Unlocking the Electricity Recovery Potential from Sustainable Management of Pig Manure Based on Geographic Information System Analysis: Case Study in Hanoi, Vietnam

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ABSTRACT

Pig production has a significant contribution to economic development in Vietnam. However, the lack of appropriate management strategies for the resulting large amounts of pig manure has caused severe environmental impacts, including greenhouse gas (GHG) emissions. Addressing this challenge, the author carried out this study to explore the potential for biogas production from pig manure in Hanoi.

This study aimed to optimize potential biogas production and reduce GHG emissions from pig manure. The study's specific objectives are to (i) identify suitable areas for biogas plants based on geographic feasibility and socioeconomic criteria; (ii) analyze the spatial distribution and amount of the potential biogas production from pig manure; and (iii) evaluate potential benefits of introducing biogas production to satisfy electricity demand and reduce GHG emissions.

The study first applied site suitability analysis to identify areas for biogas plants by (i) analyzing geographic criteria to eliminate sensitive areas; (ii) considering socioeconomic factors using the analytic hierarchy process to find suitable areas; and (iii) intersecting the restriction map and the suitability map to obtain a final map showing the suitability of areas for biogas plants. The study estimated biogas production capacity for pig farms and conducted a cluster analysis to identify spatially statistically significant clusters with high densities of potential biogas production. Following this, this study designed a baseline scenario and proposed three alternative scenarios (scenario 1, 2, and 3 for promoting energy generation in large, medium, and small-scale farms, respectively) based on farms' scale within selected clusters to optimize the available input manure and potential output capacity. Afterward, the location, number, scale, and capacity of biogas plants for each of the proposed scenarios were determined. Finally, the study calculated the net GHG (methane, nitrous oxide, and avoided carbon dioxide) emissions from manure decomposition and electricity generation from biogas for each scenario and compared these with the baseline scenario.

The results show that for scenario 1, focusing on large-scale farms, there are 2 possible sites for biogas plants with potential capacities of 1,218 and 1,350 kW in Son Tay and Thach That district, respectively. For scenario 2, focusing on medium-scale farms, there are 2 possible biogas plants with 476 and 363 kW capacities in Son Tay and Thach That district, respectively. For scenario 3, focusing on small-scale farms, there is 1 possible biogas plant with a capacity of 308 kW in Son Tay. Our results show that by using manure from approximately 8% of the pigs in Hanoi, biogas plants could help meet 1.75% and 0.76% of the electricity demands of Son Tay and Thach That, respectively, by 2025.

The GHG emission reductions from developing biogas plants are also significant. The net GHG emission of scenarios 1, 2, and 3 are -12,307, -4,021, and -1,478 tons of CO_2 eq/year, respectively, whereas the baseline scenario produces 66,971 tons CO_2 eq /year of net GHG emission. The gap between the 3 scenarios and the baseline is 84,777 tons CO eq/year.

The study results focus on identifying the potential amount of biogas of nearby spatial clusters and identifying the optimum areas, numbers, and scale of biogas plants that can help meet electricity demand in rural areas of Hanoi and contribute to a reduction in GHG emissions. Biogas plants are a viable and renewable alternative for meeting future electricity demand in rural areas; their development could provide local energy security and reduce GHG emissions.

Keywords: Livestock waste management, Biogas, Renewable Energy, Environment Pollution, AHP

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LIST OF ABBREVIATIONS

AD	Anaerobic Digestion
AHP	Analytical Hierarchy Process
ArcGIS	Geographic Information System Software
CH_4	Methane
CO_2	Carbon Dioxide
CO_2 eq	Carbon Dioxide Equivalent
COD	Chemical Oxygen Demand
ESRI	Environmental System Research Institute
EU	European Union
GDP	Gross Domestic Product
FAO	Food and Agricultural Organization of the United Nations
GHG	Green House Gas
GIS	Geographic Information System
HDPE	High-Density Polyethylene
IPCC	Intergovernmental Panel on Climate Change
kW	KiloWatts
kWh	KiloWatts hour
MJ	Megajoule
MW	Megawatt
N_2O	Nitrous Oxide
NDC	National Determined Contribution
NIMBY	Not In My Back Yard
RE	Renewable Energy

SDG	Sustainable Development Goals
TSS	Total suspended solids
UNFCCC	United Nations Framework Convention on Climate Change
VOCs	Volatile Organic Compounds

Chapter 1 Introduction

This thesis studies the potential for the production of biogas from pig manure in Hanoi, Vietnam. The thesis is organized as following orders: Chapter 1 provides the research background on pig production, manure, environmental impacts, environment and energy policy requirements, GIS application, and details of the study area. Chapter 2 explains in detail the GIS tools, AHP analysis, and mathematic equations used in the methodology. Chapter 3 delves into the results of the proposed scenarios. Chapter 4 discusses the results, related issues, research contributions, and limitations. Chapter 5 highlights the conclusions while coupling the research outcomes with policy implications to promote Vietnam's biogas utilization.

1.1.Pig production in Vietnam

Pig production is a key and traditional livestock industry in Vietnam. The country's improving living standards have driven the increase in demand for meat, with annual pig production now around 30 million heads on average. The number of pigs decreased from 27,628 million in 2009 to 26,494 million in 2013; however, it began to increase again in 2014 and then became stable (Figure 1.1).

Pork is the most popular meat consumed and produced in Vietnam and accounts for approximately 74% of total annual meat production [1]. Due to rising income and population growth, pork and consumer demand have increased steadily [2]. From 2013–2016, Vietnam's pork consumption per capita increased from 25.3 to 26.5 kg per year [2]. The total consumption of domestically produced pork in 2016 was 2.5 million tons, equivalent to 35.76 million pigs. Approximately 75% of Vietnam's total pork production is consumed domestically; however, a small part is exported to neighboring markets, accounting for 13,695 tons of live pork, equivalent to about 195,643 pigs in 2016. In 2017- 2018, Vietnam ranked in the top 10 countries globally in pork production and consumption [3,4].

Pig production in Vietnam is mostly located in provinces in the Red River Delta, Midland and Northern Mountains, North Central and the Central Highlands, and the Mekong River Delta (Figure 1.2). The Red River Delta has a high concentration of pigs with 324 heads per km^2. Dong Nai, Hanoi, and Bac Giang provinces have the highest numbers of pigs in Vietnam from 1 to 2 million heads in 2017 [5], with an average number of pigs per farm of 2,000 [6].

