Emission Rate from 1 m^2 of Untreated Litter Pile (g/h)	3.20

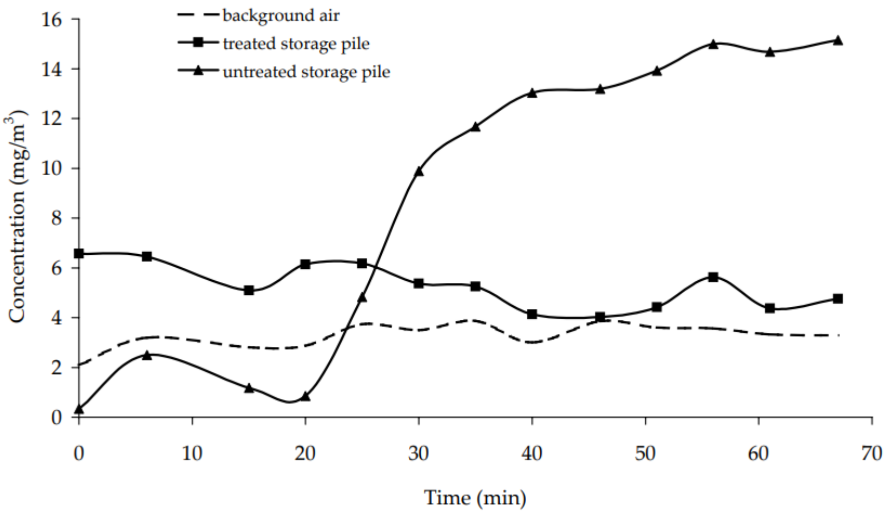


Figure 4.22: Ammonia Concentration Progress (Zemek and Marecek, 2005).

Figures 4.23 and 4.24 compare the nitrogen outputs of the poultry industry before and after the usage of the covered pilling method and the application of Amalgerol in litter piles. Figure 4.23 was extracted from the Sankey Diagram (Figure 4.9). There were 10,449.6901 tonnes of nitrogen lost through ammonia emission and 6,999.7934 tonnes of nitrogen were lost through nitrate runoff. After the usage of the covered pilling method and the application of Amalgerol, the nitrogen lost reduction is assumed to be 40%. As illustrated in Figure 4.24, the nitrogen loss through ammonia emission is reduced to 6,269.8141 tonnes of nitrogen and the nitrogen loss through nitrate runoff is reduced to 4,199.876 tonnes of nitrogen. The rest of the nitrogen is retained in the litter pile for the production of organic fertiliser.

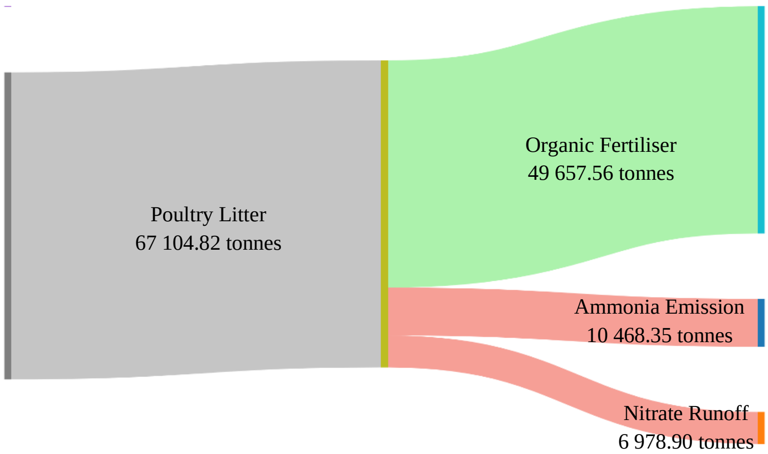


Figure 4.23: Sankey Diagram Before Covered Pilling and Application of Amalgerol.

