GREENING ANIMAL FARM: A CASE STUDY FOR A PIG FARM

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ABSTRACT

Pork meat is a highly consumed globally due to good taste and being relatively more nutritious than red meat. Hence, there is always a growing demand and need for intensive pig farm production. Currently, successfully operated pig farms practise closed-farming system, also termed Modern Pig Farm (MPF), which basically means all farming operations are done indoors, including waste storage and treatment. The Penang Government had recently passed a law mandating all Penang pig farms to meet the requirements of a MPF system. A pig farm in Penang (open-air farm) was identified as case study for this Research, with the main aim of providing sustainable green farming measures to improve the farm's overall performance to meet MPF standard. A site visit was held at the farm for site observation and data collection. The sample for raw pig waste was also collected at the farm and sent for laboratory analysis. The total pig waste generation was estimated at 51 tonnes/day. A conceptual design for the farm's overall waste treatment system was able to be provided, using a combination of different components for an overall Biogas system integration that will not allow discharge of solid or liquid if it does not meet the relevant discharge regulation parameter. There were many more recommendations for greening measures described in this Study, covering all aspects of farming production, such as improving pig pen design for better wastewater collection and reducing food waste, odour control methods, disinfection protocols, diet manipulation of pigs for higher growth performance, lesser chance of disease transmission, drainage design for optimum waste flow and others. This shows that there are many potential greening tools and measures for further improvement on sustainable pig farming.

Keywords: Modern Pig Farm (MPF), greening, waste treatment, sustainable farming

PENGHIJAUAN UNTUK LADANG TERNAKAN: KES KAJIAN LADANG TERNAKAN BABI

ABSTRAK

Daging babi dimakan oleh kebanyakan penduduk di Dunia, oleh kerana rasa yang sedap dan lebih berkhasiat daripada daging merah. Oleh itu, operasi untuk ladang babi intensif akan makin berkembang. Pada masa ini, sistem rekabentuk penternakan bumbung tertutup berjaya dijalankan. Ladang Babi Moden (MPF), di mana semua operasi penternakan berlaku di bawah bumbung ladang, termasuk proses rawatan sisa buangan. Kerajaan Pulau Pinang telah meluluskan undang-undang yang mewajibkan semua ladang babi di Pulau Pinang perlu memenuhi syarat sistem operasi MPF. Sebuah ladang babi di Pulau Pinang (ladang terbuka) telah dikenal pasti sebagai kajian kes untuk Penyelidikan ini, bagi menyediakan langkah-langkah pertanian berlestari untuk meningkatkan prestasi keseluruhan ladang supaya boleh digelar sistem MPF. Lawatan tapak telah dijalankan di ladang untuk pengumpulan sampel dari sisa babi mentah dan dihantar untuk analisis makmal. Jumlah pengeluaran sisa babi telah dianggarkan sebanyak 51 tan/hari. Konsep Reka bentuk untuk sistem rawatan sisa ladang berjaya disediakan, dengan kegunaan sistem Biogas, dan sisa rawatan pepejal atau cecair tidak akan dibuang ke tempat awam jika tidak memenuhi parameter undang-undang berkaitan. Didapati banyak lagi cadangan untuk langkah penghijauan dalam Kajian ini, yang merangkumi semua aspek operasi ladang babi, seperti meminda reka bentuk kandang babi supaya pengumpulan air sisa yang lebih cekap dan mengurangkan kadar sisa makanan, kaedah pengendalian bau, protokol desinfeksi, manipulasi diet babi untuk prestasi pertumbuhan yang lebih cekap , tahap imuniti yang lebih tinggi, reka bentuk saliran untuk aliran sisa optimum dan lain-lain. Ini menunjukkan bahawa didapati banyak langkah penghijauan yang bermanfaat.

Kata kunci: Ladang Babi Moden, kehijauan, rawatan sisa buangan, penternakan lestari

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LIST OF SYMBOLS AND ABBREVIATIONS

AD	:	Anaerobic digestion
BOD	:	Biochemical oxygen demand
COD	:	Chemical oxygen demand
CO_2	:	Carbon dioxide
CW	:	Constructed wetlands
DLS	:	Deep litter system
DOE	:	Department of Environment
DVS	:	Department of Veterinary Services
EM	:	Effective Microbes
FBT	:	Fermented bed technology
GHG	:	greenhouse gas
GoM	:	Government of Malaysia
HEPA	:	High efficiency particulate air
H_2S	:	Hydrogen sulphide
KVPF	:	Kampung Valdor Pig Farm
CH_4	:	Methane gas
MLSS	:	Mixed liquors suspended solids
MPF	:	Modern pig farming
NH_3	:	Ammonia
PV	:	Photovoltaic
SALT	:	*Skim Amalan Ladang Ternakan*
SPP	:	Standing pig population
SS	:	Suspended Solids
VBE	:	Vegetative environmental buffers

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CHAPTER 1: INTRODUCTION

1.1 Background of Study

Animal farming is ever expanding worldwide, chiefly due to the world's population growth, urbanization and modernization of the smaller cities and towns, and increased income, especially for rapidly developing countries. Globally, the pig farming industry is becoming more intensive and evolved from the traditional small-scale farming, mainly to increase production.

Malaysia, being a Muslim country, which in turn is religiously sensitive to pigs because Islam prohibits the consumption of pork. Hence farmers, suppliers and consumers should be mindful and comply to the latest laws, acts and regulations of the Country. The Government of Malaysia (GoM) is increasingly updating and amending current acts and regulations to balance livestock farming's economic viability with the perceived needs of the general public with regards to environmental pollution, religious sensitivities, health issues and urbanization/development.

In Malaysia, the total estimated population of pigs, also known as standing pig population (SPP), according to the latest Livestock Statistics for year 2020, is around 1.9 million (Department of Statistics, Malaysia, 2021). This number was found to be relatively high compared to cattle, goat and sheep which is about 660 thousand, 320 thousand and 121 thousand respectively. Also from the Livestock Statistics data, the SPP supplied 241,00 metric tonnes (Department of Statistics, Malaysia, 2021) of pork for local consumption in the year 2020. The cost for pork meat production was RM 22/kg (year 2019) and the ex-farm value for pork amounts to RM 4,033 million in year 2020. Pig meat is mostly consumed as fresh unprocessed pork and is the second most consumed meat worldwide for year 2021 (Jacobs, 2021).

In terms of these animal's livestock product, which are mainly pork from pigs, beef from cattle, and mutton from goats and sheep, pork has the highest self-sufficiency as a commodity since 2014 up to now. Figure 1.1 depicts these three livestock product's self-sufficiency ratio for year 2020 which shows that Malaysians can heavily rely on pork meat as a production resource. Fresh pig meat contains the highest amount of water and protein content if compared to beef, chicken, venison and lamb (Federation of Livestock Farmers' Associations of Malaysia, 2021). It also contains plenty of Vitamin B1, which benefits our body's nervous system, as well as a healthier option compared to red meat. China are the largest producers of pork meat, followed by the United States (Jacobs, 2021)

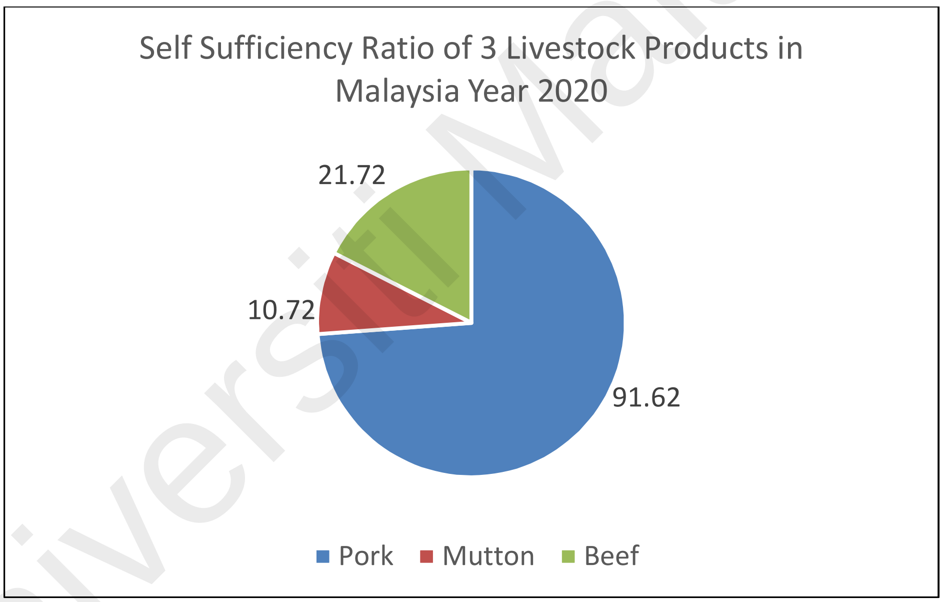

Figure 1.1: Self Sufficiency Ratio of Three Livestock Products by Commodity Percentage in Malaysia, Year 2020

(Source: Data obtained from Department of Statistics, Malaysia, 2021

1.2 Problem Statement

Township development is rapidly increasing at rural areas which may result in more and more local population living in closer proximities to livestock farming vicinities. The direct environmental and social impact from pig farming activities must be properly mitigated, in order for the local population to be able to live in harmony.

The Department of Environment (DOE), Malaysia and Department of Veterinary Services (DVS), Malaysia strongly encourages Modern Pig Farming (MPF) whereby the pigs are kept in a closed house system, in order to better mitigate and control any waste pollution emissions. In Malaysia, less than 10% of all the pig farms are currently operating as a closed house system (Gardir Singh & Wai Jing Fong, 2016).

Environmental issues such as foul odour emissions and discharge of untreated wastewater from livestock farming are becoming more heavily scrutinized by the general public and reported widely by mainstream media outlets. Other than environmental impacts, the overall management of the pig farm production will be evaluated for improvement. This includes the welfare and health management of both animals as well as the workers within the farm.

Currently, farmers have wide range of practices, technologies and methods to achieve a sustainable farming operation, therefore the key is to carefully assess, evaluate and make the right decisions for their livestock farm production.

1.3 Research Questions

i. What are the current issues with pig farming practices contributing to environmental pollution?
ii. How to green pig farms?

1.4 Aim of the Study

The aim of the study is to conduct environmental assessment of a typical Malaysian pig farm and identify possible greening opportunities. The context of greening animal farms in this Research Project is to conserve and preserve the existing environment by recommending sustainable methods on improving all aspects of livestock farming. The overall wastewater and solid waste generated from the farm will be quantified and assessment will be made on general information, overall collection, treatment, waste generation and potential for green initiative implementation.

1.5 Objectives of the Study

The objectives of this study are:

i. To determine the pollution potential of a chosen pig farm.
ii. To generate greener options that can be implemented in a pig farm.
iii. To evaluate the green options for possible implementation on animal farms.
iv. To identify factors that contribute to sustainable farming.

1.6 Scope of the Study

The study is conducted to assess the typical waste management of Malaysian pig farm. The data obtained in this study was generated from an existing pig farm in Kg Valdor, Penang, referred to as Kampung Valdor Pig Farm (KVPF).

1.7 Significance of the Study

The findings from this study are important to identify the potential of developing green options for a typical Malaysian pig-farming system, in order to considerably improve the efficiency of farming operations as well as the existing surrounding environment in a sustainable manner. The main recommendations of this Research will be able to:

a) Reduce surface and groundwater pollution caused by improper disposal of the pig waste discharges into drains, river streams and on the ground.

b) Reduce foul odour and discomfort faced by residents of nearby residential areas.

c) Reduce the emission of methane (a greenhouse gas) to the atmosphere.

d) Improve waste management systems to significantly reduce the amount of solid wastes flowing into the streams and water bodies, thus reducing the need for desludging of the water bodies and eliminate soil contamination.

e) Improve and maintain the pig's overall health, performance with proper disease management.

f) Infrastructure Design considerations for a greener pig farm

1.8 Thesis Outline

This Research Project consists of five (5) chapters and the brief outline is described as below:

Chapter 1 – Introduction on the background of the study with the current overall outlook of the pig farming industry followed by the general issues and challenges being faced, mostly from an environmental, public health and social perspective. A pig farm in Penang was identified as a case study for project's scope and then the expected desired outcomes to overcome the issues and challenges were listed out.

Chapter 2 – Literature review was carried out, initially on current local laws and regulations governing the pig farming industry and identified, then research on the general management of farms being operated in Malaysia. The environmental impacts described the major issues caused by the pig farms' waste management, and be able to get ideas on reducing the generation of it. The final sections provided the acceptable and approved technologies for treating the waste already operating at successfully run pig farms.

Chapter 3 – In this chapter, data collection, observation and sampling was performed by two ways, which was Site Visit to the chosen pig farm and desktop study of the farm's current situation and existing environment.

Chapter 4 – The data obtained from Penang Pig Farm and information from literature review was useful to be able to produce process description for waste treatment system that will significantly lower the potential environmental impacts from the pig farm. However, in order to move towards a more sustainable farming industry, the treatment system prepared is just one of many methods. Greening principles are embraced, in order to provide better farming management methods at a macro-level, which involves all aspects of the farm, and not just on waste generation and treatment.

Chapter 5 – All the greening methods, options, procedures and designs that were described in Chapter 4, were summarised for recommendations towards more sustainable animal farming.

CHAPTER 2: LITERATURE REVIEW

2.1 Pig Farm Environmental Guidelines and Regulations

The Government of Malaysia (GoM) are at all times updating and amending current acts and regulations to balance food security with the perceived needs of the general public with regards to environmental pollution. Livestock farms in Malaysia that are considered on par with international standards are certified under the Livestock Farm Accreditation Scheme or *Skim Amalan Ladang Ternakan* (commonly known as SALT). The criteria for a livestock farm to obtain SALT certification is by having implemented good animal health management programs, biosecurity programs, sanitation and hygiene programs and farm waste management programs (IBU PEJABAT PERKHIDMATAN VETERINAR, 2012)

2.1.1 Local Authority Requirements

The Penang Pig Farming Enactment 2016 was approved by the Government of Penang and gazetted in 2017 specified that all pig farming activities in the state must employ Modern Pig Farming (MPF) practices which includes the following four criteria, namely; upgrading to a closed farm system, minimum of 250meter buffer zone to nearest residential area, acceptable waste treatment system and good animal husbandry practice (Government of Penang, 2017). Figure 2.1. shows an example of an open pig farm whilst Figure 2.2 shows an example of a closed pig farm.