In recent years, livestock production in Vietnam has rapidly shifted from small-scale livestock production to large-scale farms. In 2000, the Government issued Resolution 03/2000/NQ-CP on Farm Economic Development, which prompted the transition from small

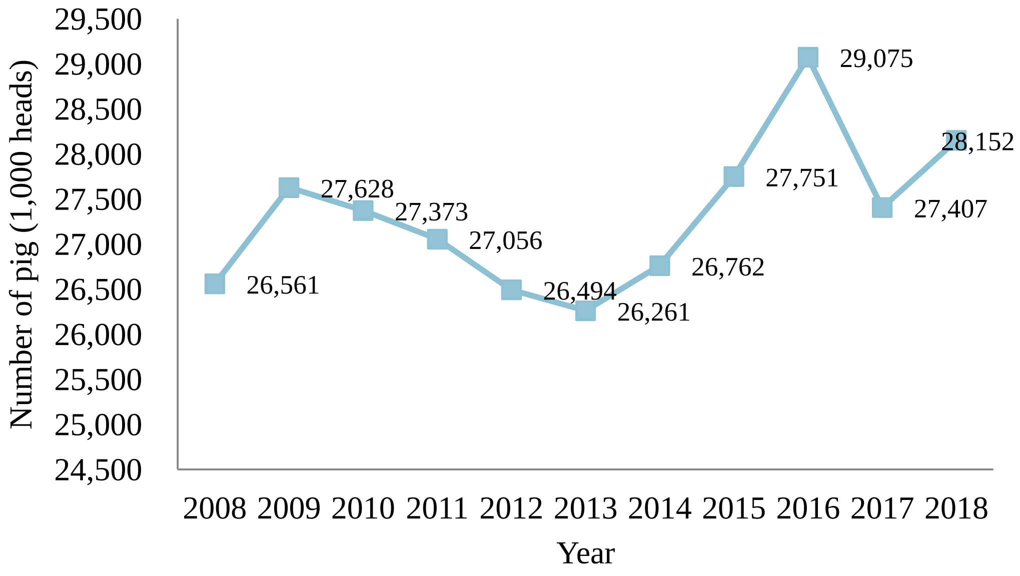

Figure 1.1. Number of pigs produced in Vietnam (2008 -2018)
Source: modified by the author based on [7]

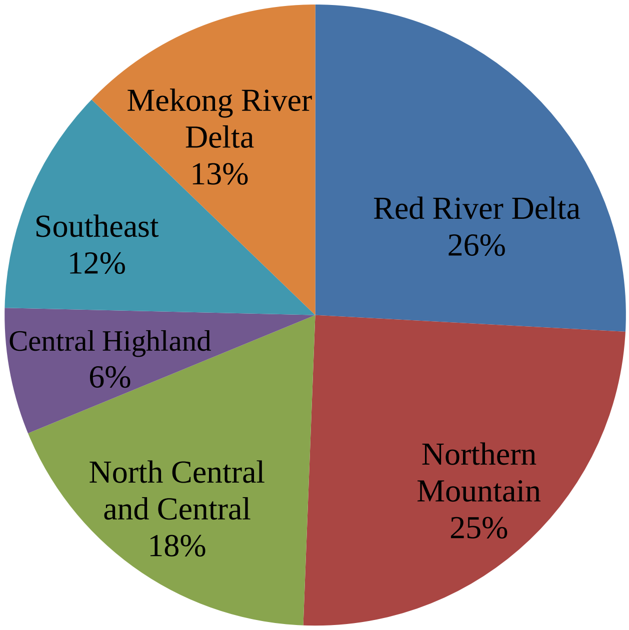

Figure 1.2. Total pig production by area in 2017
Source: modified by the author based on [7]

scale household farming to concentrated farming and led to a significant increase in the country's number of pig farms. The number of pig farms in Vietnam increased from 3,293 in 2011 [8] to 11,737 in 2020 with a total of 16.6 million heads, accounting for 51.9% of the total herd and with total pork output from these farms, accounting for nearly 56.7% of the whole country'' pork production [9]. Currently, large-scale pig farms made up 35% of the total pig heads and contributed to 43% of the total output, and this trend is expected to increase in the future [6]. Large-scale pig farms tend to be built close to big cities such as Hanoi and Ho Chi Minh City. The result has been economic efficiency and increased production of commercial agricultural products, improving livelihoods for people.

1.2. Impacts of pig manure management on the environment and current management methods

Approximately 24 million tons of pig manure is generated in Vietnam every year. The largest pig manure source is the Red River Delta, followed by the Southeast and the Mekong River Delta. Thai Binh, Hanoi, and Dong Nai have the highest pig manure density per kilometer square with 598, 390, and 219 tons/ km^2, respectively [1].

Once treated, pig manure is a valuable organic fertilizer for the farming industry. However, pig farms' proliferation leads to a high risk of environmental pollution from poor pig manure management, causing environmental pollution with risks of surface water, groundwater, soil, and air pollution [9].

Pig manure is currently managed by many methods, including composting, biogas for cooking, energy generation, and fertilizers. For composting, the solid waste is collected and mixed to produce organic fertilizer while the liquid fraction is washed off the floor and discharged into the environment. With the biogas method, the waste is collected and processed in a biogas vault. The gas generated is used to cook and generate energy; the waste left after biogas production can be used as fertilizer or discharged into fishing ponds. In some places, fresh manure is applied directly to plants as organic fertilizers. Pig manure management practices differ depending on the farm and barn systems' specific conditions, including the farm's location and size. However, it is reported that 40% of pig manure is discharged directly into the environment without treatment. Pig production is the most significant environmental pollution source from livestock manure in the country [1]. It accounts for 42% of all livestock manure produced, especially since the shift to large-scale production. When thousands of pig farms are concentrated in the same areas, their environmental and health impacts also become concentrated, creating large pig manure with liquid leaking out and causing significant problems. The waste flows into ponds and fields, making large agricultural land areas heavily polluted and unable to be cultivated. Pig manure discharge into ponds, lakes, canals, and ditches around the farms is common, causing water, soil, and air pollution around pig farms.

Poor management of pig manure can negatively impact the environment, causing water, soil, and air pollution due to the release of nutrients and organic compounds; the emission of ammonia to water, soil; and air and GHG emissions. Water pollution and soil contamination from intensive pig farms occur due to the spreading of manure with higher amounts of nitrates and phosphorous than natural processes' removal capacity [10]. Pig manure contains nitrogen, phosphorus, zinc, copper, lead, arsenic, nickel (heavy metals), and other harmful microorganisms that cause air and soil pollution. This affects soil fertility, surface water, and groundwater [1].

The current trend of pig and other livestock development in Vietnam is intensive husbandry on medium and large-scale farms. This form of farming has brought higher profits but also caused environmental pollution. Pig farming especially is water-intensive, using lots of water to clean the barn and thus discharging large amounts of untreated wastewater. Most farmers adopt a “closed cage” with a steam-cooled barn and ventilating fan for pig production. This type of barn has a water tank running along the length of the barn. This tank holds water for animals to dispose of feces and urine. Therefore, livestock waste is mixed with water into a mud-like. The amount of washing water required for a 50 kg fattening pig fluctuates in the range of 25–30 liters per head per day for a system that includes pigs cooling and water storage tanks for waste feces and urine [9]. This wastewater should be stored in a pond for storage and treatment. However, following heavy rains, livestock wastewater can spill around the farm and cause environmental pollution.

Wastewater is mainly generated from bathing pigs, washing pigsties, scrubbing and washing troughs, cleaning tools, pig urine, and leaking water from automatic drinking systems and water pipes. Wastewater from pig farms has common characteristics with other livestock wastewater such as strong odor, neutral pH, high concentrations of chemical oxygen demand (COD), total suspended solids (TSS), and nitrogen and phosphorous, which cause water pollution.