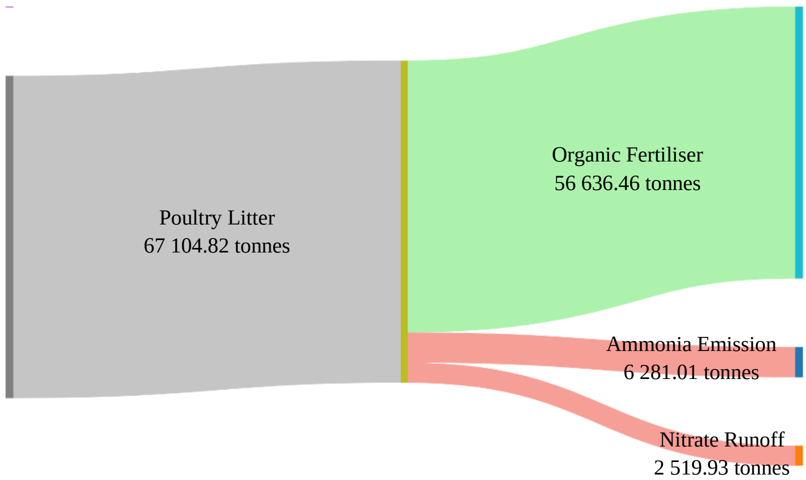


Figure 4.24: Sankey Diagram After Covered Pilling and Application of Amalgerol.

4.4.2.5 Microalgae Cultivation in Wastewater and Sludge Treatment

Without full implementation of wastewater treatment plants (WWTPs) in poultry farms and poultry processing plants, the nitrogen pollution in water bodies is a continuous threat to the environment and economic activities. Aside from that, the poultry farmers are utilising the conventional wastewater treatment facilities to remove nitrogen from wastewater. Conventional WWTPs require mechanical aeration to provide intensive amount of oxygen for the nitrification process. The aeration process is costly and has the potential to remove volatile contaminants (Muñoz, Jacinto, Guieysse, & Mattiasson, 2005). Despite achieving 86% of nitrogen removal efficiency, it has the potential risk to release nitrous oxide into the atmosphere during the denitrification process. It is preferable to mandate the poultry farmers and poultry processing plant operators to equip their facilities with WWTPs to reduce nitrogen emissions.

In recent years, researchers have explored the possibility of removing nitrogen compounds from wastewater completely with microalgae cultivation in wastewater and sludge treatment. With high photosynthetic efficiency and high lipid content, microalgae are the potential raw materials for biofuel production without competing for arable land. However, growing algae requires large amounts of water and nutrients. The aspiring way to make algal biofuel production more cost-efficient is to combine microalgae cultivation with wastewater treatment. The advantage of microalgae cultivation in wastewater treatment is its potential to treat poultry industrial effluent and eutrophic water bodies with lower costs and energy intensity than conventional wastewater treatment. Microalgae grow rapidly in wastewater and produce extensive amount of oxygen for aerobic treatment. Microalgae and heterotrophic bacteria form a symbiotic relationship to assimilate wastewater nutrients and remove organic matter (Jia and Yuan, 2017). Cultivation of microalgae in WWTPs allows the reduction of the production cost and greenhouse gas emissions with high efficiencies. This can be shown in the bio-flocculent alga-activated sludge developed by Karya et al. (2013). The prototype could remove up to 100% of ammonium. Wolfaardt et al, (1994) hypothesised that the presence of microalgae enhanced the performance of bacteria by 37%. According to Luo et al. (2013), the construction cost of a biogas slurry treatment facility with microalgae cultivation was 60% cheaper than the conventional municipal activated sludge treatment facilities.

Figures 4.25 to 4.27 compare the nitrogen outputs from the prospects of poultry wastewater before and after the full application of wastewater treatment and the utilisation of microalgae cultivation. Figure 4.25 was extracted from the Sankey Diagram (Figure 4.9). Among the 2,728.92 tonnes of nitrogen, 1,091.568 tonnes of nitrogen were discharged to rivers without treatment and 1,637.352 tonnes of nitrogen were sent to wastewater treatment plants. As shown in Figure 4.25, the nitrogen removal efficiency of 86% in wastewater treatment plants has converted 1,408.123 tonnes of nitrogen compounds into nitrogen gas, while the unconverted nitrogen was channelled to rivers. Conversely, Figure 4.26 demonstrates the full application of conventional wastewater treatment plants in poultry facilities could reduce the nitrogen discharge level down to 382.0488 tonnes. Apart from this, microalgae cultivation in wastewater and sludge treatment could fully transform the nitrogen compounds into biofuel.