Figure 2.1: Example of Open Pig Farm

Figure 2.2: Example of Closed Pig Farm

2.1.2 Guidelines for Waste Management

The Guidelines for Pig Farm Waste Management was published by the Department of Veterinary Services, Malaysia to guide pig farmers towards reducing and minimizing the generation of wastes in pig farms (Jabatan Perkhidmatan Veterinar Malaysia, 2019).

2.1.3 Guidelines for Wastewater Treatment System

A document titled "The Effluent Treatment System Guidelines for Pig Farmers" by DOE, Malaysia provided guidelines for effluent treatment systems. This documents further encourages the use of latest technology in the management and treatment of pig waste generated by the pig farms, and to ensure that the farms have a systematic treatment system (Jabatan Alam Sekitar, 2016).

The national law governing the quality of effluent from pig farms is the Environmental Quality (Sewage) Regulations 2009. Since the effluent discharged from KVPF does not flow into any inland waters within catchment areas as listed in the Third Schedule of this Regulation, the specified parameters cannot exceed the values in Standard B (Department of Environment, Malaysia, 2009) as shown in Table 2.1 below;

Table 2.1: Limit of Allowable Wastewater Quality Discharge

No.	Parameter	Unit	Max Limit
1	[1]BOD_5 at 20°C	mg/L	50
2	[2]COD	mg/L	200
3	Ammoniacal Nitrogen	mg/L	50
4.	Suspended Solids (SS)	mg/L	100
5	pH	-	5.5 – 9.0

1 – Biochemical Oxygen Demand
2 – Chemical Oxygen Demand

2.1.4 Livestock Breeding Policy 2013

This policy's main aim is to encourage livestock breeding in Malaysia to be practised in an economical and sustainable way. The genetic quality of pigs can be improved via cross-breeding between local pigs with foreign pigs (DVS, 2013) resulting in healthier, bigger and more fertile pigs which means less deaths or lower quantities of pig carcasses, indirectly lowering the pig farm's environmental impact.

2.2 Typical Pig Farm Management in Malaysia

In Malaysia, less than 10% of pigs farms currently implement closed house systems (Gardir Singh & Wai Jing Fong, 2016). Most of the traditional farming operations have been replaced with intensive farming, with the main aim of increasing the farm's productivity and income. However, it became clear from public complaints and wide reporting from media news outlets due to the polluted river streams and bad odour that the farms are lacking a fully comprehensive waste treatment system (Jabatan Alam Sekitar, 2016)

2.2.1 General Pig Farm Infrastructure

Almost all the pig farms in Malaysia house the pigs full-time in the pig pens, without using separate crates for the different stages of pig production. Even if crates are used in the pens, it is usually open-air and not fully efficient. The design of closed system pig farm should have enough space for the comfort of the pig's everyday activities such as eating and breeding, as well as taking care of their feed/ water consumption for better manure management.

The construction material of pens is usually made out of concrete, while the walls of the compartment in the crates are made of concrete or galvanized steel. Floors are usually concrete and not slag. In addition to pigs needing to be bathed, waste will accumulate and farmers need to wash the floor two times a day. Improper maintenance will cause cracks in the floor and cause waste and wastewater to accumulate.

Most pig farms in Malaysia only provide one network of drainage around the pig houses, meaning that the farm's wastewater will mix together with the rainwater. (Jabatan Alam Sekitar (JAS), 2014). The direct consequence of this is the increase for the farm's overall wastewater volume.

2.2.2 Pig Farm Production Stages

The main stages involved for pig farm production are explained in the following section:

a) Breeding

Cross breeding between the male breeds for pigs (boars) in Malaysia (*Duroc, Hampshire, Pietrain)* and the female breeds, also known as gilts (female pigs that have not bred yet) or sows, (*Landrace* and *Large White)* (Gardir Singh & Wai Jing Fong, 2016) is performed to obtain its ideal genetic characteristics depending on the farm's needs. In Malaysia, Artificial Insemination is the usual breeding method performed in the pig farms.

b) Gestation

After the sow finishes the breeding stage and is confirmed mated, it will be considered pregnant after about a month of not having heat. The pregnant sow will be relocated to a farrowing crate one week before expected its expected farrowing (giving birth) date.

c) Farrowing/Lactation

Lactating sows are provided with extra food quantity to ensure there is enough milk production to feed her piglet litter. The sow's appetite may decrease slightly due to heat issues. Farrowing sows and their piglets will be confined in individual farrowing crates with slatted floors.

d) Weaning

Piglets are classified as weaners after lactation stage with the sow has ended. Next, they are weaned at day 21 of age up to day 35 from birth. This period is the most challenging for piglets due to being away from the sow for first time and change in diet from milk to solid feed. The piglets are provided creep feed, which is their first solid feed encountered.

e) Growing and Finishing

The grower stage until finisher stage describes the period from Day 60 to market age (Day 180), whereby the live weight should be around 90-110kg per finishing pig. This means it takes approximately 5 – 6 months to rear a pig since birth until market weight. When the pig reaches around 50kg, feed intake is reduced to prevent pig obesity.

f) Gilt and Boar Replacement

Farmers will be selecting the replacement gilts during the grower to finisher stage (when its weight reaches 70 – 80 kg). If the quantity if replacement gilts could not be met, the farm will purchase new gilts for the breeding stage. The ratio of boars to sows is usually 1:60 hence, purchasing new boars is a rare event. Malaysian farmers usually import replacement boars from overseas.

A simple flowchart to summarize all the stages involved in pig production rearing can be referred to in Figure 2.3.

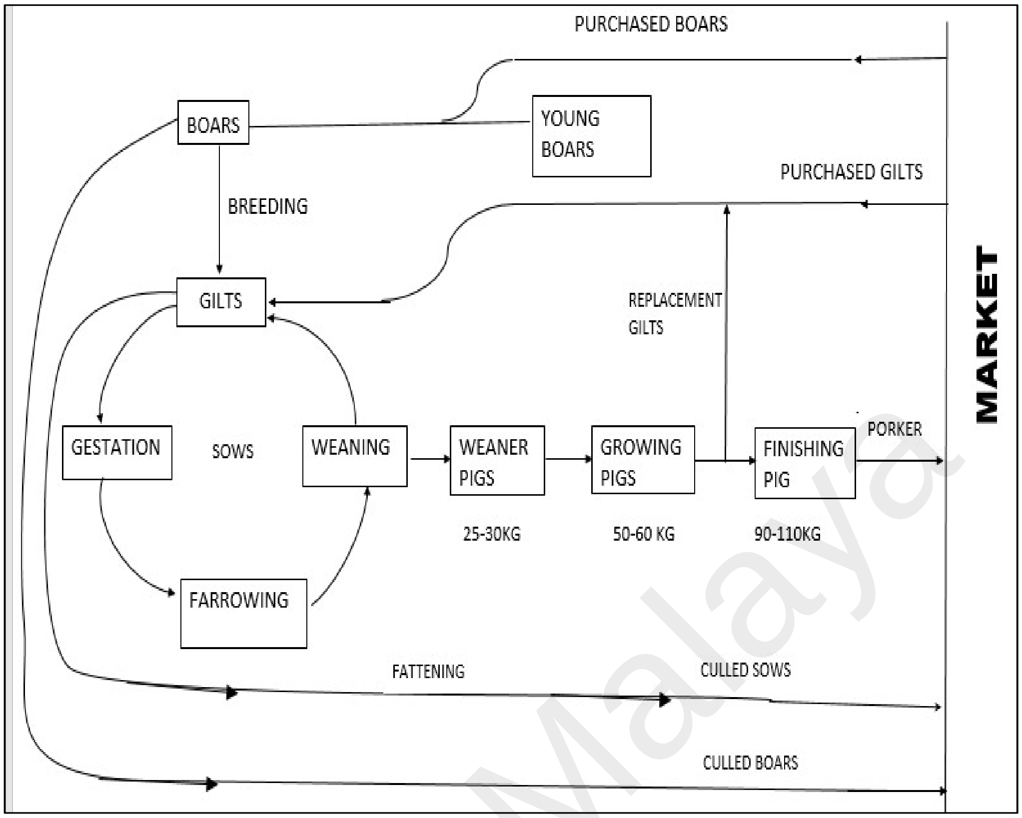

Figure 2.3: Pig Farm Production Flow Chart

2.2.3 Feeding

Feed is one of the most important aspects for commercial pig farming. The feeding budget (comprising of feed cost, labour cost and transportation cost) can reach up to 55-65 % (Agriculture and Consumer Protection Department, 2014) of the total pig production cost. On average, about 5 to 6 kg of feed will produce 1 kg of live pork from a farm (Managing Pig Health, 2021)

The main ingredients utilized in Malaysian pig farms are rice bran and palm kernel cake. Other commonly used feed includes corn/ maize, rice bran, wheat bran and pollard, fish meal, skimmed milk powder, copra meal and soybean meal, most of which are imported and costly. The average feed intake for a pig is 2kg/day, and recommended to be fed twice a day either manually with traditional feed trough or automatically using self-feeder (van Zanten, Bikker, Mollenhorst, Meerburg, & de Boer, 2015).

2.2.4 Water Usage and Waste Generation

Apart from the need for pigs to drink water, other significant usages of water in pig farms are for bathing/cooling the pigs, and washing off wastes from the pig pens, usually by hosing the floors. Since deep litter system is not commonly practiced in Malaysia, pig faeces is needs to be washed away with water (Gardir Singh & Wai Jing Fong, 2016). The average intake of daily drinking water for a pig is about 7 – 10 litres/pig (Huong, et al., 2020). Overall, the daily total wastewater generated in a pig farm is estimated at **30 - 40 litres/pig,** the main source being from bathing or cooling the pigs and washing the pig pen floors (Hai Van, et al., 2017) (Gardir Singh & Wai Jing Fong, 2016).

Pig farming activities produce certain types of solid waste, the main composition being pig faeces, pig carcass, leftover pig feed and sludge. Approximately **4 kg** of pig manure (faeces and urine) is excreted per pig on average each day (Varma, et al., 2021). The majority of farms in Malaysia will usually dispose pig carcasses by burning or burying within the vicinity of the farm.

2.3 Environmental Impacts

This section briefly describes on all the major negative environmental impacts caused by farms with poor management of waste treatment.

a) Water Pollution

Since most pig farms in Malaysia do not implement a comprehensive waste treatment system, the solid waste containing high composition of pig manure, are usually utilized as soil conditioners or compost for agricultural activities that are nearby watercourses. Therefore, water pollution can occur via surface runoff and leaching of manure fertilizer eventually contaminating the groundwater. Other than that, the dumping of untreated wastewater from the farm directly into public water bodies induces eutrophication. All of this results in highly polluted surface and groundwater with high nutrient contents of total nitrogen and total phosphorous as well as heavy metals (Thien Thu, et al., 2012).

b) Pig Manure Emissions

The manure waste produced in pig farms has potential to cause various environmental impacts such as water pollution, odour and contaminated soil. If this pig manure does not undergo the required proper treatment, it will produce highly hazardous environmental pollutants, such as GHG emissions (methane and nitrous oxide) as well as ammonia and hydrogen sulphide emission. There have been cases reported where a pig was found to be carrying an infectious disease, its excreted faecal matter will contain pathogens that are very hazardous to public health and other pigs (Boonyanuwat, Kinh, Sithambaram, & Widyawati, 2013).

c) Soil Pollution

The practise of repeated manure application as fertilizer on agricultural land without having any downtime and with improper manure storage will promote pathogenic contamination in the organic fertilizer. Hence, the pig manure will directly pollute the soil, as it contains bacteria and viruses. Moreover, accumulation of heavy metals such as copper, cadmium, and zinc in the soil causes serious environmental and health issues.

d) Air Pollution

Air pollution and bad odours from farms are probably the single most complained about issue faced by the livestock farming industry. The main sources of odour emissions from pig farms are from the pig feed, manure, farm wastewater, pig pens and waste treatment systems. If the management for these items are found to be lacking, the odour emission will get more and more intense leading to hazardous health and environmental issues.

e) Dust and Other Particles

The main source for dust and other particles are usually from pig manure, feed, animal dander, moulds, pollen and insect parts. Dust that are present at livestock farms are considered as organic dust, with high potential of having hazardous compounds. Machete & Chabo (2020) had recorded high concentratioms of the following dust aerosols in pig farms; bacteria, endotoxins, respirable dust and fungi. Prolonged period of exposure to these harmful aerosols can cause respiratory issues for both human and animal.

2.4 Pig Farm Waste Treatment Systems

Waste from pig farming activities typically consists of solid and wastewater, most of it being pig waste slurry (pig faeces and urine, wastewater from washing pig pens and bathing the pig). The section below provides detailed guidelines of the appropriate pig farm waste treatment system recommended by DVS and DOE, Malaysia. The main components of pig waste treatment combines both Physical and Biological treatment.

2.4.1 Physical Treatment

The pig waste slurry first enters the collection point (manure pump pit/ pre-storage/lagoon). The waste from the collection point is then pumped to a separator equipment for separation of the physical waste and liquid waste. The solid waste can be separated out, whilst the liquid is drained to the biological treatment system. The solid separation step is important due to:

i. The separated fluid will be easier to pump or flow to the subsequent treatment system;

ii. The liquid avoids forming a crust (scum) along with the solid waste which would interfere with the decomposition process during Biological Treatment, and

iii. Reducing the high organic load content entering the biological treatment system so that the decomposition process can occur at faster rate.

However, it should be noted that solids separated before treatment are still unstable (high in pathogens) and cannot be used for agricultural purposes yet, as commonly practised by most farmers. Further treatment of the solids is still required, before undergoing fermentation or composting process for the final product as organic fertilizer in the commercial market. Figure 2.4 illustrates an example of the solid and liquid waste separation machine.

Figure 2.4: Example of Waste Separation Mechanism

2.4.2 Biological Treatment

Regarding treatment of the pig waste, the best alternative to be adopted must have the optimum capacity to bring upon a significant improvement to the existing environment, while allowing for capitalization of the economic value of its by-products. Based on literature review, the recommended waste treatment technology options used in pig farms are all described from sub-sections 2.4.2.1 to 2.4.2.5;

2.4.2.1 Waste Stabilization Pond System

The waste stabilization pond system is one of the easiest and least expensive treatment methods for manure slurry from livestock farming. Generally, this treatment system is used at small scale livestock farming, meaning to house a maximum number of 250 animals at any given time. On a whole, there are usually 4 different types of ponds, depending on the efficiency of biological decomposition process of said ponds. Table 2.2 provides descriptions for all the ponds with their respective design criteria and accompanying picture example.