Moreover, emissions are a severe problem from large-scale farm production. Waste and spilled foods often accumulate in the barn's bottom, decomposing and producing gases such as CH_4, NH_3, CO_2, and volatile organic compounds (VOCs), which cause very unpleasant odors.

It is reported that although pig manure treatment is applied in Gia Lam district, Hanoi, it is insufficient. Surface water in the community is seriously polluted, with 4 out of 6 parameters of water quality showing average values that exceed the permitted threshold for Vietnam’s national standards: COD, Phosphate, TSS, and Ammonium levels exceeded the national limit 14, 27, 27, and 14 times, respectively. This shows that the surface water in farms is frequently contaminated with high levels of organic matter. For groundwater, the analytical results showed that ammonium has an average value of 1.23 mg/l, exceeding the threshold 12 times [11].

Pig manure is also one of the primary sources of agricultural GHG emissions [1]. There are three primary GHG emissions from livestock to the atmosphere, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) [12,13]. CH_4 and N_2O have global warming potentials of 25 and 298 times more than CO_2, respectively, over 100 years [14,15]. The total CO_2 equivalent emission from global livestock production is 7.1 Giga-tons per year, representing 14.5% of all anthropogenic GHG emissions. The emissions mainly come from feed production and manure management [11]. The Vietnam GHG inventory shows that GHG emissions from manure management account for 8.6 Mt CO_2eq and class the subsector of pig manure management as one of the country's 32 primary emission sources. These negative environmental impacts will continue their trend if appropriate measures are not properly implemented.

Besides, pig manure also releases gases formed from the respiration process. It removes pathogens, parasites, and harmful microorganisms such as E. coli, Salmonella, Streptococcus fecalis, and Enterobacteriae from human and ecological environments [1].

Problems due to pig manure management's environmental pollution are most pronounced in the intensively farms in Thai Binh, Hanoi, and Dong Nai. The most considerable amount of waste is from pig production, with 24.96 million tons [16].

1.3. Environmental and Energy Policies of Vietnam

1.3.1. International strategies, policies on sustainable development, and environmental protection

The Sustainable Development Strategy for 2011–2020 issued by the Government in 2003 aimed to improve people's material, cultural, and spiritual life to ensure harmonious development through human resources, scientific and technological capacity, infrastructure, and economic and security potential to ensure economic growth, improved quality of life, and environmental protection.

A total of 115 Vietnam SDG (VSDG) targets have been nationalized from 17 global SDGs and delivered in the "National Action Plan for Implementation of Agenda 2030 for Sustainable Development." Until now, there are some targets relevant to environmental issues that Vietnam has made efforts to improve, including the ability to access safe water (SDG 6) and electricity with affordable and clean energies (SDG 7) as well as the improvement of the protection and management of the environment and natural resources [17].

Some SDGs focus on promoting clean and green energy to address climate change and ensure sustainable development for society, including SDG 9 promoting innovation and the use of sustainable resources for industries and the development of green, efficient infrastructure and sound technologies, SGD 11 promoting sustainable waste management systems for rural and urban development, and SDG 13 for combating climate change and natural disasters.

Simultaneously, the Kyoto Protocol and Paris Agreement, legal documents that the United Nations Framework Convention on Climate change (UNFCCC) launched for all countries of the world to address climate change issues, were signed and ratified by Vietnam in 2002 and 2016 respectively. Accordingly, Vietnam committed to reducing GHG emissions by 8% by 2030; the nationally determined contribution document reaffirms this determination to climate change response and contribution to the UNFCCC.

1.3.2. National policies, strategies, and plans on GHG mitigation and Renewable Energy

The Law on Environmental Protection issued by the National Assembly of Vietnam in 2014 indicated that environmental protection should be ensured with targets on economic development, security, gender equality, biodiversity conservation, and climate change response.

The Law on Energy Efficiency and Conservation issued by the National Assembly of Vietnam in 2010 pointed out that energy efficiency and conservation shall be associated with the strategy and master plan for energy and environmental protection. It gave rules on the economic and efficient use of power to increase renewable energy use.

The law on energy saving and efficiency issued in 2010 includes policies for energy saving and efficiency, labeling energy and increasing renewable energy use, and providing subsidies and priority for green energy consumption.

The National Climate Change Strategy focused on reducing GHG emissions and promoting clean and renewable energies for meeting a low-carbon economy. The agriculture sector highlighted that cultivation techniques should be changed, and appropriate management and use of animal waste for biogas should be implemented with a target of 20% reduction of GHG emissions every 10 years.

The National Green Growth Strategy's objective is to achieve a low-carbon economy and natural resource protection. Targets included reducing GHG emissions by 8 to 10% the amount in 2010, reducing energy consumption per GDP value by 1 to 1.5% annually, and reducing GHG emissions by 1.5 to 2% annually by 2030 2050, respectively.

The Vietnam National Target Program to Respond to Climate Change launched in 2008 with a series of activities to address climate change effects and work towards a low-carbon economy.

The rural clean water and environmental sanitation national target program and the national target program on energy efficiency and conservation issued by the Government in

2012 were established to address water and energy efficiency issues.

The plan to manage GHG emissions and carbon trading activities in the international market mentioned the Nationally Appropriate Mitigation Action (NAMA) framework of Vietnam. It aimed to control GHG emissions by implementing international treaties and agreements which Vietnam took part in for green growth and sustainable development. This includes developing GHG reduction solutions technologies, biogas systems, livestock manure, and poultry storage and treatment.

The program for GHG emissions reductions in the Agriculture and Rural development sector up to 2020 set a target to reduce 20% of GHG emissions in the agriculture sector.

1.4. Biogas production and its benefits

Livestock environmental pollution, especially on the farm-scale, is a pressing problem in many rural areas of Vietnam. Many technologies to treat pollution from livestock waste have been implemented. One of the technologies popularly applied for livestock waste treatment in Vietnam is biogas technology.

Biogas is produced from decomposing organic material under an anaerobic environment. The fermentation process breaks down organic material and turns it into energy used for heating, cooling, cooking, or producing electricity through burning (Figure 1.3). In nature, biogas generation is a vital part of the biogeochemical carbon cycle [18].

Biogas has a long history of use in developing and industrialized countries. In the 17^{th} century, Jan Baptita Van Helmont first determined gases evolving from decomposed organic materials. In 1770, the Italian Volta collected gas and investigated its burning ability, and in 1821 Avogadro identified methane. Among developing countries, China and India lead in biogas use [19]. Initially, biogas technology focused on small-scale farms. However, larger farms have now become the focus of new biogas technologies [18]. In China, biogas plants were first built in the 1940s for wealthy households. Since the 1970s, biogas research and technologies have been progressing rapidly and are promoted vigorously by the Government. Many biogas digesters have been constructed in rural areas, and the number of farms using biogas is increasing. In India, simple biogas plants were utilized for rural households starting in the 1950s, and a massive increase in biogas plants took place in the 1970s through strong government support [18].

Biogas' compositions are mostly methane (50–70%) and carbon dioxide (30-50%); however, they also include other gases such as hydrogen and hydrogen sulfide. Its calorific value is 21–24 MJ/m^3. Its characteristic properties are pressure and temperature-dependent [18].