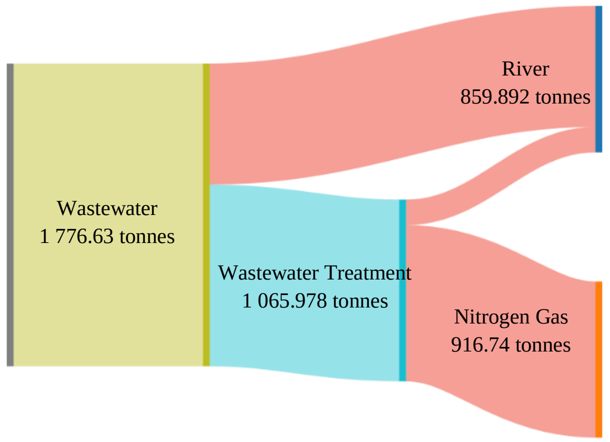


Figure 4.25: Sankey Diagram Before Full Application of Wastewater Treatment and Utilisation of Microalgae Cultivation.

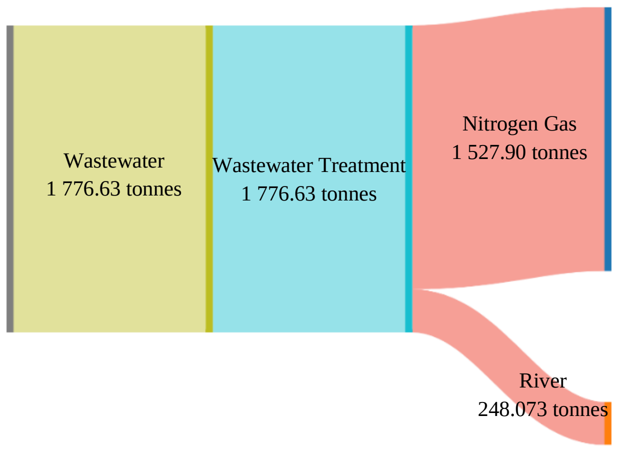


Figure 4.26: Sankey Diagram After Full Application of Wastewater Treatment.

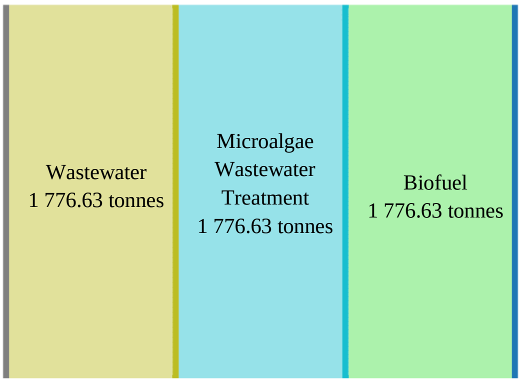


Figure 4.27: Sankey Diagram After Utilisation of Microalgae Cultivation.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This research measured the degree of circularity in Malaysian poultry industry with a LCA of nitrogen. The outline of the nitrogen flows in the Sankey Diagram showed that the industry operates in a combination of a LE model and a CE model in which the waste generated was disposed of and recycled for self-use and general use. Among 277,280.3914 tonnes of nitrogen output, 42.34% was lost to the environment; 29.59% was retained in the poultry products and 28.06% was recovered to generate electricity and produce animal feed meal and organic fertilisers. The nitrogen materials were mostly lost through ammonia emission, nitrate runoff as well as waste disposal and wastewater discharge without treatment. As for the nitrogen input, it was fully dependent on agricultural products such as maize and soybean. Based on the low nitrogen recycling rate in 2019, it could be concluded that the circularity development in Malaysian poultry industry is still lacking. The suppressed industrial circularity was mainly caused by the barriers concerning ineffective implementation and governance mechanism, imbalanced industrial development, limited financial capacity from local financial institutions and lack of a supportive enabling environment. Government initiatives, including the introduction of appropriate governance structure, industrial development gap reduction, budget reinforcement and enabling environment enhancement were proposed as the solutions to assist and guide the poultry farmers in adopting a CE model in their daily operations. In return, the poultry farmers should cooperate with the government by utilising smart farming activities and technologies such as feed ingredient substitution, by-products rendering, ammonia reduction, appropriate litter handling and microalgae cultivation in wastewater and sludge treatment plants to achieve the embracement of CE at its highest potential.