Table 2.2: Description for All Waste Stabilization Ponds

No.	Type of Pond	Description
i.	Anaerobic Pond	 Pond density - 0.4 m^3/pig Pond size area – 0.16 m^2/pig Pond depth – 3.9 m Retention Time – 10 days

No.	Type of Pond	Description
ii.	Facultative Pond	 Pond density - 0.8 m^3/pig Pond size area – 0.32 m^2/pig Pond depth – 3.0 m Retention Time – 20 days
iii.	Aerated Facultative Pool	 Pond density - 0.8 m^3/pig Pond size area – 0.24 m^2/pig Pond depth – 4.0 m Retention Time – 20 days

No.	Type of Pond	Description
iv.	Aerobic/ maturation pond (completely mixed aeration)	 Pond density - 0.2 m^3/pig Pond size area – 0.16 m^2/pig Pond depth – 1.5 m Retention Time – 5 days

The major costs involved is the cost of initial construction and maintenance of once every 2 - 3 years for sludge cleaning. The system needs to be well maintained periodically, because failure to do so would result in the system not being able to achieve the required level of wastewater quality standards. Sludge from the ponds are usually used for composting.

2.4.2.2 Bio-filter System

The bio-filter system is an integrated system that modifies the existing biological treatment pond system by adding water pumps, bio-filter tanks, sedimentation tanks and solid waste collection tanks. This system decreases use for area of land and has the ability to reduce the level of pollution up to the wastewater guideline standards set by DOE. However, this system involves very high capital expenditure. Sludge that is produced after this treatment system will be utilized for one of the following activities:

- Agricultural crop; used as compost or soil conditioner.

- Soil reclamation: used as organic matter for the soil.
- Spread in forest areas as an organic fertilizer.
- Fish rearing; used in fish ponds as fertilizer for algae.

The bio-filter consists of a tank containing a functional media (see Figure 2.5) to increase the surface area of attached microorganisms for the decomposition of organic matter in wastewater. Bio-filter systems are usually stable and able to treat various concentrations of wastewater.

Figure 2.5: Bio-filter Containing Functional Media Balls

2.4.2.3 Aerobic Bioreactor System

The concept for this system is more or less similar to the Bio-filter system described above, but it does not use a bio-filter tank with functional media. A case study for this system is the 'Toyo Bioreactor System' (refer Figure 2.6) currently in use at a pig farm in Mersing, Johor Bahru (Liang, Kayawake, Sekine, Suzuki, & Lim, 2017). This system was designed for the use of a total of 6,000 SPP with a daily wastewater generation of 40L /pig. The system consists of a solid separator fluid, receiver tank, aeration tank, Bioreactor unit, sedimentation tank and purifier. The unique feature of this system is the use of Effective Microbes (EM) that allows the growth of aerobic microorganisms. This method helps to speed up the process of organic matter decomposition, during treatment of wastewater and composting of livestock solid waste (Jabatan Perkhidmatan Veterinar Malaysia, 2019). Construction and operational costs depends on the livestock population, concrete materials and activating agents used. Overall, the Aerobic Bioreactor System can reduce the pollution rate in accordance to the quality standards set by DOE.

Figure 2.6: Example of Toyo Bioreactor System

2.4.2.4 Biogas System

Anaerobic digestion (AD) is a biochemical process whereby organic materials can be converted to biogas in the absence of oxygen. According to Abdeshahian et al., (2016), treatment of animal waste with Biogas system is highly beneficial due to the:

- Production of renewable energy
- Reduction in foul odours and GHG emissions.

- Solids recovered can be utilised for compost or fertilizer

There are four main biological processes in anaerobic digestions and these processes are summed up in the Table 2.3.

Table 2.3: Biological Processes in Anaerobic Digestion

Process	Description
Hydrolysis	Complex organic matter and high molecular weight material is decomposed into simpler and soluble compounds by the hydrolytic enzymes. Carbohydrate, lipid, and proteins are converted to glucose, glycerol and pyridines.
Acidogenesis	Product of hydrolysis stage are further metabolized by the acidogenic bacteria into short chain fatty acids and alcohol together with hydrogen, H_2 and carbon dioxide, CO_2.
Acetogenesis	The alcohols and volatile fatty acids generated from acidogenesis stage are then converted to acetic acid, H_2 and CO_2 by acetogens which are precursors for biogas production.
Methanogenes	The product from the previous stage can be broken down into two main gasses by the methanogenic bacteria, methane and carbon dioxide

ADs are globally renowned since it can generate biogas which then can be used to generate power to be sold to the electricity supply grid. It is also a common treatment method for animal waste in Europe and China as fuel can be recovered from the AD and used for combined heat and power (Khoshnevisan, et al., 2021). Other advantages of using ADs are as follows:

i. Recovery of Biogas - AD system is usually regarded as net energy user.
ii. Biogas product can be stored to generate power which can then be exported to the grid.
iii. Reduces Biomass Generation - AD has the potential to remove 50% of feed sludge solids and the digested sludge is usually well stabilized.
iv. Odour Control - AD is a closed system, hence this helps prevent the release of odour-causing compounds such as Hydrogen sulphide (H_2S) and volatile solids

inside the sludge. This will help improve the air and odour conditions of the surrounding community.

Overall, a biogas system is the process of anaerobic (closed system) decomposition of organic matter in a digestive tank (digester). The main component from biogas is methane gas, CH_4 (60 - 70%) and carbon dioxide, $C0_2$ (30 - 40%) (Kumaran, Hephzibah, Sivasankari, Saifuddin, & Shamsuddin, 2016). Methane emissions can be controlled by making it a renewable energy source such as fuel and electricity generation. This process produces sludge that has been stabilized (digested) from the AD. The settled sludge (solids) can potentially be used to fertilize crops or as a soil conditioner with minor dewatering and binding treatment.

2.4.2.5 Constructed Wetlands

Constructed Wetlands (CW) involves a treatment process carried out in an open pond that houses wetland or vascular plants, which is a kind of vetiver grass. This system is ideal for treating wastewater with high loads of organic and chemical contaminants and at the final discharge point, overall volume of the initial wastewater is reduced as well.

The main role of CW is to finalise effluent treatment by obtaining cleaner wastewater which can then be recycled back into the pig farm. The wetland plants are able to absorb organic matter, particularly ammonia and phosphate (Pongthornpruek, 2017) hence, ammonia contamination (projecting foul odour) is prevented from occurring in the downstream areas of livestock farms. The wetland can be designed for a horizontal surface flow as seen in Figure 2.7. The course media usually consists of crushed limestone and the main bed media can be gravel or sand. The wetland media plays a number of roles, such as for biofilm development whereby the microorganisms living between the pores can treat waste materials, support the wetland plants in place and prevent soil build-up (Lesikar, Weaver, Richter, & O'Neill, 2019)

CW offers a more budget friendly and sustainable option for wastewater treatment because it requires less power consumption during its operation & maintenance (Wu, Lei, Lu, Guo, & Dong, 2015). Not only does it minimize the effluent pollutant load, it also decreases the volume of wastewater. CW also has an added advantage, whereby other than being mainly a wastewater treatment system, it also expands the richness of the land environment as well as being visually aesthetic. The final wastewater produced after this treatment will then be able comply with Environmental Quality (Sewage) Regulations 2009 Standard B by DOE, Malaysia.

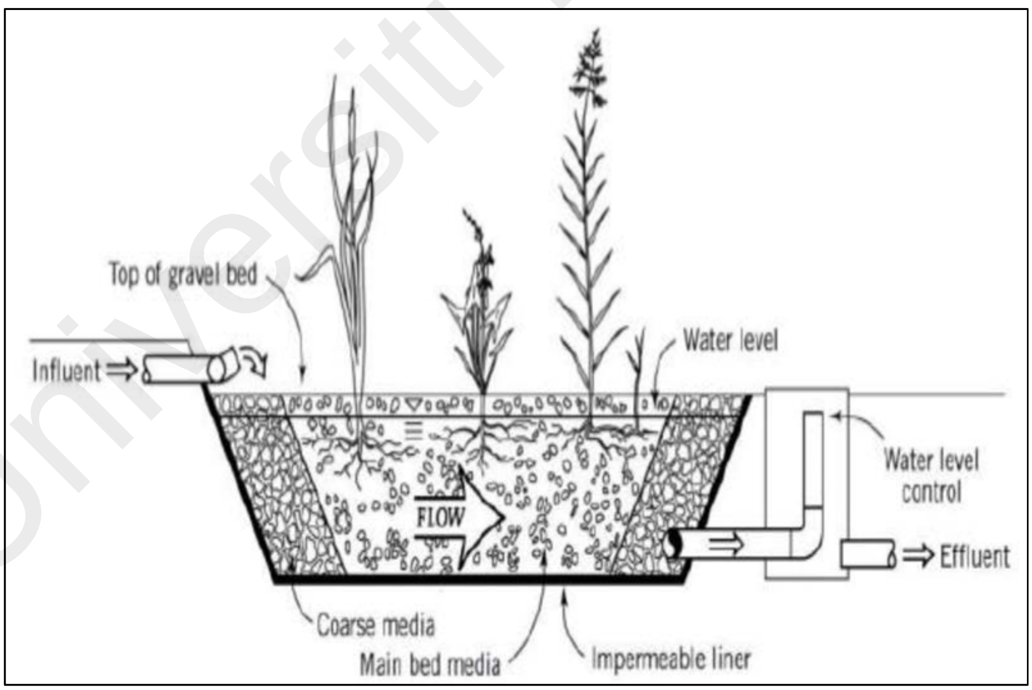

Figure 2.7: Constructed Wetland Horizontal Surface Flow (Source: Jabatan Alam Sekitar, 2016)

2.5 Research Gap

Most of the literature available in greening pig farms focuses mainly on livestock's waste management, that includes collection, treatment and final disposal or recycle/reuse. However, the financial implications of following the waste management guidelines may not be practical for all, specifically on a smaller farm, mainly due to lower feed input resulting in lower waste output. This work intends to provide the recommendations and feasible options that can be used to green pig farms

2.6 Summary of Literature Review

Initial research was done on environmental laws and regulations related to pig farming to gain knowledge on specific aspects of pig farming that are closely monitored for compliance with local and national regulations, and from the perspective of the farmers. Also, useful information was obtained on the exact waste parameters and characteristics that is allowed to be discharged or disposed.

Next, I needed to understand the inner workings or day-to-day operation and management of a typical pig farm. This would prepare me for when Site Visit is undertaken to my own pig farm case study. I obtained valuable information on the facilities layout and design, all the stages experienced by the pigs during their production cycle, and expected quantities of food intake, water usage and waste generation.

There was a number of literature studies to be found on the topic of environmental pollution borne from improperly managed pig farming. However, there were plenty useful research studies found for the corresponding mitigation measures, waste treatment techniques and protocols/ procedures to run a well-managed and sustainable pig farm. The final part of Literature review section had described all the recommended and accepted waste treatment systems for implementation on pig farms

The Department of Veterinary Services (DVS), Malaysia, Malaysia recommends that each individual pig farm needs to properly evaluate and assess their own farm's overall management and operations information, especially on waste generation, in order to properly decide the waste treatment system to be implemented. Usually, an integration of a few treatment systems are designed for installation, in order for the pig farm waste quality final discharge can comply with DOE, Malaysia's Environmental Quality (Sewage) Regulations 2009 (Jabatan Perkhidmatan Veterinar Malaysia, 2019).

CHAPTER 3: METHODOLOGY

3.1 Introduction

In this chapter, the methodologies used to gather, collect and collate data are presented. Also discussed here was a general work plan flow for this Research Study. Site visit was done for field observations and farming operations. After that, desktop study was performed to gather all available information on existing environment around KVPF site. Figure 3.1 shows the flowchart for this Study.

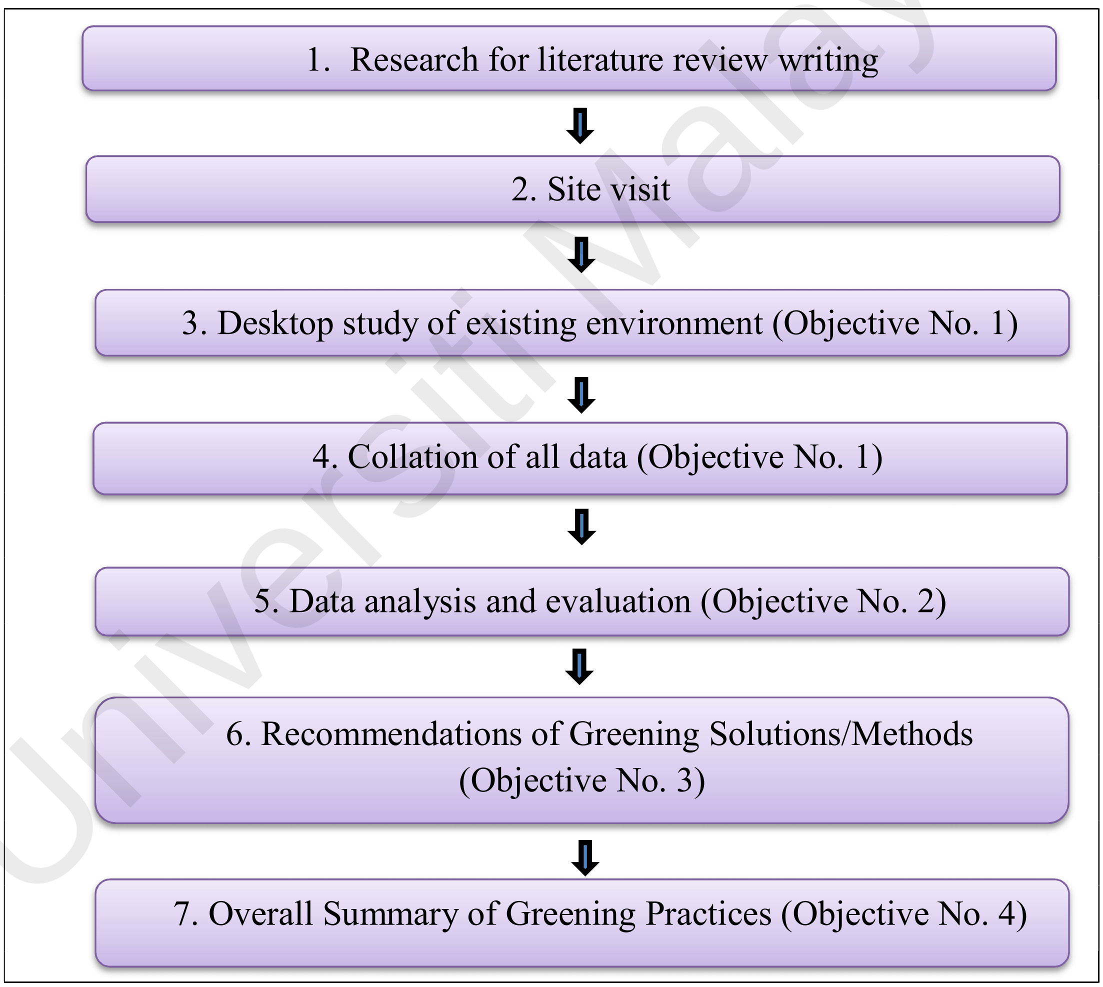

Figure 3.1: Research Project Flowchart

3.2 Description of Kg Valdor Pig Farm Site Location

Kg. Valdor is well known for its agricultural activities, primarily pig and poultry farming. The primary access within the town is Jalan Valdor, the southern end of which connects to Jalan Sungai Bakap. There are an estimated total number of 35 pig farms and 1 pig slaughterhouse within 1km radius of Kg. Valdor. The Kg Valdor Pig Farm (KVPF), selected for this Research Study, is located in the centre of Kg. Valdor, a small town located between Simpang Ampat to the north and Sungai Bakap. to the South, in South Seberang Perai, Penang, Malaysia. Figure 3.2 below shows the location of the farm with its surrounding layout.