There are three stages in the biogas process: hydrolysis, acidification, and methane formation. In the first stage, bacteria decompose and break down insoluble organic polymers.

In the second stage, acid-producing bacteria convert sugars and amino acids into carbon dioxide, hydrogen, ammonia, organic acids, and acetogenic bacteria convert organic acids into acetic acid, hydrogen, ammonia, and carbon dioxide. In the final stage, methanogens convert these final components into methane and carbon dioxide, which can be used as green energy.

Biogas can use many organic matter types as inputs, including food scraps, sludge from wastewater treatment plants, animal manure and field biomass from agriculture, and other biodegradable waste by-products from industrial facilities. Biogas technology is the most cost-effective method for treating livestock wastewater today. This technology has a lower construction cost compared to other technologies. Still, it is highly effective in killing germs that cause disease in humans and animals and decomposing organic matter into biogas.

Furthermore, biogas can bring many benefits for society, the users, and the environment, including through the production of energy such as electricity for heating, cooling, and lighting; production of fertilizer from manure slurry; and economic benefits from energy generation and environmental protection.

Biogas can contribute to a reduction in GHG emissions in the agricultural sector by three methods: (i) manure decomposition; (ii) generation of renewable energies instead of using of traditional fossil fuels that cause GHG emission; (iii) usage of by-products of the biogas process to replace chemical fertilizers. Besides, odor emission and pathogens will be reduced or removed effectively [20].

In theory, biogas can be converted into electricity using combustion engines, fuel cells, or gas turbines [21,22]. Accordingly, biogas is burned, and hot air is turned out for combustion engines, which turns it into mechanical energy and generates electricity through an electric generator. Biogas can be used as input fuel for many kinds of internal combustion engines (piston), including gas engines, diesel engines, gas turbines; external combustion engines (Stirling motors); and steam engines by burning for heating water. The larger the engine, the higher the efficiency of the biogas. This means that it is more viable with more biogas and bigger motors.

Many studies mention the contributions of biogas to electricity generation. In Thailand, biogas electricity generation from waste from pig farms was supported by the government's feed-in tariffs and the Clean Development Mechanism and contributed to CO_2 reduction. A biogas plant of 870 kW capacity can generate 6,144 MWh of electricity per year and reduce CO_2 emissions by 32,750 tons compared to generating electricity from fossil fuel [23]. Another study on biogas electricity generation from pig farms

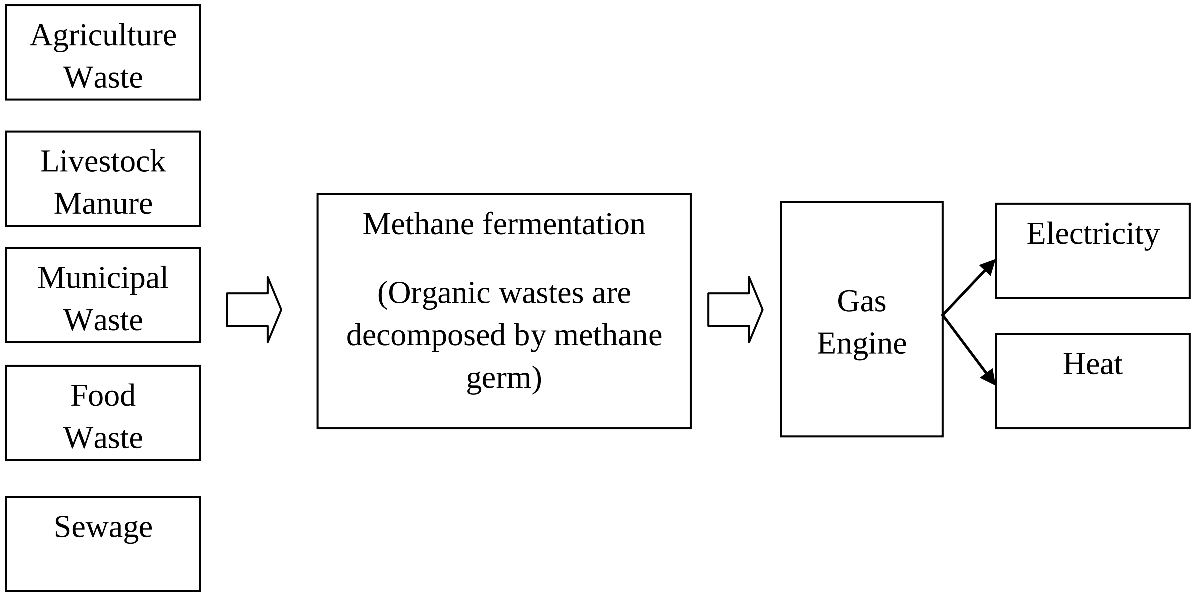

Figure 1.3. Outline of biogas production for generating energy
Source: Modified by the author based on [24–26]

with over 1,000 heads/farm estimated that with around 4.3 million heads, 2.67×10^8 kWh (equal to US$ 26.7 million of electricity charge savings) of electricity could be produced annually, reducing carbon dioxide production by 180,000 tons [27]. In Turkey, biogas is widely used in rural areas, and 780 kWh of electricity was produced from 800 farms.

1.5. Biogas practices for pig manure in Vietnam

The Vietnam Government has made significant efforts to address those environmental problems from pig manure management. One of the essential solutions is a program that promotes biogas development. Under this program, the government has set a target to encourage biogas from manure to 45% of the total manure discharge used for biogas production by 2020. Biogas' potential is enormous, with an annual release of approximately 85 million tons of livestock waste. Therefore, it is essential to produce biogas and integrate it into the economy. It will allow the utilization of energy potential from manures, enhancing environmental quality and making a circular economy.

However, biogas production in Vietnam has been funded mainly by non-governmental organizations and is mostly limited to small-scale production with more than 1 million current operations [28]. Medium and large-scale farms have started to develop different biogas plants, but only 0.3% of the 17,000 farms across the country utilize waste to produce biogas [29]. The actual situation of building biogas plant implementation and the government targets in practice has a considerable gap.

In Vietnam, livestock development's current trend is towards larger-scale farms with more animals and higher profits. However, due to the tropics' livestock characteristics, the amount of livestock wastewater is often high. Livestock wastewater includes animal manure, urine, washing water from farms, and livestock. To treat each farm's daily wastewater volume, with works up to several tens or hundreds of cubic meters per day, requires medium or large-scale biogas plants.

Currently, the medium and large-scale biogas technologies in Vietnam include the following three main types: tubular biogas tanks, KT1 and KT2 biogas tanks with a volume of 50–200 m^3, and high-density polyethylene (HDPE) covered biogas. These biogas tanks are built of bricks and cement with a work of 10–200 m^3 and are generally considered as medium-sized biogas tanks. The advantage of this type of tank is that the wastewater is moved along the biogas tank, making the organic matter decomposition highly efficient by microorganisms. This type of tank is easy to build, but if the tank's bottom is not suitably reinforced, especially in coastal plains with soft ground, the tank will quickly settle, crack, and get damaged. Fixed-cap biogas tanks have the same shape as the widely built KT1 and KT2 tanks and have volumes of 10–200 m^3. The advantage of this type of tank is the sustainability of the structure. HDPE-covered biogas requires three ponds with one HDPE-covered biogas pond and two sedimentation ponds. HDPE covered biogas technology was first researched and installed in the United States in 1992. It has been applied and improved by many countries in Latin America and Asia. This technology was first used in Thailand in 2002 and Vietnam in 2006 since waste is stored in the biogas ponds for 30–50 days at an outdoor temperature of 25–35°C.