5.2 Recommendations for future work

Throughout this research, several recommendations are proposed for the improvement of future studies. In inventory analysis, a survey on the farming practices of all poultry farms shall be carried out to construct the nitrogen flow in the supply chain accurately. As each poultry farm has different operating procedures, some of the material flow might be left out while connecting the material flow nodes. In this research, the farming practices were collected from the integrated poultry farming companies only. Hence, the LCA performed might have a lower accuracy level. Aside from that, it is preferable to obtain the figures from the local government's statistical data than from research papers. The government's statistical data has precise information and figures with nationwide coverage. It can be used as a reliable source for this research. In comparison, most of the data from research papers are applicable in certain fields and locations only, due to the narrowed research topics and locations. In addition, SimaPro, Tableau and Python are the recommended tools to build a Sankey Diagram. Even though the procedures of using these tools are more complicated than SankeyMATIC, they have no issues in plotting circulation flows in a Sankey Diagram and they give a better material flow visualisation.

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APPENDICES

Appendix A: Nitrogen Flow Quantification

The nitrogen flow quantification in each supply chain division was done separately. The calculation started from feed milling, followed by poultry farm operations, wastewater treatment and poultry waste management.

Feed Milling

The nitrogen input of the feed mill was back-calculated from animals' nitrogen intake. In 2019, the populations of broilers, breeder, local fowls and layers are as follows:

$$\text{Broiler population} = 179\ 893\ 205\ \text{head}$$
$$\text{Breeder population} = 14\ 682\ 328\ \text{head}$$
$$\text{Local fowl population} = 11\ 384\ 160\ \text{head}$$
$$\text{Layer population} = 79\ 103\ 943\ \text{head}$$

Half of the breeders and local fowls were assumed to be male and they have the same feed intake rate as broilers. Based on the poultry farming guidelines prepared by Akinbobola (n.d.), 50 broilers should consume about 130 kg of feed in a month and the broiler feed has 20% of crude protein. Besides, protein is generally assumed to have 16% of nitrogen (Marrioti, Tome and Mirand, 2019).

$$\text{Male breeder} = 7\ 341\ 164\ \text{head}$$
$$\text{Male local fowl} = 5\ 692\ 080\ \text{head}$$

$$\text{Broiler \& male birds} = \text{Broiler population} + \text{Male breeder} + \text{Male local fowl}$$
$$\text{Broiler \& male birds} = 179\ 893\ 205 + 7\ 341\ 164 + 5\ 692\ 080$$
$$\text{Broiler \& male birds} = 192\ 926\ 449\ \text{head}$$

$$50 \text{ birds consume } 130 \text{ kg/month of feed}$$
$$192\ 926\ 449 \text{ birds consume } 501\ 608\ 767.4 \text{ kg/month of feed}$$
$$\text{Broiler feed} = 501\ 608\ 767.4 \text{ kg/month} \times 12 \text{ months}$$
$$\text{Broiler feed} = 6\ 019\ 305\ 209 \text{ kg}$$

$$\text{Broiler nitrogen feed} = 6\ 019\ 305\ 209 \text{ kg } \times 20\% \times 16\%$$
$$\text{Broiler nitrogen feed} = 192\ 617\ 766.7 \text{ kg}$$
$$\text{Broiler nitrogen feed} = 192\ 617.77 \text{ tonnes}$$

Female birds were assumed to have the same feed intake rate as layers. Based on the poultry farming guidelines prepared by Akinbobola (n.d.), a layer chicken can last up to 2 years and would have consumed nearly 69 kg of feed from day old until 2 years old of age. Therefore, the feed intake rate was assumed to 34.5 kg/head. the maximum crude protein requirement for layers is 16.5% (Complete Feed Solutions, n.d.).