Figure 3.2: Map Location of Farm (Source: (Google Earth, 2019))

3.3 Description of Existing Environment

KVPF is surrounded predominantly by land plots on which pig and poultry farming is carried out in Kg. Valdor, and residential dwellings that are occupied by the respective farm owners or operators. Based on field observations, the activities within a 500 m radius of KVPF can be classified into plantation (oil palm) and animal farming (pig and poultry). Figure 3.3 shows the existing landuse within the vicinity of KVPF.

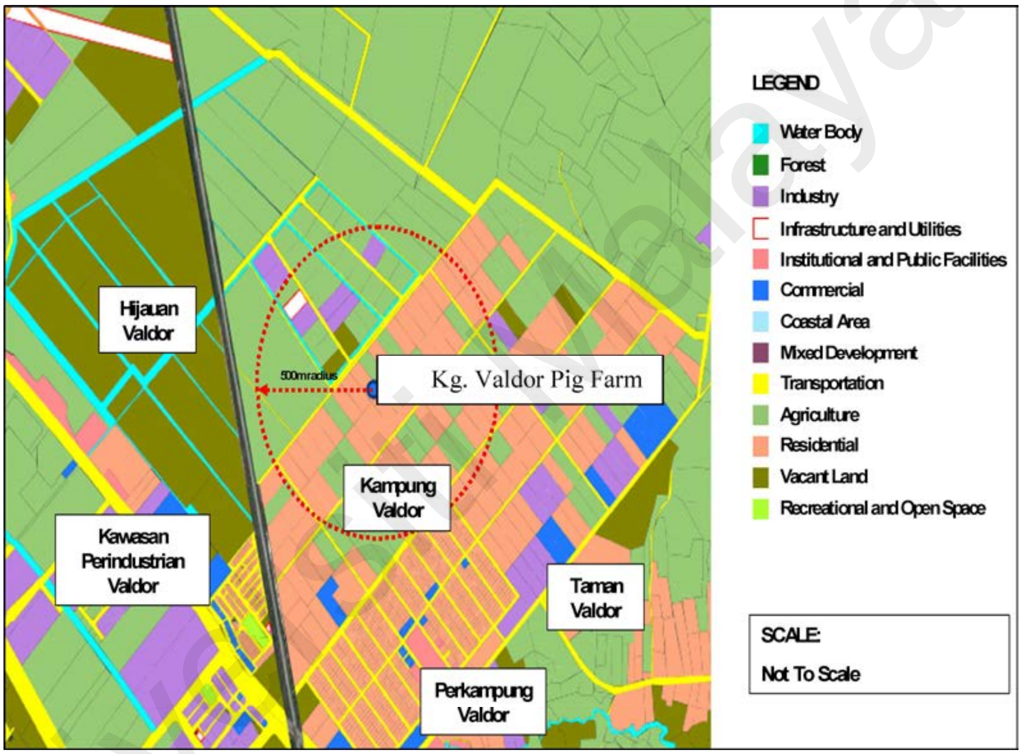

Figure 3.3: Landuse Within Farm Vicinity

(Source: PLANMalaysia@PulauPinang)

Snapshots of local newspaper articles from year 2018 and 2020 in **Figure 3.4 and Figure 3.5** illustrate the issues affecting the local population in Kg. Valdor and the surrounding areas due to pollution issues caused by the pig farming practices.

Figure 3.4: Media Clippings of Odour Emission Issues from Pig Farms in Kg Valdor, Penang
(Source: The Straits Times: Asia (2018) and TheStar News (2018))

Figure 3.5: Media Clippings of Waste Dumping Issues from Pig Farms in Penang.
(Source: FMT News (2020) and Bernama (2020))

The nearest river to KVPF is Sg. Jawi (closest point at approximately 2 km). Wastewater that is discharged from KVPF flows into internal drains and eventually into Sg Jawi. The farm is mostly surrounded by oil palm plantation estates and mini-industrial scale factories.

At present, the pig farm waste from KVPF are being disposed to the local drainage network and river streams with minimal treatment, thereby resulting in a high amount of organic pollutants contaminating the surface water as well as groundwater and generating foul odour. The pig farm wastes that are discharged into the streams in Kg. Valdor is carried through the drainage systems and flows into Sg. Jawi. Build-up of sludge along these drains and the subsequent release of methane gas into the atmosphere are characterized by extremely foul odour which can be smelled by people of surrounding road networks, including the North-South Highway. The Government of Penang has passed a decree to all the owners and farmers of pig farms that they have until 31st December 2021 to employ MPF practices (closed farming) (Government of Penang, 2017). Therefore, there is a drastic need to provide greener solutions for KVPF.

The pig waste slurry from KVPF is currently channelled into a sump pit within the farm. A simple decanter system (refer to Figure 3.6) is used to separate the settled solids and the liquids as the only waste treatment method. The solids are then transported out of the farm for disposal to landfill and the liquid is dumped into Sg. Jawi. The current method of wastewater treatment produces unclean discharge and causes water pollution in Sungai Jawi. The following Figure 3.7 and Figure 3.8 shows further field pictures of the river pollution caused by the improper waste treatment and subsequent discharge from KVPF.

Figure 3.6: Decanter System at Pig Farm

Figure 3.7: Dirty River Flow Beside Farm

Figure 3.8: Polluted River Water at Confluence with Sg. Jawi

3.4 Kg Valdor Pig Farm Data Collection

A Site Visit was held at KVPF to gather initial data to assess existing farm conditions. Data collection was obtained through observation or estimation of information and then finally collated. KVPF currently does not operate as a MPF closed house system, with minimal waste treatment method and overcrowding of pigs at certain pens was observed (Figure 3.9). Table 3.1 presents the KVPF infrastructure components area size obtained.

Figure 3.9: Overcrowding in Pig Pens

Table 3.1: KVPF Components Size

KVPF Site Components	**Approx. Area Size (m^2)**
Administrative area	
Workers' quarters (room, canteen, and bathrooms)	1,500
Office rooms	200
Feed and disinfection storage rooms	800
Parking lot	1,000
Compound	600
Farming area	
Pig pen housing	1,000
Waste treatment (Sump pit, Decanter system and solid/liquid storage)	800
Inter-network roads and drainage	1,000
Miscellaneous (boundary areas)	500
Total KVPS Site area	7,400 = **1.83 acres**

The total acreage for KVPF site was calculated to be **1.83 acres**. Sampling of the raw pig waste manure was collected to be analysed at an accredited laboratory on their corresponding properties and results (attached in Appendix A). Table 3.2 summarizes the characteristics of sample obtained from laboratory analysis, that must be reduced via proper treatment.

Table 3.2: Characteristics of Pig Farm Waste Manure

No.	Parameter	Unit	Lab Analysis for KVPF Pig Manure
1	BOD_5 at 20^oC	mg/L	15,700
2	COD	mg/L	23,650
3	Ammoniacal Nitrogen	mg/L	120
4	Suspended Solids (SS)	mg/L	20,030
5	pH	-	6.47

Farming operations were observed as well, with recording of pig manure flowrate obtained in-situ at pig house discharge point using simple flowmeter and water usage estimated by obtaining flowrate of water used from the hose for KVPF pig pens and duration of use. The initial data obtained was then compiled into Table 3.3;

Table 3.3: Summary of Farming Data

No.	Description of Data	Value
1.	Total number of pigs/ SPP	1,000 SPP.
2.	Average weight per pig	50 kg
3.	Pig manure (faeces + urine) produced daily on average per pig	4 kg/day
4.	Average water usage (washing pig pens, bathing/cooling pigs and drinking) per pig	30 Litres/day
6.	Amount of feed given per pig on average	2 kg/day

3.5 Assessment of Pig Waste Treatment Systems and Farm Data

Based on the Literature Review done for the different types of pig waste treatment systems recommended and accepted by local authorities, a simple assessment of each treatment technology is summarized in Table 3.4 in order to decide the most feasible combination of waste treatment system for KVPF.

Table 3.4: Assessment of Waste Treatment Systems

No.	Treatment Technology	Assessment Summary
1.	Waste Stabilization Pond System	• Requires vast amount of land area for all treatment ponds • Not in line with MPF (closed farming) system due to open-air ponds. • Difficult to control stench of foul odours • Very cost-effective to construct and operate/maintain. • Treated effluent for final discharge can be reused as cleaning water straight to farm.
2.	Bio-filter System	• Involves very high capital expenditure • Biological treatment ponds integration also not in line with closed farm concept. • Sludge produced can be recycled as fertilizer for crops or as a soil conditioner
3.	Aerobic Bioreactor System	• Requires highly trained and competent operator for the Bioreactor. • Utilizes exclusively foreign technology as provider for major machinery equipment, hence not locally available. • High operation and maintenance costs as it needs to be continuously operated. • Better economic value for pig farms that are on much bigger scale than KVPF (more than 5,000 SPP).
4.	Biogas System	• Technology is widely used with proven results that achieve the desired parameters to comply with DOE's regulations

No.	Treatment Technology	Assessment Summary
		• Treated sludge produced can be recycled as fertilizer for crops or as a soil conditioner • Biogas produced can be used to generate power saving or even eliminating utility costs. • Reduces release of GHG to the atmosphere.
5.	Constructed Wetlands	• Cost-effective due to low power consumption during its operation & maintenance. • Decreases the volume of effluent, and final treated water can be reused straight to farm

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Farm Data Evaluation

From the initial data compiled in Table 3.3, a simple basis of the design criteria of KVPF can be summarised as shown in Table 4.1

Table 4.1: Initial Farm Design Basis

No.	Description of Data	Value obtained
1.	Total number of pigs/ SPP	1,500 nos.
2.	Average weight per pig	50kg
3.	Pig manure (faeces + urine) produced daily on average per pig	4kg/day
4.	Average wastewater per pig	30L/day
6.	Density of waste (from lab results in Appendix A)	1.017kg/L
7.	Total flowrate pig slurry waste	(34kg/day x 1,500 SPP) = 51,000 kg/day = 51 m^3/day = 2.13 m^3/hour
8.	KVPF Design Flowrate (20% safety factor)	2.13 m^3/hour x 1.2 = **2.55 m^3/hour**

It was estimated that a total of **51 tonnes/day** of pig waste slurry is generated by KVPF with a Design flowrate of **2.55 m^3/hour**. A comparison table of the waste discharge quality parameters was also produced between the Lab Analysis (refer to Appendix A) results of KVPF raw pig waste against the stipulated allowable limit set by DOE, Malaysia is shown in Table 4.2.

Table 4.2: Pig Manure Characteristics for Treatment

No.	Parameter	Unit	KVPF Lab Analysis	Maximum Allowable Limit
1	BOD_5 at 20°C	mg/L	15,700	50
2	COD	mg/L	23,650	200
3	Suspended Solids (SS)	mg/L	20,030	100
4	Ammoniacal Nitrogen	mg/L	120	50
5	pH	-	6.47	5.5 – 9.0

4.2 Recommended Waste Treatment System Process Description

Following the assessment of the waste treatment technologies available for pig waste, the waste treatment system concept can be recommended through the integration of the different processing systems as well as the available data from KVPF, in order to achieve a Modern Pig Farming (MPF) closed-house system with the final discharge of waste quality that conforms to the required environmental regulations. Therefore, the following process description for the KVPF waste treatment system was proposed.

A. Slurry Waste Collection Point

Slurry waste consisting of the farm's wastewater mixed together with pig manure (faeces and urine) will be initially collected at the slurry collection point or commonly known as Manure Pit. This is to ensure that the accumulated waste is well mixed and the concentration of waste entering the treatment system always remains standardized as well to ease sampling. The manure pit can be built using a tank or by digging a hole and covering the perimeter of the hole with cement or plastic so that slurry does not seep into the ground. Trash traps or filter screens are installed to ensure that no other solid waste, such as wood, rock, gravel and bones enters the pit.

B. Solid and Liquid Waste Separation

Slurry waste from the manure pit will then be pumped into a Manure Separation Tank in order to separate the solid and liquid waste via gravity settling. This process usually takes several hours and will reduce the pollutant load in the liquid slurry. This is the best method to gather the solid waste, referred to as sludge, in order to be pumped towards the anaerobic digester for biogas production. The liquid waste at the top of the tank contains organic pollutants, referred to as effluent, will be channelled to the anaerobic-aerobic tank for further treatment. The flow of the effluent to the tanks should be smooth and clear of all forms of floating solids such as leaves, grass, and possible floating sludge.

C. Anaerobic Tank

Effluent from the manure separation process is then channelled into an Anaerobic tank. The tank is designed with the optimum hydraulic retention time (HRT) for the purpose of reducing the organic content of BOD and SS. Anaerobic tanks are particularly effective for large scale dairy animal population due to SS deposition and degradation of BOD at this stage. The high content of organic matter inside the tank avoids the occurrence of any aerobic zone. Natural occurring microorganisms in the anaerobic type effluent acts to decompose organic matter through anaerobic digestion in the absence of oxygen.