In practice, depending on the location's conditions, any farm size can use one of the biogas methods. Treatment of livestock manure by biogas plants is considered a useful solution to reduce methane emissions and produce clean energy.

There is only one biogas production facility for electricity generation in Vietnam that uses waste from pig farms. This facility, located in Binh Duong province, has a total installed capacity of 17,000 m^3 (equal to 2 MW). Other facilities are designed only to produce biogas to replace fuel oil or coal for cooking and distillation. The remaining gas is burned away or discharged directly into the environment [30]**.**

Since 2010, the government has raised many policies to encourage investment in renewable energy (RE) to meet 4.5% of the country’s energy demand through renewable sources [31]. The National Energy Development Strategy implemented a development strategy for the energy sector, including coal, oil and gas, electricity, and RE, based on 2020 with a vision to 2050. The goal is to increase RE's share, including biogas, to approximately 5% in 2020 and 11% in 2050 [30]. Vietnam’s nationally determined contributions (NDCs) 2016 set a goal to reduce its GHG emissions by 8% by 2030 without conditions and by 25% with international support [32].

According to the Vietnam 2nd National Communication Report that was submitted to United Nations Framework Convention on Climate Change (UNFCCC), the GHG emission reduction potential of biogas implementation is about 22.6 Mt of CO_2. The cost of CO_2 reduction for the delta and mountainous areas are 4.1 and 9.7 USD/tons CO_2, respectively, contributing 1,200 billion VND for fuels [6].

To support Vietnam's policy-making processes, the author relized that it is necessary to research and assess bioenergy resources' actual potential properly. Thanks to those assessments, the government can introduce mechanisms and policies to subsidize the purchase of output electricity produced from bioenergy. By proposing a viable method to determine the optimization of potential biogas and suitable areas for biogas facilities, this study will provide implications for implementing appropriate related mechanisms and policies.

1.6. Electricity Demand in Vietnam

Electricity consumption in Vietnam has significantly grown in the last ten years in line with its industrialization, higher living standards, and urbanization. Vietnam is expected to need 6.6 billion kWh in 2021, and this will increase further to 15 billion kWh by 2023. As a country with a population of over 90 million and an annual gross domestic product (GDP) growth of 7%, it is necessary to increase power generation every year [33].

In 2015, the GDP growth rate reached 6.68%, the peak of the last five years. In March 2016, the revised 7th Vietnam Power Development Plan for 2016–2020 was published with a vision reaching 2030. This decision’s objectives are to ensure national energy security and achieve the socio-economic development targets. It provided evidence that the electricity demand in Vietnam will grow at a high rate in the future. The total power installed capacity estimation will be 60 GW by 2020 and 129.5 GW by 2030 [34].

The high demand for electricity puts Vietnam’s electricity industry under pressure to add new supplies to ensure energy security. Although Vietnam’s electricity installation rate has increased sharply in recent years, power shortages have continued. Every year, Vietnam imports electricity from China and Laos to meet the rising electricity demand during the dry season. The Vietnam Ministry of Industry and Trade forecasted that starting from 2021, a severe shortage of electricity would take place [35].

One of the leading causes was that the power supply depends mainly on hydroelectricity and coal thermal power, with other power resources being undeveloped. To date, the hydroelectricity potential of Vietnam has almost been exploited. Until 2013, the installed capacity of hydroelectricity was the primary source of electricity production in Vietnam. However, as this power is mainly dependent on rainfall, power shortages often occur during El Nino years. Simultaneously, with the ongoing climate change, extreme weather events are becoming increasingly more severe. Frequent droughts make hydroelectricity an unreliable and unstable power supply. Thus, the power source structure's proportion of hydroelectricity has continuously reduced and gradually been replaced by coal-fired thermal power. However, in recent years, domestic coal production has been insufficient to supply all electricity plants; it was necessary to use imported coal or mixed coal (mixed domestic and imported coal) to generate power. The author believes that these ongoing power shortages also reveal the need to exploit other energy resources and invest in these to meet the electricity consumption demand in Vietnam.

1.7. GIS application

It is essential to identify optimal locations for biogas plants considering geographic and environmental feasibility, transportation distance, and socioeconomic conditions to increase biogas production and its effectiveness in Vietnam. A geographic information system (GIS) is a really powerful tool that can help us manage geographical data and spatial factors and help us identify the optimal locations for installing biogas plants.

Many previous studies have employed GIS as a tool for decision-making on resource management, suitability, and optimization analysis in many countries and regions [36–41].

Samira Zareei [41] used information on population and land use to develop a model for evaluating biogas production from rural household waste and livestock manure and identified the optimal locations for Iran's biogas plants. J. Höhn et al. [42] used GIS to analyze the spatial distribution and amount of potential biomass feedstock and find the most suitable locations for biogas plants by optimizing transportation distance in southern Finland. Sliz-Szkliniarz et al. [39] determined the optimal sites for installing anaerobic digesters (AD) by applying a GIS model that focused on animal manure and cosubstrates in Poland. Perpiña et al. [43] and Silva et al. [44] conducted a multicriteria assessment in GIS with an analytic hierarchies process (AHP) to identify suitable sites for the construction of biomass plants. Hali Akinci et al. [45] used GIS and AHP for determining suitable lands for agriculture use in the Yusufeli district, Turkey. K. Laasasenaho [46] identified potential bioenergy areas and optimized biomass transportation and plant size by using a combined approach with R software and GIS tools. Sedat Yalcinkaya Izmir [47] identified potential plant sites based on a location-allocation analysis in GIS, which incorporated location, sizes, and transportation costs in Izmir, Turkey. The unit cost of electric energy as compared to the existing feed-in tariff for biogas plants. Mohamed Mahmoud Ali et al. [48] applied GIS to show the amount of waste, the potential for biogas, and the corresponding energy potentials in countries in Africa. This pointed out that the revenues from the sale of biogas-generated electricity and digested slurry could pay for the initial investment within 6.5 years without subsidy. Valenti et al. [49] applied GIS in combination with a techno-economic assessment to determine the size and location of 4 biogas plants. They determined that the system could satisfy 27% of the total electricity demand of agricultural practices with a discounted payback period of fewer than 6.5 years for the biogas power generation system. Kamalakanta Sahoo et al. [50] developed a GIS-based model with multicriteria analysis to study sustainable crop residues' availability and optimize biogas plants' location. Scarlat et al. [36] conducted a spatial assessment of biogas potential from farm manure across Europe with a 1 km threshold. Mohamed [51] assessed the land suitability and capability of Chamarajanagar, India, by combining GIS and remote sensing to optimize land use. Sorda et al. [52] created a spatial simulation to evaluate biogas technology's potential diffusion based on the relevant financial schemes for electricity to make investment decisions. Regarding spatial optimization for GHG emissions, one study used a GIS technique for calculating the fixed CO_2 contained in tree biomass in the Neyyar Wildlife Sanctuary, Western Ghats, India [53]. Another study used GIS to model CO_2 emissions with pupils' commutes in the UK [54]. A study that identified biogas plants' optimal locations from animal manure to reduce travel costs for North Dakota supply chains was a useful reference for spatial optimization regarding cost reduction [55].