$$\text{Female breeder} = 7\ 341\ 164 \text{ head}$$
$$\text{Female local fowl} = 5\ 692\ 080 \text{ head}$$

$$\text{Layer \& female birds}$$
$$= \text{Layer population} + \text{Female breeder} + \text{Female local fowl}$$
$$\text{Layer \& female birds} = 79\ 103\ 943 + 7\ 341\ 164 + 5\ 692\ 080$$
$$\text{Layer \& female birds} = 92\ 137\ 187 \text{ head}$$

$$\text{Layer feed} = \text{Layer \& female birds} \times 34.5 \text{ kg/head}$$
$$\text{Layer feed} = 92\ 137\ 187 \text{ head} \times 34.5 \text{ kg/head}$$
$$\text{Layer feed} = 3\ 178\ 732\ 952 \text{ kg}$$

$$\text{Layer nitrogen feed} = 3\ 178\ 732\ 952 \text{ kg } \times 16.5\% \times 16\%$$
$$\text{Layer nitrogen feed} = 83\ 918\ 549.92 \text{ kg}$$
$$\text{Layer nitrogen feed} = 83\ 918.55 \text{ tonnes}$$

$$\text{Feed nitrogen} = \text{Broiler nitrogen feed} + \text{Layer nitrogen feed}$$

$$\text{Feed nitrogen} = 192\ 617.77 \text{ tonnes} + 83\ 918.55 \text{ tonnes}$$
$$\mathbf{Feed\ nitrogen = 276\ 536.32\ tonnes}$$

According to the feed millers, the feed mill waste was discarded with several methods, including general waste disposal, reselling and reuse in fertiliser production.

$$\mathbf{Disposal\ (Feed\ Mill) = 0.0072\ tonnes}$$
$$\mathbf{Organic\ fertiliser\ plant\ (Feed\ Mill) = 0.0053\ tonnes}$$
$$\mathbf{Reselling = 0.0075\ tonnes}$$

By summing up the feed mill waste with feed nitrogen, the total nitrogen input in feed milling was obtained.

$$\text{Feed Mill} = \text{Feed nitrogen} + \text{Disposal} + \text{Organic fertiliser plant} + \text{Reselling}$$
$$\text{Feed Mill} = 276\ 536.32 + 0.0072 + 0.0053 + 0.0075$$
$$\mathbf{Feed\ Mill = 276\ 536.34\ tonnes}$$

From the annual feed mill report of Malaysian Feedmillers Association, (2017), 15% of the raw materials were supplied by the domestic agriculture industry and 85% were imported.

$$\text{Domestic Agricultural Products} = \text{Feed Mill} \times 15\%$$
$$\text{Domestic Agricultural Products} = 276\ 536.34 \text{ tonnes} \times 15\%$$
$$\mathbf{Domestic\ Agricultural\ Products = 41\ 480.451\ tonnes}$$

$$\text{Imported ingredients} = \text{Feed Mill} \times 85\%$$
$$\text{Imported ingredients} = 276\ 536.34 \text{ tonnes} \times 85\%$$
$$\mathbf{Imported\ ingredients = 235\ 055.889\ tonnes}$$

Poultry Farm Operations

The nitrogen flow quantification in poultry farm operations utilised the production of chicken meat and chicken eggs in 2019 as the starting basis.

$$\text{Eggs produced} = 654\ 000 \text{ tonnes}$$
$$\text{Meat produced} = 1\ 589\ 081 \text{ tonnes}$$

According to British Lion Eggs and USDA, protein makes up around 12.6% of eggs and 27% of chicken meat. Besides, protein is generally assumed to have 16% of nitrogen (Marrioti, Tome and Mirand, 2019).

$$\text{Nitrogen in eggs} = 654\ 000 \text{ tonnes} \times 12.6\% \times 16\%$$
$$\text{Nitrogen in eggs} = 13\ 184.64 \text{ tonnes}$$

$$\text{Nitrogen in meat} = 1\ 589\ 081 \text{ tonnes} \times 27\% \times 16\%$$
$$\text{Nitrogen in meat} = 68\ 648.3 \text{ tonnes}$$

$$\text{Poultry products} = \text{Nitrogen in eggs} + \text{Nitrogen in meat}$$
$$\text{Poultry products} = 13\ 184.64 \text{ tonnes} + 68\ 648.3 \text{ tonnes}$$
$$\mathbf{Poultry\ products = 81\ 832.94\ tonnes}$$