This tank not only produces biogas, but also helps the performance of the aerobic processes that will occur on the next stage, by reducing the use of oxygen in the aerobic tank, which saves on operational costs in the long run. The accumulation of sludge at the bottom of the tank should be monitored periodically, and removed from the anaerobic tank to Bio digester tank every 3 months.

D. Aerobic Tank

The effluent from the Anaerobic tank is then discharged into the aerobic tank. In order to aid in this treatment process, mechanical systems such as a surface aerator and air blower can be installed in the tanks to supply more oxygen to the microorganisms.

The main objective for this tank is for degradation of organic matter and BOD in effluent. This tank contains air diffusers which will pump oxygen at all times via an air blower. The retention time for this tank is usually 24 hours, to allow microorganisms to thrive in it. The oxygen level in the aerobic tank is ensured to exceed 2 mg/L at all times. The bacteria in the tank will stabilize the organic matter aerobically. The concentration of bacteria in the tank must be within ratio of 2000 - 3000 mg/L (measured in mixed liquors suspended solids scale, MLSS). The advantage of this system over anaerobic ponds is that this system does not generate foul odour and produces better quality effluent.

E. Sedimentation Tank

Next, the effluent from the aerobic tank is fed into the sedimentation tank or settling tank to reduce the amount of suspended solids in the effluent. The sludge that has settled at the bottom of the tank is pumped back to the aerobic tank to obtain MLSS in excess of 2000 mg/L. Once the MLSS in the aerobic tank has reached 2000 mg/L, the remaining sludge in this tank will be pumped to the Bio digester tank

The sedimentation process occurs by gravity, whereby the active bacteria are collected and recycled into an aerobic tank for the purpose of effective continuous treatment. Detention time is usually more than 3 hours. Typically, the BOD level of the treated effluent reaches 20 mg/L with the discharge resembling clear, treated effluent without suspended solids. The effluent will be drained towards an artificial Constructed Wetland, while the sludge will be channelled into an anaerobic digestive tank.

F. Constructed Wetland

The effluent from the sedimentation tank is then treated using an artificial wetland treatment system. The CW in KVPF will resemble an open pond, with a horizontal surface flow and the main function of completing the effluent treatment to obtain clean water, within the limit of allowable discharge effluent quality before being released into the public drainage network or possible reuse for farm cleaning activities and washing pigs.

The plants that live in the wetlands, such as vetiver grass, can reduce the ammonia content, phosphorus and metals in the effluent by using the plant material composition as nutrients. A detention period of 1 day is sufficient for CW. The method of operation is fairly simple, with the plants needing to be kept fertile, hence a little organic fertilizer is mixed in the first couple weeks, to ensure the tree stays fertile in the water. Vetiver trees are expected to grow vertically within 1m after four to six months of operation, and vetiver leaf cuttings are done periodically for finishing purposes. The wetland plants absorb organic matter, especially ammonia and phosphate, ensuring the avoidance of ammonia contamination at the downstream areas of KVPF.

G. Anaerobic Digester Tank

Anaerobic digestive tanks or referred to as Bio-digester is a tank that collects the solid sludge (manure) to be fermented anaerobically (without oxygen). This method is natural and does not require air assistance. Typically, an anaerobic digestive tank design requires a retention time of 20-25 days, and biogas is produced on a daily basis. Biogas contains about 60% methane and the remaining 40% carbon dioxide. The resulting biogas can be used directly on the farm. The sludge separated from the Manure separation tank as well as the Sedimentation tank is pumped into the bio-digester system. Microbes will induce the fermentation process inside this bio-digester and produce biogas in anaerobic conditions based on the suitability of temperature, moisture content and acidity. The liquid (digestate filtrate) is also channelled to the CW system for further treatment. This anaerobic digestive system can eliminate the problem of odour because the foul smell of sludge is contained within the bio-digester tank. Sludge that is treated in an anaerobic digestion tank will then be channelled out into the post-digestion tank for polishing purposes.

H. Post Digester Tank

Sludge from the anaerobic digestive system is then channelled into the Post Digester tank after digestion. The main functions for this tank is to further stabilize the resulting dry sludge by eliminating bacteria in the sludge so that it is more suitable for fertilizer application on the farm. Sludge from the bottom of Post-Digester is removed periodically and can be used as good organic manure for bio-fertilization.

I. Biogas Holder

Biogas storage tanks can come in various shapes, whether in the form of tanks, cylinders or even balloons. The methane gas produced in the anaerobic digestive tank will be stored in a low-pressure storage device such as a balloon or gas bag made of hydrogen sulphide corrosion-resistant material, such as high-density polyethylene (HDPE), low-density polyethylene (LDPE), linear low density polyethylene (LLDPE), and chlorosulfonated polyethylene covered polyester (Thien Thu, et al., 2012). Biogas produced daily must be collected efficiently and not released to the atmosphere, since it can to be used for application purposes in the field, either as fuel or electricity generation. The electricity generated can be used for farming operation needs or sold to electricity suppliers. Biogas monitoring will be done manually, by monitoring the balloon expansion and also the biogas pressure in the meter. Daily biogas production can be recorded using a biogas meter. Biogas in the gas holder will then be sent to the gas engine to produce electricity.

The Pig Waste Biogas Treatment System to be designed for Kg Valdor Pig Farm can be broken down to 4 main processes (detailed in Table 4.3), which are;

I. Collection of Raw Waste;
II. Anaerobic Digestion
III. Energy and Solid Recovery;
IV. Effluent Treatment.

Table 4.3: **Processes and Components of a Waste Treatment System**

No.	Process	Components	Description
1.	Collection of Raw Waste (Slurry)	Manure pit	Homogenize incoming raw waste.
		Manure Separation Tank	Separate the solid (sludge) and liquid (effluent) waste
2.	Anaerobic Digestion	Bio-digester tank	Treat sludge waste anaerobically, using microbes for fermentation process.

No.	Process	Components	Description
3.	Energy and Solid Recovery	Biogas Holder	Store biogas to prevent release into atmosphere
		Heat Recovery	Recover heat generated from the gas engine to be used for the pre-treatment and digestion processes.
		Gas Engine	Generate electricity using biogas as source of fuel.
		Solids Recovery	Solid sludge can be further dewatered and packaged as fertilizer.
4.	Effluent Treatment	Aerobic Tank	Remove ammoniacal nitrogen, phosphorus, BOD and COD from effluent.
		Anaerobic Tank	Further removal of phosphorus, BOD and COD from effluent.
		Sedimentation / Settling Tank	Remove TSS from digestate.
		Constructed Wetlands	Polish treated effluent for discharge into public drainage or reuse at KVPF.

The overall Process Flowchart of the KVPF processing components was summarized and shown in **Figure 4.1.**

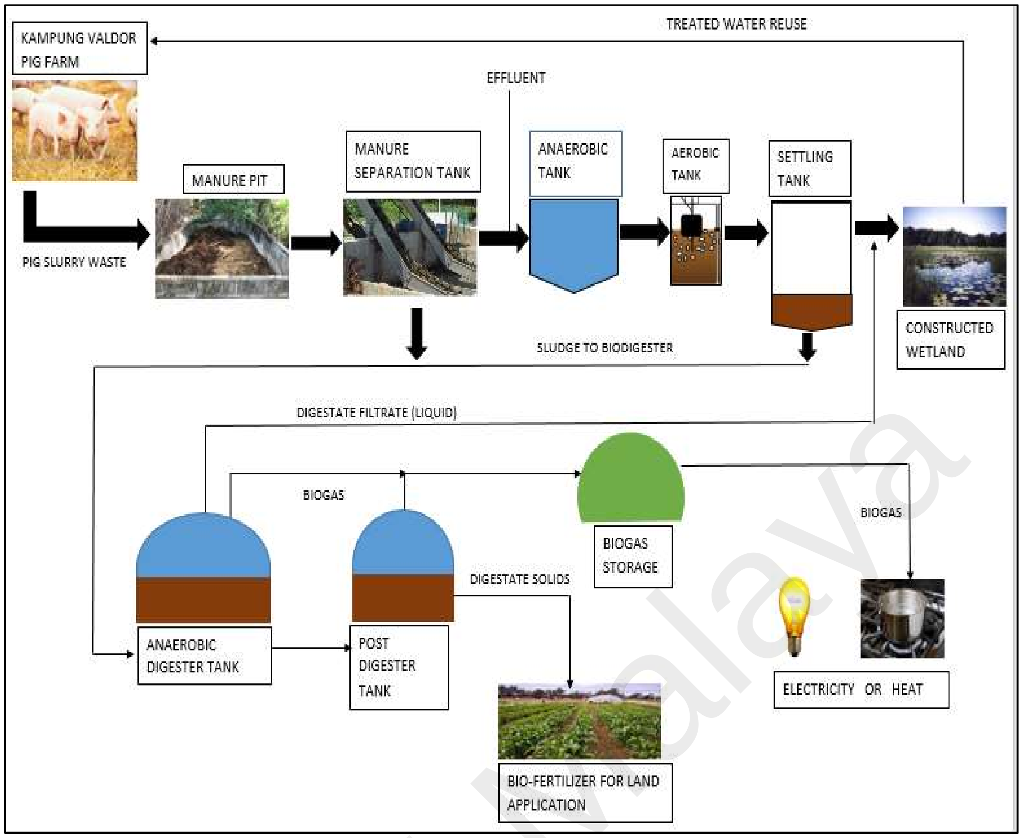

Figure 4.1: Recommended Farm Process Flowchart

4.3 Greening Options for Pig Farm

The following section will further describe other possible greening options and methods to be implemented for a well-managed Modern Pig Farm (MPF). Improvement in pig farm management practices and animal husbandry will directly lead to healthier livestock as well as good breeding and production performance, which in turn leads to reduction or even total elimination of negative environmental impacts. Utilization of green technologies as well as other greening practices should be considered to evolve towards more environmentally friendly and sustainable farming livestock production. The main pollution sources to be controlled or eliminated from pig farms are wastewater, solid waste, gaseous emissions and foul odours.

4.3.1 Waste Treatment

The main 3R concepts of greening in livestock farming should be adhered to and is categorised as (Jabatan Perkhidmatan Veterinar Malaysia, 2019);

A. Reduce - Reduction of pig waste from the source will eventually reduce the amount of waste that needs to be treated and can save costs. Through proper feed management, the quality and quantity of pig manure will be much better, resulting in less pollution emissions. The same goes for water usage management during pig farming operations. One method is to use a high-pressure water jet when cleaning off the waste at the pig pen floors for more efficient cleaning and water usage.

B. Recycling/ Reuse – The treated farm waste that has produced the desired waste quality parameters in the form of water and solids can be reused for cleaning pig pens and fertilizing crops or livestock grass.

C. Recovery - Energy and nutrient recovered through biogas technology will reduce the odour and impact of GHG to the environment. The biogas produced can be utilized as source for electricity and heat.

4.3.1.1 Deep Litter System

A large majority of Malaysian pig farms generally do not practise closed house systems, and typically construct concreted pig pens since it is generally simple to maintain and clean. However, there is argument to be made that breeding the pigs in this man-made environment suppresses the pigs' natural behaviour which can lead to the animals being more susceptible to diseases.

An alternative method for housing the pigs in farms has been gaining a lot of traction around the world, that is by developing a Deep Litter System (DLS), or also known as Fermented Bed Technology (FBT) whereby feed and bedding material is created out of

Effective Microbes (EM) (Laishram, et al., 2018). EM uses microorganisms, enzymes and probiotics which are used to treat the pig waste manure and for feeding as well.

DLS or FBT, when implemented and operated efficiently, will drastically reduce amount of water usage as otherwise used at typical pig houses with concrete pens. The bedding material containing EM, can effectively decompose the pig manure and urine to produce high quality compost (Zhou, Hu, Zhang, & Tan, 2014). This would also reduce water consumption compared to a conventional pig farm because the floor does not need to be washed and pigs do not need to be bathed.

The EM to fed to the pigs contains high amount of nutrients and vitamins, that are able to boost the pigs' immune system, less exposure to harmful pathogens, better manure quality discharged, which leads to less air pollution and odour. (Laishram, et al., 2018). However, it should be noted that DLS or FBT can only be used in a small-scale closed house system (Helen, et al., 2012). A summary of the basic requirements and advantages of using DLS is shown in Table 4.4.

Table 4.4: Deep Litter System Requirements and Benefits

DLS Requirements	Benefits
Bedding raw material includes maize, wood chips or sawdust, wheat, rice hulls/ straw/ husk, barley straw and corn cobs.	• Capital and operating costs lower than conventional farming designs. • Can be used for small scale farming and intensive scale farming too.
Deep pit floor with depth range of 30 – 60 cm and area size of between 1.5 – 2.5 m^2	• Faeces and urine will be treated in the pen, drastically lowering amount of water usage compared to conventional farming house.
Addition of EM to bedding suggested at frequency of every 2 – 4 weeks to regulate temperature	• With properly regulated temperatures, the pigs are able to avoid heat-stress. • Produce good quality compost • Decreases air pollution as well as number of insect flies present.
EM feed for pigs	• Improves pig's health and lowering chances of diseases from occurring.

A list of recommended waste treatment systems that was described previously under Section 2.4 is categorised and sorted based on the scale of farm production in Table 4.5

Table 4.5: Summary of Pig Farm Waste Treatment System

	Small-scale Farm	**Medium-scale farm**	**Intensive-scale farm**
SPP	< 250	251 – 1,000	> 1,000
Recommended Treatment System	1. Waste Stabilization Pond System 2. Deep Litter System 3. Anaerobic Digestion	1. Waste Stabilization Pond System 2. Bio-filter System 3. Anaerobic Digestion 4. Constructed Wetlands	1. Aerobic Bioreactor System 2. Anaerobic Digestion 3. Constructed Wetlands

4.3.2 Pig Farm Design Guidelines

The farm site should basically be situated at a wide land area to cater for potential future expansion and a buffer of at least 250m from the nearest residential/ commercial area border as listed in Malaysia Standard Industrial Classification 2008 (DEPARTMENT OF ENVIRONMENT, 2012). Tall trees are highly encouraged to be planted at surrounding landscaping areas to act as an absorbent for odour and dust pollution from farming activities

Currently, with the growing need for a MPF, it is recommended to provide separate pig pen housing for each stage of pig's life cycle. For example; group or individual sow pen, farrowing pen, individual boar pen, gestation pen (Figure 4.2), weaning piglet pen, growing and fattening pens and breeding gilt pen.