Several approaches from these studies were applied in this paper to facilitate implementing biogas plants with optimization of pig manure management for generating biogas energy in Hanoi, Vietnam. Until now, there is no study that applied GIS for biogas plant optimization, which considers both spatial cluster analyses optimize feedstock sources to potential plant options and the environmental benefits of biogas production with the calculation of net GHG emissions.

1.8. Objectives

This study aimed to optimize potential biogas production and reduce GHG emissions from pig manure. By using the GIS, the author identified the ideal areas, the scale of biogas plants and took into consideration GHG emissions reductions.

The study's specific objectives are to i) identify suitable areas for biogas plants based on geographic feasibility and socioeconomic criteria; (ii) analyze the spatial distribution and amount of the potential biogas production from pig manure; and (iii) evaluate potential benefits of introducing biogas production to satisfy the electricity demand and reduce GHG emissions.

1.9. Study Area

Hanoi is located in the north-east region of Vietnam (20°53′–21°23′ North and 105°44′–106°02′ East) and situated in Vietnam's Red River delta, nearly 90 km away from the coast.

In 2014, Hanoi's average GDP growth was 8.8%, accounting for up to 13% of Vietnam's GDP. Hanoi is the largest socioeconomic development center of Northern Vietnam. With an estimated nominal GDP of USD 32.8 billion in 2018, Hanoi is the second most productive economic center in Vietnam.

Hanoi has high temperatures with high humidity and heavy rainfall as located in a humid subtropical climate zone with four distinct seasons. The average temperature in Hanoi is 23.6°C annually with 79% of humidity and 1245 mm rainfall. Hanoi has hot summers with showers and cold and dry winters with little rain [56]. These climate conditions are suitable for the anaerobic digestion of agricultural by-products and other organic materials.

Of the 30 districts and towns (12 urban districts, 1 town, and 17 rural districts) in Hanoi, 25 are heavily reliant on agriculture, and large-scale pig raising thrives in rural and suburban districts. These districts are vast rural areas with right natural, economic, and social conditions for developing high-quality commodity agricultural production (Figure 1.4).

Hanoi is the second-largest pig-producing region in Vietnam, after the Dong Nai province (Figure 1.5). The number of pigs in Hanoi has been relatively stable in recent years, at approximately 1,600,000 heads per year (Figure 1.6). Recently, the number of large-scale farms is increasing, and the number of small-scale farms is decreasing. In 2016, approximately 679 pig farms were located in different rural areas of the city. Until now, those numbers have been changing due to the socioeconomic situation. On average, there are 2,000 to 5,000 pigs per farm in Hanoi [6].

Presently, Hanoi has 13 essential large-scale pig farms located in Son Tay, Quoc Oai, My Duc, Ung Hoa, Thanh Oai, Gia Lam, and Thach That [57], and there are plans for more in Chuong My, Soc Son, Phu Xuyen, Dong Anh, and Me Linh. Hanoi targets that farm animal husbandry will account for 70% of the total livestock population by 2025 [58].

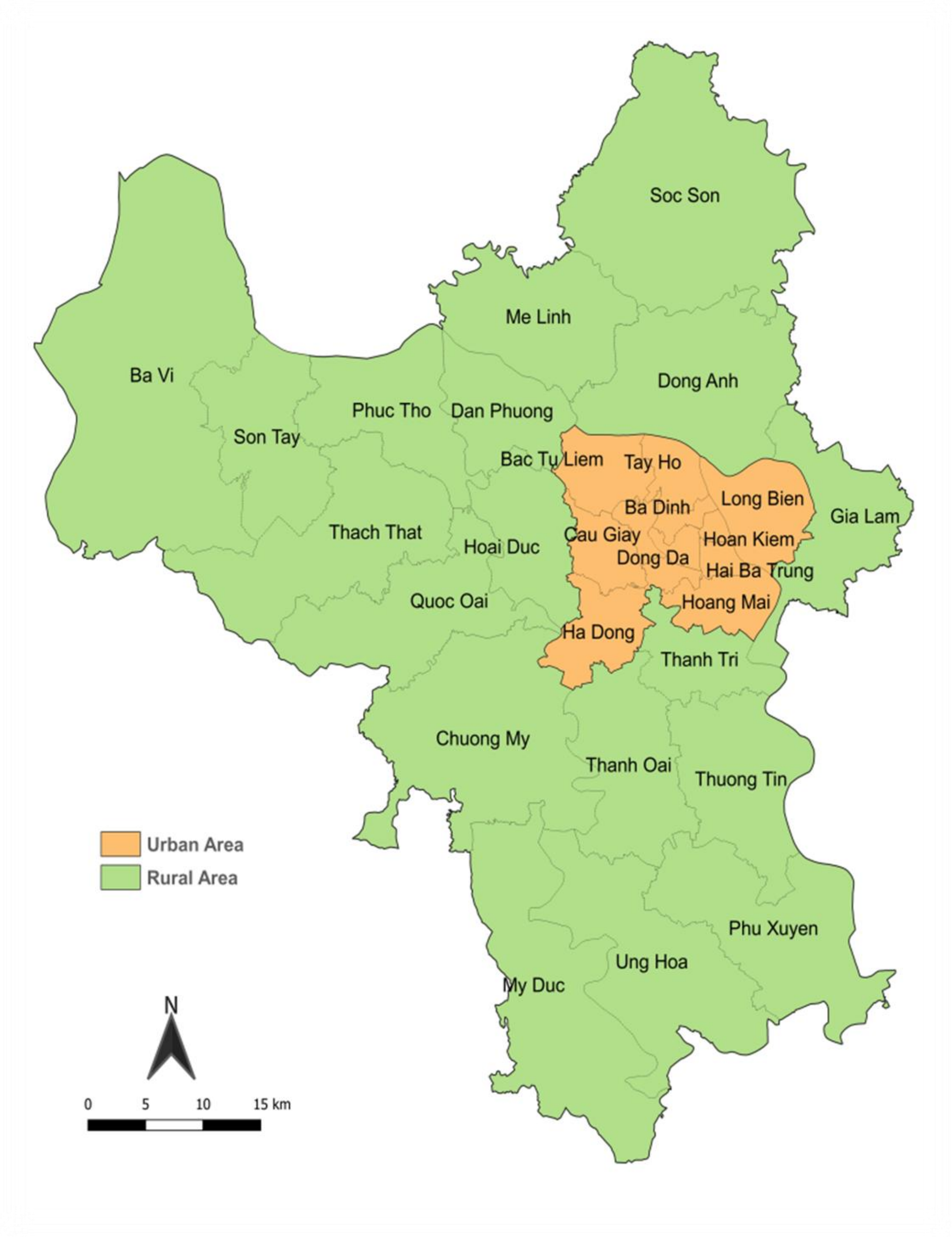

Figure 1.4. Map of Hanoi
Source: modified by the author with ArcGIS 10.6 based on layers from Hanoi Urban Planning Institute of the Hanoi People Committee [28]