According to Ferket, et al. (2002), 35% of the nitrogen consumed is retained within the animals, while the rest is excreted as manure (45%) and ammonia (20%). Hence, the nitrogen flows in poultry farm operations were finalised with the following values:

$$\mathbf{Feed\ nitrogen\ (100\%) = 276\ 536.32\ \ tonnes}$$
$$\mathbf{Retained\ nitrogen\ (35\%) = 96\ 787.71\ tonnes}$$
$$\mathbf{Manure\ (45\%) = 124\ 441.34\ tonnes}$$
$$\mathbf{Ammonia\ (20\%) = 55\ 307.26\ tonnes}$$

The nitrogen content in inedible parts was calculated by substracting the poultry products from retained nitrogen.

$$\text{Nitrogen in inedible parts} = \text{Retained nitrogen} - \text{Poultry products}$$
$$\text{Nitrogen in inedible parts} = 96\ 787.712\ \text{tonnes} - 81\ 832.94\ \text{tonnes}$$
$$\textbf{Nitrogen in inedible parts} = \mathbf{14\ 954.77\ tonnes}$$

Wastewater Treatment

Research conducted by Avula, Nelson and Rakesh K. Singh (2009) shows that primary and secondary food processing generates 26.5 L/bird of wastewater. The wastewater generated in food processing has a mean concentration of 361.25 mg/L total nitrogen (Maizatul Azrina Yaakob, et al, 2018). With the assumption of all of the reared broilers and half of the local fowl were slaughtered, the number of slaughtered chickens was calculated by subtracting the number of breeders. According to Agrofood Statistic 2019, the numbers of broiler and local fowl in 2019 are 179 893 205 and 11 384 160.

$$\text{Wastewater per head} = 26.5\ \text{L/head}$$
$$\text{Total nitrogen concentration} = 361.25\ \text{mg/L}$$

$$\text{Slaughtered chicken} = \text{Number of broiler} + \text{Number of local fowl}$$
$$\text{Slaughtered chicken} = 179\ 893\ 205\ \text{head} + 5\ 692\ 080\ \text{head}$$
$$\text{Slaughtered chicken} = 185\ 585\ 285\ \text{head}$$

$$\text{Wastewater generated} = \text{Wastewater per head} \times \text{Slaughtered chicken}$$
$$\text{Wastewater generated} = 26.5\ \text{L/head} \times 185\ 585\ 285\ \text{head}$$
$$\text{Wastewater generated} = 4\ 918\ 010\ 053\ \text{L}$$

$$\text{Total nitrogen in wastewater} = \text{Wastewater generated} \times \text{Total nitrogen concentration}$$
$$\text{Total nitrogen in wastewater} = 4\ 918\ 010\ 053\ \text{L} \times 361.25\ \text{mg/L}$$
$$\text{Total nitrogen in wastewater} = 1.7766 \times 10^{12}\ \text{mg}$$
$$\textbf{Total nitrogen in wastewater} = \mathbf{1\ 776.63\ tonnes}$$

The generated wastewater was channelled to rivers and wastewater treatment plants. S. Al-Shididi, M. Henze and Z. Ujang (2003) claimed that the efficiency of nitrogen removal in wastewater treatment plants is 86%. The removed nitrogen was converted into nitrogen gas, whereas the unconverted nitrogen was discharged into rivers.