The distance between the pig houses should be at maximum 10m apart (Pig-farming.net, 2020) to avoid over-exhaustion of the livestock and proper width and height of the pens for good ventilation of the pigs to avoid heat-stress. The slaughterhouse, if located in the farm site also, should be furthest away from the pig pen breeding area (Jabatan Perkhidmatan Veterinar Malaysia, 2019).

Figure 4.2: Pregnant Sows in Gestation Pens

The construction material for the pig pen structure would be reinforced concrete, whilst the walls of the crates in the pig pen should made of galvanized steel. The slatted floors of the pig pen should be higher by approximately 60cm from the ground and slightly sloping. Slatted floors are used to reduce water usage for washing the floor because the small holes allow pig manure to drop directly into the drainage system.

The drainage system for rainwater must be separated from the effluent/wastewater drainage system from the pig pen. Wastewater drainage should be located under a covered area whilst rainwater drainage can be located at an uncovered area. The floor of the pig pen shall be designed so that the wastewater from the pig pen can flow directly to the drainage system, without seepage on the ground, and subsequently for treatment (Figure 4.3). The wastewater and rainwater drainage systems should be constructed of concrete so that the livestock effluent does not permeate and contaminate groundwater.

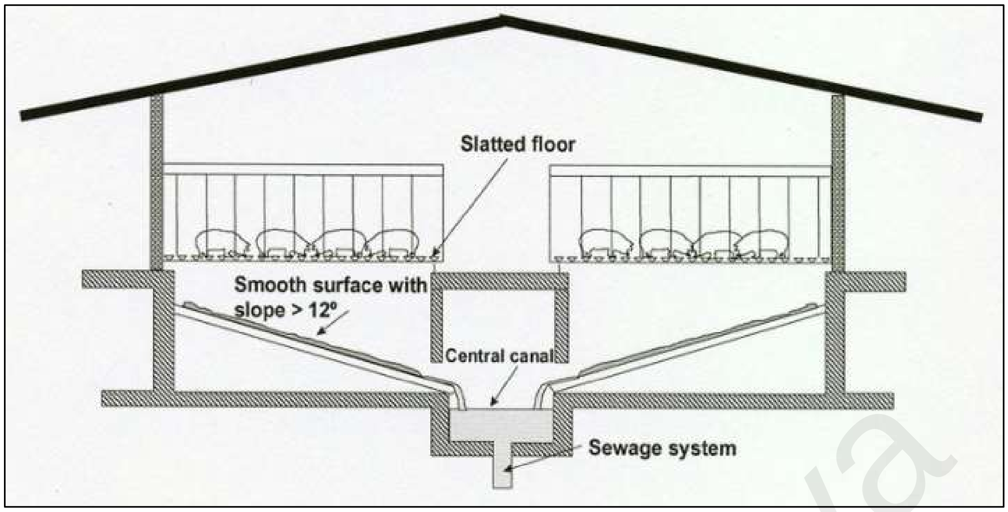

Figure 4.3: Sketch Example of Pen Slatted Floor

Farmers need to wash the floor at least twice a day to further prevent any waste build-up to occur. All the pig houses should have a separate drainage network to cater for wastewater flow from the pig pens and rainwater flow. In summary, the design basis for a greener MPF should have the following criterion;

- The pig farm should be at an elevated level to avoid flooding from heavy rainfall.
- The pig farm needs to have shade, usually from self-planted trees, to avoid the pigs getting overheated from sunlight and to absorb odour and dust pollution.
- To be located downwind from nearest residential areas (recommended 250m distance) to avoid local population being affected by air pollution or foul odours and farm operation noise.
- The number and size of the pig pens depend on the expected numbers of pigs to be housed in each production phase.
- Pig pen floors should be slatted to allow pig manure (faeces and urine) to drop between the small holes
- Pen floors should be sloped for ease of manure flow to drainage system, thereby reducing water usage for cleaning.

- Well-designed drainage system provided in order to channel the pig farm wastewater to an appropriate waste treatment system without seepage to adjacent land area or polluting nearby water courses. Rainwater should be directed into separate drainage system, and not be allowed to mix with the pig farm slurry.
- Good connection access to nearby road networks, water and electricity sources in case of any emergency.

4.3.2.1 Pig Farm Housing Design

The design of the pigs' housing, or also known as barns, is an important feature for greening the farm to control diseases, reduce stress, better breeding performance and good ventilation for the pigs to avoid heat-stress. The distance between the barns should be at minimum of 6m and at maximum 15m apart. The width range is 8-10m and length of (Pig-farming.net, 2020). The slaughterhouse, if located in the farm site also, should be furthest away from the pig pen breeding area (Jabatan Perkhidmatan Veterinar Malaysia, 2019). In order to manage the sunlight, ventilation and disease outbreak, all pig house/barn should be designed to have two rows of pens, as seen in Figure 4.4

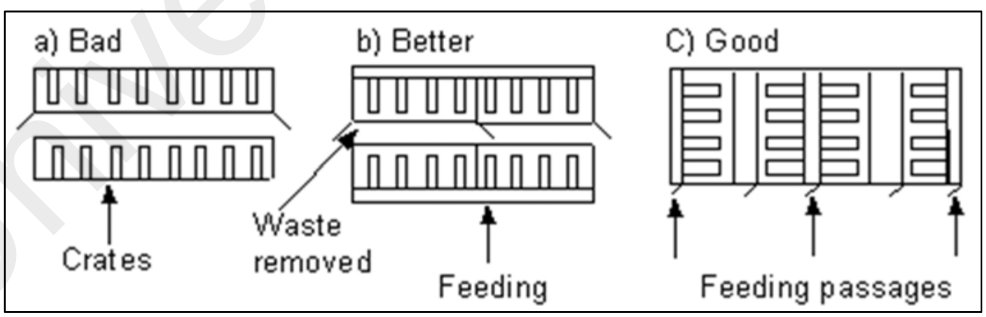

Figure 4.4: Pig Pen Layouts

The farrowing pen in a pig farm is probably the most important unit for the farm pig production, since it entails the management of farrowing sow and their newly born suckling piglets. Both the sow and piglets are confined together in farrowing crates hence, there must be proper management of the pen hygiene to avoid any disease outbreak. A barn can contain anywhere between 6 – 24 farrowing pens/crates, depending on the number of sows at the pig farm.

Farrowing crates are metal crates or stalls inside the pen for the farrowing sows to give birth at. The crates are designed in a way whereby the sows can only move forwards or backwards, and being unable to turn left or right. The recommended pen area is of 2.4 m length by 1.8 m wide. The crate within the pen should have a dimensions of 2.1m length and width that can be adjusted between 0.5 up to 0.9m to cater for piglet growth (Global Ag Media., 2021). The lactation area is designed to be narrow enough to encourage the sow to lie down at an angle so that the piglets can reach the udder for milk. Figure 4.5 shows an example of a well-designed farrowing pen with crate.

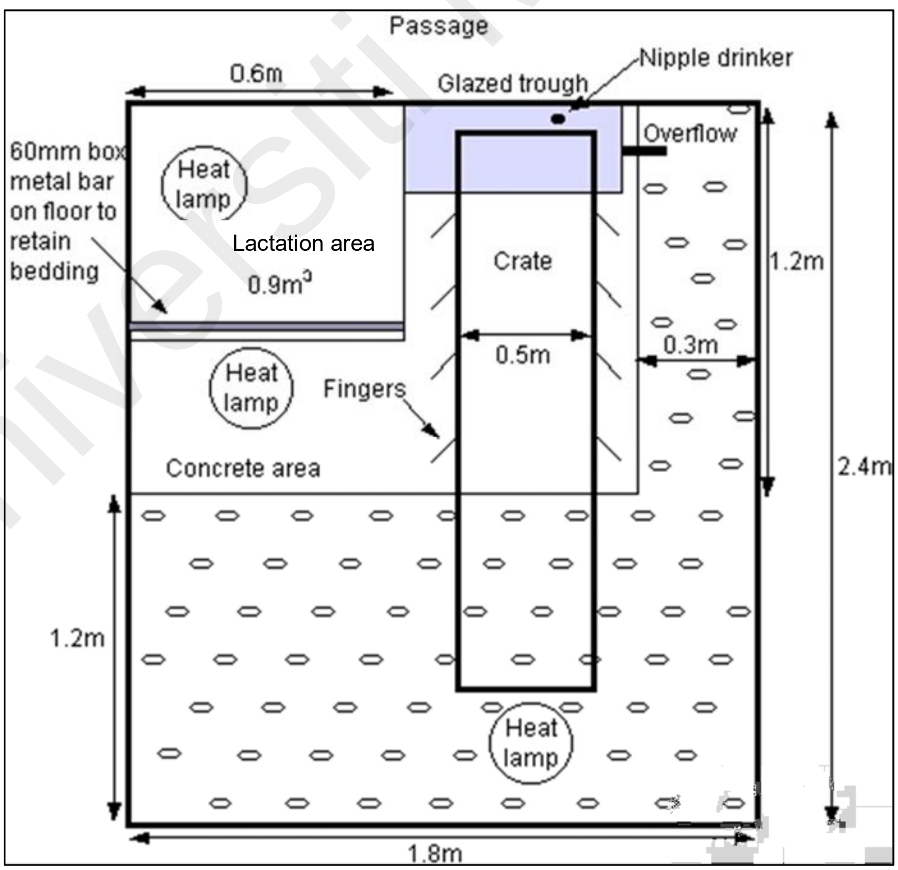

Figure 4.5: Recommended Farrowing Pen Design

The floor can be slatted as seen in Figure 4.5 and ensured to be always well maintained so as to not damage piglets' legs. Cleanliness of floor must always be monitored, and should not be too slippery for the piglets to walk on. Metal rail bars installed within the lactation area have 3 main purposes that are firstly, to allow access for the sow to enter; secondly, to avoid the lactating sow crushing her piglet and; thirdly, as a design barrier to allow piglet litter access to the udder without worrying about getting crush by the lactating sow (Global Ag Media., 2021). The nipple drinker is also vital for water consumption.

Temperature control is important as well, as the piglets require about 31-34 °C. Pig farms in winter countries would need to mechanize by providing heated floor as warm surface for piglets, whereas heat lamps would suffice in tropical countries like Malaysia. The main aim of the farrowing pen's unique design is to ensure that the lactating sows and her litter are kept indoors safely (see Figure 4.6), specifically to reduce piglet mortality rate, which would directly increase farm productivity.

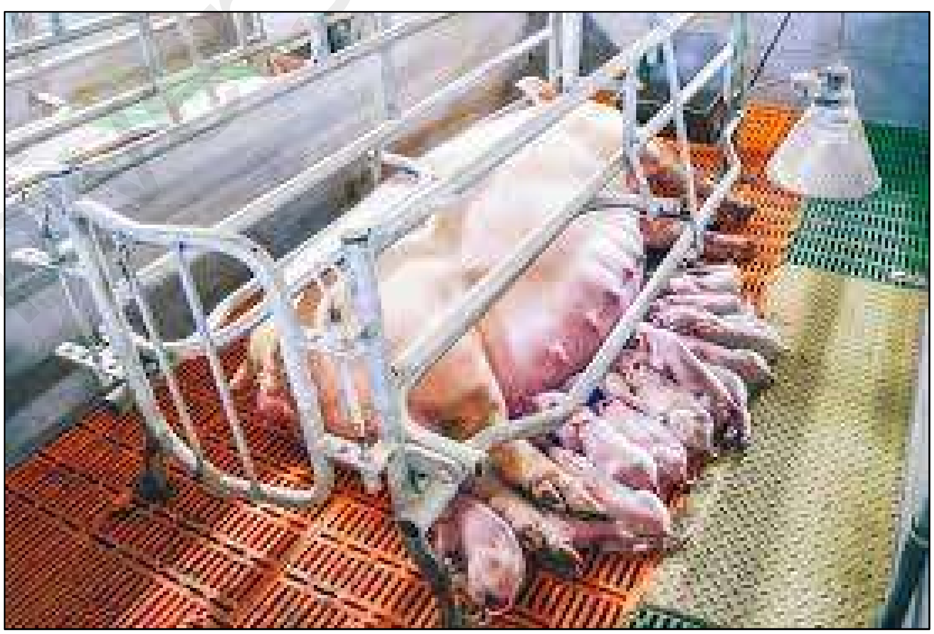

Figure 4.6: Example of Farrowing Crate

4.3.3 Odour Management

Odour Units (OU) are used to describe odour concentration whereby, 1 OU/m^3 is the quantity of odorant per cubic meter of air at the odour threshold. Pig farm odours can be composed of hundreds of odorous compounds, the significant gasses being ammonia (NH_3), hydrogen sulphide (H_2S) and volatile organic compounds (VOC). Table 4.6 provides the data range of main odorous compounds recorded in pig farms (Park, et al., 2020)

Table 4.6: Odour Concentration Range at Border of Pig Farms

	Odour	**NH_3**	**VOC**	**H_2S**
Range	35 to 980 OU/m^3	5 to 40 ppm	1 to 28,500 $\mu g/m^3$	1 to 90 ppm

Ammonia (NH_3) will emit strong odours nearby the pigs' manure, but disperses easily since it is lighter than air. NH_3 concentrations at 20 ppm and above may cause the pigs to experience bad respiratory effects (Ni, Heber, & Lim, 2018). For humans, exposure to NH_3 above 50 ppm for longer than 2 hours will start to have a negative effect, the fatal level being 700 ppm and above.

Hydrogen sulphide (H_2S), with its distinctive rotten-egg smell, is a very toxic gas at high levels and acts quickly on humans by shutting down many parts of the body's system. Hydrogen sulphide concentrations are usually lower than ammonia in pig farms, (between 1 – 9 ppm). However, when the manure undergoes agitation or mixing, high concentrations of H_2S are produced. Park et al (2020) found that hydrogen sulphide was able to record a maximum level of 90 ppm at the waste collection area. This level can start causing unpleasant health effects to humans, with the fatal level being 100 ppm and above.

4.3.3.1 Green Methods for Odour Control

The consideration for all aspects of a pig farm must be studied before being able to carry out the appropriate odour control methods. Not only would this mitigate odour pollution, but also improve the air quality within the vicinity. The end result produces better overall health and productivity for both farm workers and animals. The following methods are greening recommendations for a pig farm's odour control.

a. Regular Cleaning of Pigpens

The pig pen surfaces of floors, walls and equipment are easily susceptible to having traces of manure and pig feed being attached, since farm workers and pigs might step on the same areas. Therefore, a schedule for daily housekeeping must be followed and to ensure the traces and residues of solid particles can be removed using the correct disinfectant. The use of a high pressure water jet is a good idea to be able to clean off surface areas efficiently.