$$\textbf{Nitrogen discharge} = \textbf{710.652 tonnes}$$
$$\textbf{Wastewater treatment} = \textbf{1 065.978 tonnes}$$

$$\text{Nitrogen gas} = \text{Wastewater treatment} \times 86\%$$
$$\text{Nitrogen gas} = 1\ 065.978\ \ \text{tonnes} \times 86\%$$
$$\textbf{Nitrogen gas} = \textbf{916.74 tonnes}$$

$$\text{Unconverted nitrogen} = \text{Wastewater treatment} \times 14\%$$
$$\text{Unconverted nitrogen} = 1\ 065.978\ \text{tonnes} \times 14\%$$
$$\textbf{Unconverted nitrogen} = \textbf{149.24 tonnes}$$

$$\text{Total nitrogen discharge} = \text{Nitrogen discharge} + \text{Unconverted nitrogen}$$
$$\text{Total nitrogen discharge} = 710.652\ \ \text{tonnes} + 149.24\ \text{tonnes}$$
$$\textbf{Total nitrogen discharge} = \textbf{859.89 tonnes}$$

Poultry Waste Management

Among 14 954.77 tonnes of nitrogen in inedible parts, a portion of the nitrogen was lost during the cleaning operations in food processing. The remaining nitrogen in poultry by-products was calculated.

$$\begin{aligned}\text{Poultry by} - \text{products}& \\ &= \text{Nitrogen in inedible parts} \\ &- \text{Total nitrogen in wastewater}\end{aligned}$$
$$\text{Poultry by} - \text{products} = 14\ 954.77\ \ \text{tonnes} - 1\ 776.63\ \text{tonnes}$$
$$\textbf{Poultry by} - \textbf{products} = \textbf{13 178.14 tonnes}$$

The by-products were sent to rendering plant for material recovery and disposed accordingly.

$$\textbf{Rendering plant} = \textbf{5 271.256 tonnes}$$
$$\textbf{Disposal (By} - \textbf{products)} = \textbf{7 906.884 tonnes}$$

From the nitrogen flow quantification in poultry farm operations, 124 776.1671 tonnes of nitrogen were excreted as manure, while 55 456.0743 tonnes of nitrogen were lost through ammonia emission.

$$\text{Manure} = 124\ 441.34\ \text{ tonnes}$$
$$\text{Ammonia} = 55\ 307.26\ \text{tonnes}$$

A biogas plant located in Johor handles the poultry waste from a population of 1.2 million laying hens. Each bird is estimated to excrete 3.5 kg of manure that has 0.9% of nitrogen within 30 to 42 days of the feeding period (Department of Veterinary Services Malaysia, 2019). The anaerobic digestion in biogas plants has a solid waste weight reduction of 60% after each cycle (Mes, et al., n.d.). The yielded solid waste from the biogas plant was used in the production of organic fertiliser. With this information, the nitrogen flows in the biogas plant were computed.

$$\text{Manure for biogas production}$$
$$= \text{Layer population} \times \text{Manure per head}$$
$$\times \text{ Nitrogen content in manure}$$
$$\text{Manure for biogas production} = 1.2\ \text{M head} \times 3.5\ \text{kg/head} \times 0.9\%$$
$$\textbf{Manure for biogas production} = \textbf{37 800 tonnes}$$

$$\text{Biogas} = \text{Manure for biogas production} \times 60\%$$
$$\text{Biogas} = 37\ 800\ \text{tonnes} \times 60\%$$
$$\textbf{Biogas} = \textbf{22 680 tonnes}$$

$$\text{Organic fertiliser plant} = \text{Manure for biogas production} \times 40\%$$

$$\text{Organic fertiliser plant} = 37\ 800 \text{ tonnes} \times 40\%$$

$$\textbf{Organic fertiliser plant (Biogas)} = \mathbf{15\ 120\ tonnes}$$

$$\text{Remaining manure} = \text{Manure} - \text{Manure for biogas production}$$

$$\text{Remaining manure} = 124\ 441.34 \text{ tonnes} - 37\ 800 \text{ tonnes}$$

$$\text{Remaining manure} = 86\ 641.34 \text{ tonnes}$$

The remaining manure were either used in the production of organic fertiliser or applied on soil without prior treatment.

$$\textbf{Organic fertiliser plant (Manure)} = \mathbf{51\ 984.81\ tonnes}$$

$$\textbf{Disposal (Manure)} = \mathbf{34\ 656.54\ tonnes}$$

By summing up the waste from feed mill, biogas plant and poultry farms, the total nitrogen material for the production of organic fertiliser was calculated.