The pig pen floors are most susceptible since farm workers and pigs might step on the same areas. If the floors are solid and not slatted, manure scraping must be performed every day, or even twice a day, towards the drains. Bedding material containing EM is also another control method to reduce odour. Excess food waste must also be monitored and removed quickly, or else it can lead to high odour levels. Washing off the floors with water should be done at least twice a day which reduces exposure time of manure to emit odours at the pen.

b. Effective Ventilation

Pig pen designed for effective ventilation rates is another useful method of odour control, since higher rates will lead to lower humidity levels, which in turn creates less odour causing molecules in the air space (Somagond, et al., 2020).

There are few design methods that can be done on pig pen roof for effective ventilation such as installing a negative pressure fan, evaporative air-cooler or fibre reinforced plastic fan. Another roof design adjustment is to cover it with an ultraviolet-stabilized plastic film from the inside (Pig-farming.net, 2020).

c. Slatted Pen Floor

The slatted pen floors allow pig manure to drop into the drainage network underneath and lined as a slope for ease of manure flow is an important aspect for odour control because it minimizes the exposure period of manure at the pen. Somagond, et al. (2020) found that odour emission levels could be reduced by as much as 50% when slatted flooring is well designed and washing the floor takes place twice a day. The slat floor material of preference in descending order is polyethylene, cast iron, metal or plastic slats and lastly concrete (Somagond, et al., 2020). Apparently polyethylene emits the least amount of ammonia odour, but due to its high cost, cast iron slat is more economical option for the pen floor.

d. Manure Collection Point

The pig manure that flows from the MPF's drainage network will arrive at the waste collection point, known as the Manure pump pit, the first step of the waste treatment system. Therefore, this collection point is considered the highest risk for odour pollution, especially from emission of toxic hydrogen sulphide due to constant manure agitation. The odour control methods at manure pits are listed below:

- To ensure that the collection point avoids receiving pig manure slurry that is dry and not diluted. Diluted manure slurry will emit less odour compared to more concentrated slurry.

- Pit design modification – To install sloped wall lining around the pit to reduce surface area of manure collection. Deepen the pit to minimize air flow.

- To cover the whole pit using natural or permeable covers which would lower the temperature inside the pit and avoid volatilization of gasses. An impermeable floating plastic cover can reduce odour by 89% whereas natural covers reduce the odours by 60% (Liu, Murphy, & DeRouchey, 2014). Budget analysis should be evaluated to decide selection of cover type.

e. Diet Alteration

Analysis of the pig's manure after reducing their feed protein (FP) composition has shown to have produced 40 % lower Nitrogen as well as lower pH value. Synthetic amino acids were used as nutrient replacement to compensate for the low FP diet. This resulted in lower ammonia gas emissions as well (Liu, Murphy, & DeRouchey, 2014)

f. Spraying Oil

Mixing vegetable oil with water for spraying purposes was found to be very effective method to stop dust particles being released into the air at a farm house or office/admin areas. Respirable dust concentration levels were recorded to be lowered significantly as well as ammonia and hydrogen sulphide concentrations (Somagond, et al., 2020)

g. Bio-filter Media

Bio-filter medias are considered the best odour control method if correctly used and maintained, despite being the highest financial investment cost amongst all odour control methods. It is basically used as end-of-pipe technology, as it breaks down contaminated air at ventilation exhaust fans before releasing cleaner air back into environment. It has an organic media bed made up of either soil, sawdust, straw, peat moss or compost and when the odorous air passes through, the microorganisms decompose the odorants with an efficiency range between 80 – 90% of reduced odour levels (Liu, Murphy, & DeRouchey, 2014). Figure 4.7 provides a sketch to show the Bio-filter media mechanism.

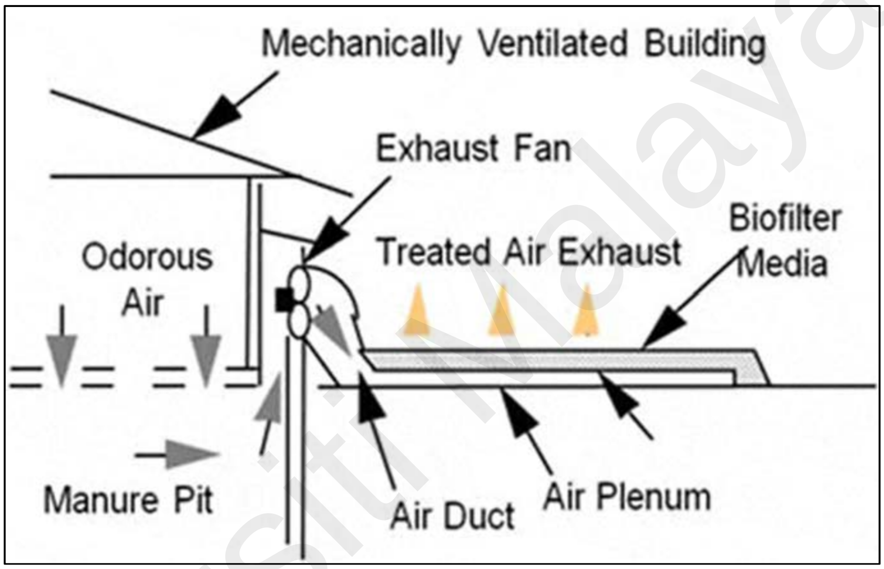

Figure 4.7: Example of Bio-filter Media in Operation

h. <u>Wet Scrubber</u>

Wet scrubbers were designed to also treat contaminated air at ventilation exhaust fans. The wet scrubber does not have microbial bed like the Bio-filter, instead mixes acid chemicals with water to lower dust and odorant levels. Although the Bio-filter is more effective overall for lowering odour levels, the wet scrubber has higher ammonia removal efficiency hence, can be utilized based on specialised requirements for reducing ammonia emission levels (Somagond, et al., 2020).

i. Vegetative Environmental Buffers (VEBs)

Vegetative Environmental Buffers (VEBs) are planted trees, vegetation and shrubs that are arranged in a linear configuration that are strategically located and surrounding the perimeter of the farm site (Liu, Murphy, & DeRouchey, 2014). VEBs main objective is the minimization of odour from the livestock farm, with secondary objectives of filtering the surrounding air, adsorbing and decomposing components from dust particles and ammonia via tree leaves and improving the natural landscape environment's visual aesthetics as shown in Figure 4.8.

Detailed planning for VEB design and installation is vital for optimum results because once the plants have fully grown, its effectiveness can keep increasing if the plants keep growing over time and remain healthy. The main data needed before planting is to obtain the wind speeds and pre-dominant directions of the vicinity, and farm site location orientation. It would be very useful if data on the farm's odour emission profile and directions can be obtained too during the design stage, in order to verify the tree species and quantity to be used at the particular placement configuration.

VEB basically lowers odour and dust particles in two methods. The first method is to reduce wind speeds, encouraging vertical atmospheric mixing above the farm due to wind direction and distance to the farm. This will diminish flow of odour emissions, whilst dust particulates will accumulate at the VEB (refer Figure 4.9), bringing about the second method of odour control whereby, the dust particles are retained and filtered within plants whilst the tree leaves carry out adsorption and absorption of the odorous compounds from the livestock farm The 70% reduction in odour concentration, including ammonia and hydrogen sulphide proves the efficiency and cost-effectiveness of VEB implementation for decreasing air pollution and odour emission.

Figure 4.8: Fully Grown VEB at Pig Farm

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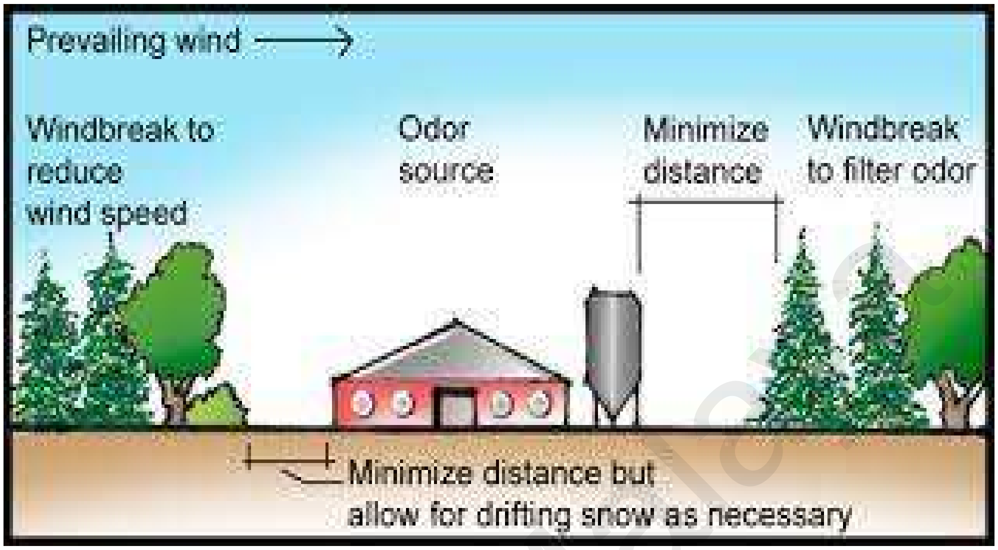

Figure 4.9: VEB Windbreak Mechanism

4.3.4 Feed Management

Modern pig feed mainly consists of wheat, maize and soy, although the prices of these globally traded commodities can be volatile, due to economic growth of the biofuel industry. Increasing importance is being given towards integrating more agricultural waste products into the diets of pigs. This shows that its diets can indirectly have a positive impact to the environment. Locally sourced feed is more economical, and can even be more nutritional when mixed with biotics or vitamins at the optimum ratio.

The amount and type of feed is vital for body growth, good immune response, breeding performance and the production of good quality pork meat. Table 4.7 below detailing the types of feed that should and shouldn't be fed to pigs;

Table 4.7: Feed That Pigs Can and Cannot Eat

Feed that pigs can eat	
1.	Commercially prepared pig rations from grain, fruit and vegetable (high cost)
2.	Fresh vegetables and fruits that have not been contaminated (contact with other raw meat)
3.	Food waste mixed agricultural products and cooked properly
4.	Agricultural products - raw vegetables, banana plantain, corn/maize, yam, sweet potato that are cooked
5.	Wheat bran, rice bran, broken rice, oats, barley, groundnut and soybean
Feed that pigs cannot eat	
1.	Processed foods that contain salt, sugar, dairy and flavourings (milk, cheese, pet food, meat from grocery market, chocolate, fast food)
2.	Animal carcass including any part if it that is uncooked. Pigs that feed on carcass will be at risk of contracting diseases that are contagious to humans.
3.	Raw fish including bones
4.	Food waste from restaurants or any public kitchens without proper cooking
5.	Any feed that has come into direct contact with the above items or has been contaminated

The recommended feeding intake quantity for the different stages of pigs at farm production cycle is shown in Table 4.8

Table 4.8: Recommended Feeding Intake

Pig Stage	Daily Feed Intake (kg)	Feed Type
Gestating Sow	1.8 – 2.8	Wet feed
Farrowing/Lactating Sow	4 – 4.5	Dry feed
Suckling piglet	0.04 – 0.06	Milk from lactating sow
Weaner pig	0.5 – 1.5	Creep feed
Grower	1.5 – 2.0	Dry feed
Finisher	2.0 – 2.5	Dry feed
Boar	2.0 – 2.2	Dry feed

In summary, good feed management is vital since it directly affects the main commodity and should always cover the following recommendations;

a. Feed Source

Livestock should be supplied with food sources certified by the DVS Malaysia such as corn, soybean waste, fish meal and premix. The choice of food provided will determine the quality of the waste produced.

b. Feed Monitoring

The feed supplied must always be ascertained and monitored in terms of its quality and nutrition. Feed samples can be sent to an accredited laboratory for analysis. Providing the required food quality will reduce the production of heavy metal pollutants such as copper, zinc and so on (Jabatan Alam Sekitar (JAS), 2014).

c. Feeding Schedule

Generally, pigs are fed according to a fixed schedule at rate of two times a day. The pigs' health and breeding performance will be negatively affected if feeding schedule is disrupted.

d. Excess Food Waste

Excess food waste should either be discarded or mixed with the treated solid waste and composted. Implementing this method will decrease the amount and quality of waste/effluent produced since it will not be mixed with the waste undergoing treatment.

4.3.4.1 Feed Trough

Feed troughs must be cleaned regularly, in order for the pigs to consume fresh and clean feed. To avoid food waste, sufficient feeder space is necessary in order for the pig to be able to consume its fair share of food. Troughs must be anchored to avoid it overturning. Appropriate facilities and equipment should be used as methods of providing food and drink. This helps reduce the quantity of food spilled onto the floor and reduces waste. The method of feeding is either through a trough or self-feeder and can be done manually or automatically. The storage of food must always take into account that it being kept dry and safe from pests, especially flies to avoid pathogen transmission.

Once the piglets are at the weaning stage, their feed in Malaysia are usually high in fibre (Jabatan Alam Sekitar (JAS), 2014) Therefore, it will flow best in a round-type feeder, whereby the drum can be moved by the piglets to agitate the feed (refer Figure 4.10) and should be placed at the centre of the pen for optimum spatial use. The amount of feed dispensed to the feeder must be monitored to avoid excess food waste, and gradually increased as the piglets grow. The feed should be dropped on the floor two times a day at pre-set quantity and time so that the pigs are fed on a regular schedule and able to grow healthily. The straight feeders are usually used for the sows, with single or double troughs, should be located at the side or end of the pen and be automated for better feed management (refer Figure 4.11).

Figure 4.10: Example of Round Self-feeders

Figure 4.11: Automated Straight Feeder

4.3.5 Renewable Energy Potential

a. Biogas Generation

Approximately 4kg of pig manure is generated per pig each day, which if not treated well, will deteriorate the environment by causing air, water and soil pollution as well as health issues. However, if the manure undergoes anaerobic digestion, it not only reduces GHG emission, but has potential to produce energy from the biogas produced. Table 4.9 below shows estimation for potential energy produced from pig manure in Malaysia if all pig farms use Biogas digester to treat the pig manure.