$$\begin{aligned} &\text{Organic fertiliser plant} \\ &\quad = \text{Organic fertiliser plant (Feed Mill)} \\ &\quad + \text{Organic fertiliser plant (Biogas)} \\ &\quad + \text{Organic fertiliser plant (Manure)} \end{aligned}$$

$$\begin{aligned} &\text{Organic fertiliser plant} \\ &\quad = 0.0053 \text{ tonnes} + 15\ 120 \text{ tonnes} + 51\ 984.81 \text{ tonnes} \end{aligned}$$

$$\textbf{Organic fertiliser plant} = \mathbf{67\ 104.82\ tonnes}$$

A study conducted by Chastain, Camberato and Skewes (2003) stated that the composting activity results in an approximately 26% nitrogen loss in the forms of nitrate and ammonia.

$$\text{Organic fertiliser} = \text{Organic fertiliser plant} \times 74\%$$

$$\text{Organic fertiliser} = 67\ 104.8153 \text{ tonnes} \times 74\%$$

$$\textbf{Organic fertiliser} = \mathbf{49\ 657.56\ tonnes}$$

$$\text{Nitrogen loss} = \text{Organic fertiliser plant} \times 26\%$$
$$\text{Nitrogen loss} = 67\ 104.8153\ \text{tonnes} \times 26\%$$
$$\text{Nitrogen loss} = 17\ 447.25\ \text{tonnes}$$

$$\mathbf{Nitrate\ Runoff} = \mathbf{6\ 978.90\ tonnes}$$
$$\mathbf{Ammonia\ emission\ (Fertiliser)} = \mathbf{10\ 468.35\ tonnes}$$

The summation of the nitrogen waste disposed of from feed mills, food processing plants and poultry farms gave the total nitrogen disposal in the poultry industry.

$$\begin{aligned}\text{Total nitrogen disposal} \\ &= \text{Disposal (Feed Mill)} + \text{Disposal (By} - \text{products)} \\ &+ \text{Disposal (Manure)}\end{aligned}$$
$$\begin{aligned}\text{Total nitrogen disposal} \\ &= 0.0072\ \text{tonnes} + 7\ 906.88\ \text{tonnes} + 34\ 656.54\ \text{tonnes}\end{aligned}$$
$$\mathbf{Total\ nitrogen\ disposal} = \mathbf{42\ 563.43\ tonnes}$$

The summation of the ammonia emission in poultry farms and organic fertiliser plants gave the total ammonia emission in the poultry industry.

$$\text{Total ammonia emission} = \text{Ammonia} + \text{Ammonia emission (Fertiliser)}$$
$$\text{Total ammonia emission} = 55\ 307.26\ \text{tonnes} + 10\ 468.35\ \text{tonnes}$$
$$\mathbf{Total\ ammonia\ \&\ N2O\ emission} = \mathbf{65\ 775.61\ tonnes}$$

Appendix B: SankeyMATIC Input Data

Domestic Agricultural Products [41480.451] Feed Mill
Imported Ingredients [235055.889] Feed Mill

Feed Mill [276536.34] Poultry Farms
Feed Mill [0.0072] Disposal #EB2B17
Feed Mill [0.0053] Fertiliser Plant #145A32
Feed Mill [0.0075] Reselling #47E347

Poultry Farms [81832.94] Products
Poultry Farms [42563.4228] Disposal #EB2B17
Poultry Farms [37800] Biogas Plant
Poultry Farms [5271.256] Rendering Plant #47E347
Poultry Farms [55307.26] Ammonia Emission #EB2B17
Poultry Farms [1065.978] Wastewater Treatment
Poultry Farms [710.652] River #EB2B17
Poultry Farms [51984.81] Fertiliser Plant #145A32

Wastewater Treatment [916.74] Nitrogen Gas #EB2B17
Wastewater Treatment [149.24] River #EB2B17

Biogas Plant [22680] Methane #47E347
Biogas Plant [15120] Fertiliser Plant #145A32

Fertiliser Plant [49657.56] Organic Fertiliser #47E347
Fertiliser Plant [6978.90] Nitrate Runoff #EB2B17
Fertiliser Plant [10468.35] Ammonia Emission #EB2B17