Table 4.9: Approximation of Biogas Generation from Pig Manure

Parameter	Unit	Value
Standing pig population (SPP) in Malaysia [A]	million	1.9
Average pig manure excreted per pig [B]	kg/day	4.00
Total mass of pig manure	tonnes/day	7,600
Biogas produced per kg of pig manure [C]	m^3/tonne	50
Total biogas produced	m^3/day	380,000
Total methane gas produced (assume 65% CH_4 in pig manure after anaerobic digestion)	m^3/day	247,000
Energy produced (Energy content of CH_4 is 37,750 kJ/m3 with gas engine conversion efficiency of 45%) [D]	TJ/day	3.73
Energy produced (1 Terajoule [TJ] = 0.278 Gigawatt hour [GWh])	Gw.h/day	1.04
Energy produced (Gas engine operating 253 working days/year)	Gw.h/year	263.12

Source:
A - (Department of Statistics, Malaysia, 2021)
B - (Varma, et al., 2021)
C - (Jabatan Perkhidmatan Veterinar Malaysia, 2019)
D - (Kumaran, Hephzibah, Sivasankari, Saifuddin, & Shamsuddin, 2016)

Total pig manure in Malaysia is estimated to generate about 7,600 tonnes/day, and be anaerobically digested to produce 247,000 m^3 of methane gas, which can theoretically generate 298.54 GW/h of electric power annually.

A well operated biogas plant will dramatically reduce GHG emissions, as methane gas is considerably more harmful if released to the atmosphere than carbon dioxide. In fact, methane gas is estimated to be 25 - 35 times the global warming potential of carbon dioxide (EPA, 2020). Methane gas generated at the farms can be stored and used to generate electricity and heat. Solids recovery process can also be performed on the digestate solids from bio-digester tanks, in order to produce bio-fertilizer. The solids can undergo binding with rice husks for packaging as fertilizer.

b. Solar power

In order to install a solar photovoltaic (PV) system at a pig farm, the structural integrity of the animal houses must be considered, especially at the roof structures due to extra load of a PV system. If all the proper measures are taken to erect solar PV system, the reconstruction of pig houses can in fact, improve the indoor and outdoor ventilation of animal houses, reduce indoor temperature and stimulate the appetite of pigs (edie newsroom, 2012).

A Thesis Report done in Sweden attempted to study if an investment in a photovoltaic system is economically feasible at a Swedish pig farm. Their main findings showed that it can be feasible depending on the electricity need of the farm (Ekman & Jonsson, 2014)

A British renewable energy specialist company, Eco2Solar has successfully installed a 39.6kWP solar photovoltaic system on a pig farm at Leicestershire, England. The power generated from the solar panels basically run the farm's pig feeding facilities (edie newsroom, 2012)

CP Foods, a company based in Bangkok, Thailand had earlier successfully generated biogas at all their pig farms, around 98 numbers. It enabled them to cut electricity costs by 50-80% of the total electricity used on the farm, as well as reduce foul odour and GHG emissions. As of this year, they are able to generate 250kW from their solar farms implemented at 4 of their pig farms so far. They are currently expanding to their other pig farms. (Charoen Pokphand Foods Public Company Limited, 2021)

4.3.6 Biosecurity in Pig Farms

Scheduled vaccinations and veterinary care for each stages of the pigs' production life cycle, from birth to culling/market/death, is one of the main requirements for good animal husbandry practices in a pig farm. Disease and health problems are a constant issue in livestock farming. History has shown that when an epidemic or pandemic disease outbreak occurs, it can have devastating social and economic impacts due to high numbers of human and pig mortality, as well as huge financial losses to stakeholders.

One of the worst case for an epidemic disease outbreak was reported to be the Nipah Virus 1998 incident in Malaysia. Other significant disease outbreaks were African swine fever, Porcine respiratory and reproductive syndrome, and Foot-and-mouth disease which has led to development of biosecurity measures in pig farming (J. & Van Immerseel, 2019).

Biosecurity can be defined as implementation of protocols to minimize risk of exposure and transmission of pathogenic (disease carrying) microorganisms (Pandolfi, Edwards, Maes, & Kyriazakis, 2018). The main aim for biosecurity is to prevent transmission inside the pig farm as well as other pig farms. The following sub-sections will describe the general biosecurity measures to follow as useful greening tools for pig farms.

4.3.6.1 New Incoming Pigs Management

As described under section *2.2.2: Pig Farm Production Stages*, introduction of new gilts and boars in pig farm, that are purchased from outside, is a common industry practice. The likelihood of infectious agents being transmitted in the farm is highest when there are new external pigs entering. The first biosecurity protocol would be to set a list of health requirements for the new incoming pigs. The list should have categories of possible diseases and the scheduling period for vaccinations and veterinary care.

The next recommended protocol is to have a properly designed separate unit for quarantines. The quarantine unit must be designed to avoid any exposure to infectious organisms, located furthest away from pig houses and to house the pig in isolation for a minimum of 30 days, unless the incubation period of the diseases is known to be less (Alarcón, Allepuz, & Mateu, 2021). All farm workers in contact with the pigs to be quarantined must wear separate clothes, and to shower before coming into contact with other pigs or workers.

4.3.6.2 People and Vehicle Management

The people working in Pig farms may also spread diseases to the pigs and not just vice versa. For example, the H1N1 viruses had originated from humans. The first measure is to have a visible list at the guardhouse stating the entry and movement of different personnel tasks, such as the farmer's role, drivers, electricians, engineers, veterinarians and etc. This would provide clear idea of the location and route permitted to everyone.

Anybody entering the farm must register their details in a registry book at the guardhouse. There must also a visible map of the farm's site layout to demarcate the areas that are in contact with the animals and areas that aren't. Basically, anybody that is crossing between the area must follow the required disinfection protocol, such as change of clothes and showering. Dedicated footwear cleaning and disinfection stations must also be placed at the areas after contact with animals as well as hand-washing stations. All pigpens must have an area for clothing change including safety boots.

The map of the farm layout should also show the road networks within the farm for vehicle movement. This is important for minimization of contact between people and with the pigs. The farm must provide an area lot specifically designed for animal shipping in or out of vehicles. Vehicles that have been in areas that are considered in contact with the livestock must undergo cleaning and disinfection before fully exiting the farm.

4.3.6.3 Security Barrier

Depending on the farm size and layout, a security barrier should be erected around the farm perimeter with the aim not only preventing entry of trespassers, but also wild animals, which include dogs, wild boars, birds and bats since they are all potential disease carriers. The barrier can either be a chain link fence or solid wall. If problems with big animals such as wild boars persist, the next biosecurity measure is to have double fencing, or thicker walls erected. Bird-proof nets/screens should be placed at any areas that have possible entry access for birds into the farm house, such as open enclosures and windows, to prevent Salmonella transmission (Global Ag Media, 2021). For entry prevention of pathogenic microorganism, the use of high efficiency particulate air (HEPA) filters are highly recommended at the windows or ventilation inlets/outlets (Alarcón, Allepuz, & Mateu, 2021).

There should also be a security camera operating full-time at the guardhouse that is able record the entryway in high resolution video format. A security guard must always be stationed there too, usually at 12-hour shifts. Therefore, the farm can be under surveillance 24 hours daily.

4.3.6.4 Feed and Water

Various pathogens may contaminate feed, such as in soybean meal or vitamin D supplements, that are ingested by the pigs. One recommended biosecurity protocol is to have a separate feed storage area for when new feed suppliers deliver or when new feed products that can be potentially contaminated, are ordered. This storage area should be equipped with the proper sampling tools for measurement and testing.

Other chemical additives such as formaldehyde, fatty acids and essential oils has been proven to be able to eliminate bacteria and virus in the animal feed (Alarcón, Allepuz, & Mateu, 2021). A study done by Prof. Dr. Loh Teck Chwen (2017) showed that by adding medium-chain triacylglycerol with the lactating sow's milk and fed to piglets at pre-weaning stage, better growth performance of the piglets was observed, as well as improved gut morphology. Fermented fruit mixed with rice bran also showed good growth performance for pigs at weaner stage with less mortality rates. Furthermore, the addition of post-biotic metabolites to grower pig's feed, resulted in improved gut microflora balance, increase in growth rate and better immunity towards pathogens (Chwen, 2017)

The water used for drinking in pig farms must be analysed once every six (6) months for it's bacteriological, chemical, and physical quality parameters to ensure the absence of any indicator organism and is potable. Another biosecurity measure is to clean and disinfect the water storage tanks and pipes every six (6) months to prevent biofilm formation (Alarcón, Allepuz, & Mateu, 2021).

4.3.6.5 Cleaning and Disinfection in Pigpens

The main biosecurity protocol in pigpens is the cleaning and disinfection. The pens are either hosed with water or can be automated with high pressure water jets. Detergents can be mixed with the water as next cleaning step before rinsing and drying. After that, disinfection is recommended to be done using phenyl compounds, chlorine, and iodine to eliminate pathogenic microorganisms.

The second biosecurity protocol is when carrying out injection during vaccinations, the needles should be changed after every use. However, if the farm records can show that all animals are healthy and no medical records issue, it would be acceptable for same needle to be used at each group pen, such as boar pen, sow pen, grower pen, but to ensure the needle is sterilized with boiling water after each injection, and up to maximum use on 8-10 pigs before disposing into an identified waste bin (Pandolfi, Edwards, Maes, & Kyriazakis, 2018).

4.3.6.6 Pig Carcass Disposal

The general disposal method for pig carcasses is by burying at an isolated area in a deep pit far away from farm production site. Waterlogged areas should also be avoided for fear of groundwater seepage. Lime is initially used to cover the carcass. The pit is excavated up to 0.2 m from the soil surface to prevent earth deposition. Lime inhibits bacterial growth and therefore helps with decomposition, which in turn prevents foul odours from being emitted. After the hole is closed, lime is again sprinkled around the pit. If the pig farm wishes to burn the carcass due to insufficient or unsuitable areas for burying, approval must be obtained from Malaysia's DVS or DOE beforehand (Jabatan Alam Sekitar (JAS), 2014).

An alternative greener method for disposal of pig carcass is by composting the carcass in a suitable manner. Carcass composting will biologically decompose the pig carcass that is covered by other carbon material such as sawdust and straw under aerobic conditions and converts them into a harmless and odourless product that can be used as fertilizer or soil amendment (Linden, 2015)

The composting facilities should be installed within the pig farm site since it is relatively cheap and easy to operate and maintain (Technology and Innovation Branch (Environmental Stewardship Division), 2011). The advantage of having the ability to compost the carcass within the farm boundary in a safe way, is that prevention measures also come into place, by cutting down the carcass storage duration and reduced contact exposure with outside vehicles and people. Another biosecurity hazard mitigated is the containment of a disease outbreak, since composting of the infected animals can be done within the farm which avoids contact with anyone outside the farm.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Most farmers tend to choose the cheapest option for farm management, in order to comply to the bare minimum requirements on quality controls and environmental regulations, but this usually hurts the overall farm production or profitability in the long term. Therefore, it is imperative for animal farms to start adopting green farming principles to reach a sustainable farming concept.

The concept of sustainable farming is the ability to market enough amounts of farming products (meat, milk, eggs, etc.) that is economically profitable to the farm, whilst taking care of social welfare of farmers and workers and at same time being environmentally responsible and not allowing any pollutants emission release. This Study has shown that waste treatment management is just one, of many other green farming options, to be implemented to achieve a MPF system. Information on the entire farm's production process and operations is important to make a decision but, most times it more efficient to utilise a combination of green methods and options.

In fact, there should be more social engagement between farm stakeholders, that could be facilitated by the Government, whereby valuable knowledge sharing of green measures can take place. Kampung Selamat in Penang for instance, has around 70 small scale farms within less than 10 km. They may benefit by making group decisions together, such as implementing a centralized integrated centre for energy recovery, waste treatment, feed preparation and long list of other green farming options.

5.2 Recommendations

Amongst all the green options that are discussed in this study, some requires significant financial commitments, whilst others do not. Therefore, as a future work recommendation, the operational and capital expenditures should be carefully evaluated according to the farm's capacity. The greening of a farm must also include the overall financial return to ensure a successful sustainable livestock farm production.

A list of all the recommended green measures for pig farming has been summarized and compacted into a checklist in Table 5.1. However, this is by no means an exhaustive list, as global farming technology keeps developing rapidly, the shift of climate change and with pathogenic microorganisms developing more resistance to current vaccinations, so too the constant addition/update of greener measures to be assessed and implemented.

Table 5.1: Checklist Tool for Greening Pig Farm

NO.	GREEN OPTIONS /MEASURES/ DESIGN		POLLUTION IMPACTS MITIGATED			
			Soil	Public Health	Air / Odour	Water bodies
1.	Waste treatment system	i. Waste Stabilization Ponds ii. Anaerobic Digestion iii. Bio-filter System iv. Constructed Wetlands v. Aerobic Bioreactor System vi. Deep Litter System or Fermented Bed Technology	✓	✓	✓	✓
2.	Farm Design Criteria	i. Site located downwind and 250m buffer from nearest residential area ii. Separate pens for each stage of pig's life iii. Separate drainage network for pig waste and rainwater iv. Plant tall trees to absorb dust and provide shade v. Facility's material of construction vi. Pig's life cycle management	✓	✓	✓	✓
3.	Pig pen	i. Slatted floors ii. Farrowing pen for sows to feed piglets iii. Mechanical scrappers for manure cleaning iv. High pressure water jet for cleaning v. Design layout	✓	✓	✓	✓

4.	Odour Control	i. Regular Cleaning of Pigpens ii. Effective Ventilation iii. Manure Collection Point iv. Diet Alteration v. Oil spraying vi. Bio filter media/ Wet scrubbers	✓	✓	✓	
5.	Feed	i. Feed intake – type and quantity management ii. Automation for feeding iii. Feed schedule and monitoring iv. Effective Microbes (EM) v. Fermented fruit vi. Agricultural co-products (rapeseed meal)	✓	✓	✓	✓
6.	Implement Renewable Energy system on site	i. Biogas Plant ii. Solar Farm iii. Integration with fish farm/pond	✓	✓	✓	✓
7.	Biosecurity	i. Quarantine unit for new pigs ii. Disinfection protocols for workers and vehicles iii. Security/Safety barrier iv. Additives (formaldehyde, fatty acids essential oils) to animal feed v. Potable water system maintenance vi. Cleaning and disinfecting pens vii. Vaccination protocols viii. Composting pig carcass ix. Vegetative Environmental Buffers (VEBs)	✓	✓	✓	✓

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