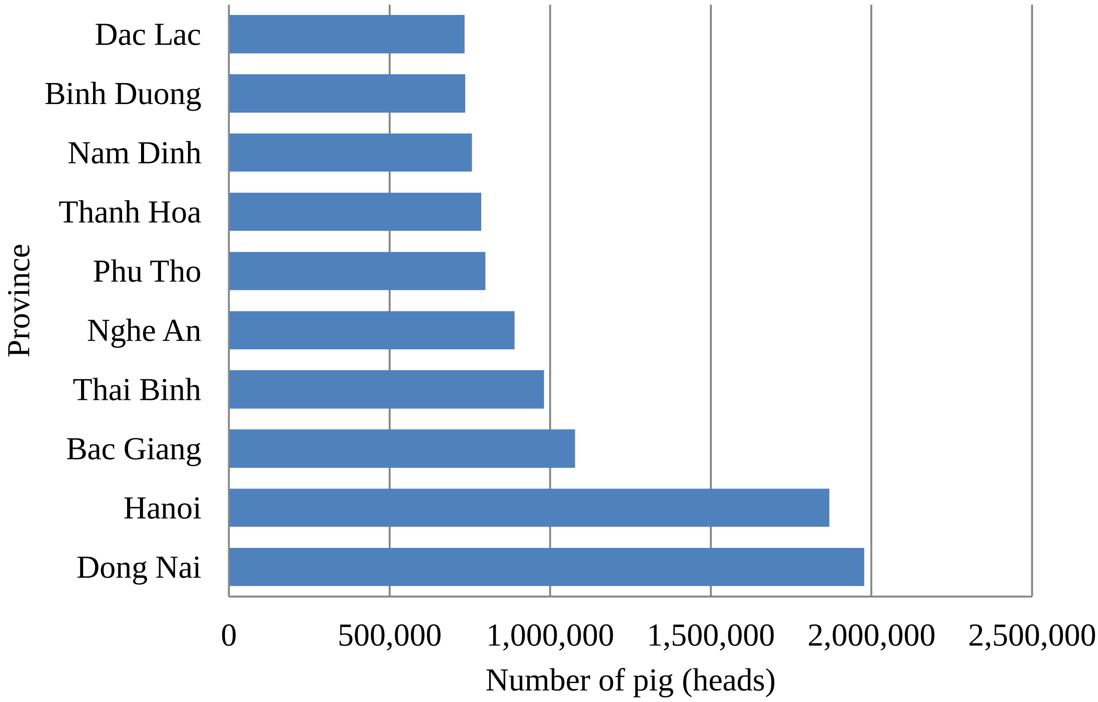

Figure 1.5. Top 10 largest pig production provinces in Vietnam in 2017
Source: modified by the author based on [7]

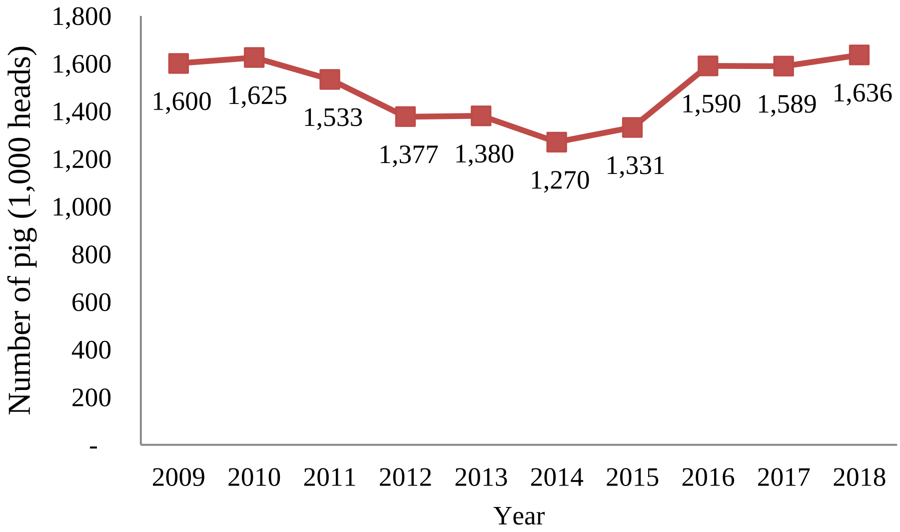

Figure 1.6. Number of pigs in Hanoi (2009-2018)
Source: modified by the author based on [7]

Chapter 2. Materials and Methods

2.1. Research Method Framework

This study comprises an analysis of potential biogas production from pig manure. Firstly, the study applied a site suitability analysis to identify available locations for siting biogas plants by (i) analyzing geographic criteria to eliminate sensitive areas, (ii) considering socioeconomic factors with AHP to identify suitable areas, and (iii) combining the restriction map and the suitability map to obtain the final map with available areas for sitting biogas plants. The study then estimated the biogas production capacity of pig farms and conducted a cluster analysis to identify significant clusters in terms of spatial and statistical issues with a high density of potential biogas production by spatial analysis. Afterward, the study designed a baseline scenario and proposed three other scenarios based on farm-scale within the selected clusters of farms to optimize the available input manure, their areas, and the potential energy capacity. From here, the author could determine the location, number, scale, and power of biogas plants for each of the proposed scenarios. Finally, the study calculated the net GHG (methane, nitrous oxide, and avoided carbon dioxide) emissions from manure decomposition and fossil fuel-based electricity generation for scenarios and compared them with the baseline scenario.

The research framework is outlined and presented in Figure 2. This study's spatial analyses were performed using ArcGIS software version 10.6 (Environmental Systems Research Institute, New York, the United States of America). The author collected livestock-related data from the Department of Livestock Production (Vietnam Ministry of Agriculture and Rural Development) and the Livestock Production Center (Hanoi Department of Agriculture and Rural Development). Spatial data were provided by the Hanoi Urban Planning Institute of the Hanoi People Committee**.**

2.2. Suitability Analysis for sitting biogas plants

Suitability analysis is used to identify the appropriateness of a given area for a particular use. Suitability analysis usually involves combining criteria on social, ecological, economic, physical, and biological fields. The results are often displayed and visualized on a spatial distribution map that is used to highlight areas from high to low suitability. Suitability analysis uses Equation (1) [59]:

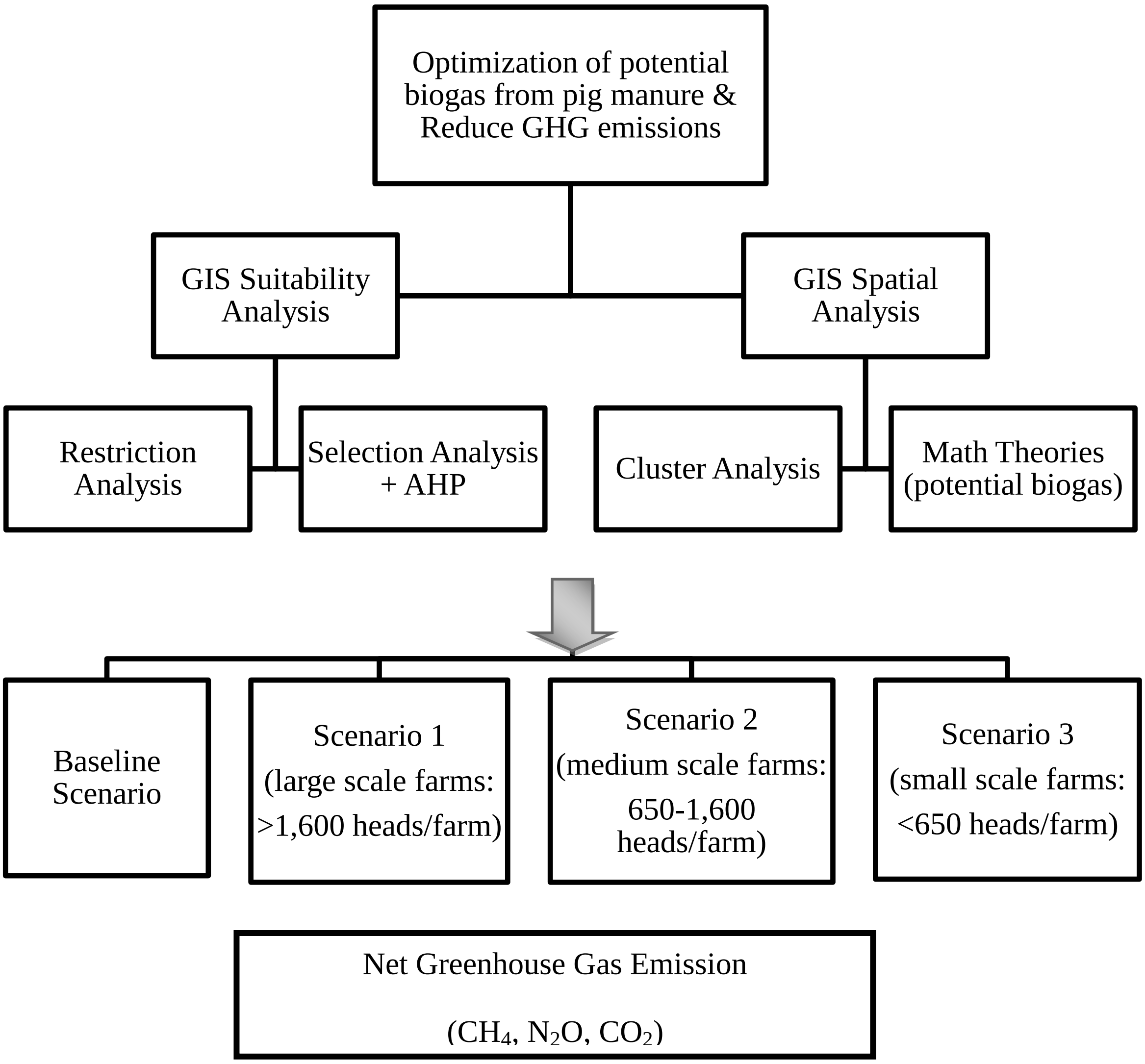

Figure 2.1. Research Method Frameworks
Source: Developed by the author

$$S = \sum_{i=1}^{n} W_i C_i \times \prod_{j=1}^{m} Rj \quad (1)$$

where

W_i: Weights for Criteria i

C_i : Criteria for Selectivity analysis

i : roads, elevation, and flood area

Rj: Restriction area

j: Transportation networks (roads and railways); land use (residential houses, public buildings, bridges, water stations, pump stations, electric stations, bus stations); surface water (rivers, lakes, canals); protected areas (national parks) and essential places (airports).

2.2.1. Restriction Analysis of factors affecting biogas plant development

Restricted areas are those areas that must be avoided during the development of biogas plants. In the spatial analysis for planning, it is necessary to restrict some layers that could interfere with the biogas project's development. Restricted areas can be identified as shown in Equation (2).

$$R = \prod_{j=1}^{m} Rj \quad (2)$$

There are some critical steps in the restriction procedure, including (i) determine restriction criteria; (ii) create buffers for the selected restriction areas; (iii) convert them to raster; (iv) combine all restriction factors to obtain the restriction map [28].

The restriction model is based on the Boolean intersection procedure, where restriction factors are classified into Boolean suitable or unsuitable images.

The restriction factors consist of transportation networks (roads and railways); land use (residential houses, public buildings, bridges, water stations, pump stations, electric stations, and bus stations); surface water (rivers, lakes, and canals); protected areas (national parks); and essential places (airports) (Figure 2.2).

The buffer for a restricted area is a zone that surrounds the restricted area and extends by a specified safe distance called the buffer criteria. The criteria for buffering different restriction factors used in this study are based on the national standards for constructing buildings and commercial infrastructure and previously published related studies. The author found suitable distances for buffers for all the mentioned layers considered for the restriction analysis in several secondary literature sources, as shown in Table 2.1 [22,41,60,61].

Based on these values, buffer criterion or distances surrounding transportation networks, land uses, surface water, protected areas, and essential places are determined as 20, 200, 500, 500, and 500 meters, respectively, and areas within these buffers were considered to be restricted on our map.

The spatial vector layers were processed using the tools from the extract, overlay, and proximity toolboxes to produce a map illustrating the restricted areas for biogas development and determine optimal zones.

Following this, the author used tools in the ARCTool box to convert all feature classes (polyline or point) to a raster. The outputs were maps with one value for the restricted area and one value for the available area. Lastly, the restriction maps were combined to obtain the overall restriction map by multiplying the final raster maps with the raster calculator using spatial analyst tools.

2.2.2. Selectivity Analysis of suitable criteria for sitting biogas plants

Selectivity analysis is used multiple weighted criteria to rank and score sites. Selectivity analysis can be calculated based on Equation (3).

$$C = \sum_{i=1}^{n} W_i C_i \quad (3)$$

For this study, three criteria for the suitability of biogas plants' locations were taken into consideration: elevation, road network distance, and flooding area. A lower height is better for optimizing collection and transportation. It is ideal for sitting the biogas plants in low lands as hilly high lands are not appropriate since it may cause difficulties for manure or material collection, transportation, and grid networks. Road network distance is essential for spatial resource distribution, optimization of service stations, and collection costs. The closer the pig farms are to road networks, the cheaper transportation costs will be. The general rule of “the closer, the better” helps narrow the distance from collection points or farms to biogas plants and vice versa. With flooding areas, preferences are given to non-flooding areas and areas further from rivers. The further from waterways and flooding areas, the lower the risk of floods affecting production.

Reclassify tools classify these criteria in ArcGIS with the Quantile method, which distributes a set of equal values into groups. Based on proximity to roads for the road networks and elevation and distance from rivers for flooding area, locations were assigned one of five values for location consideration: best, good, medium, bad, worst. For road networks, distance from roads was classified from 0 to 39,127 meters as best to worst value

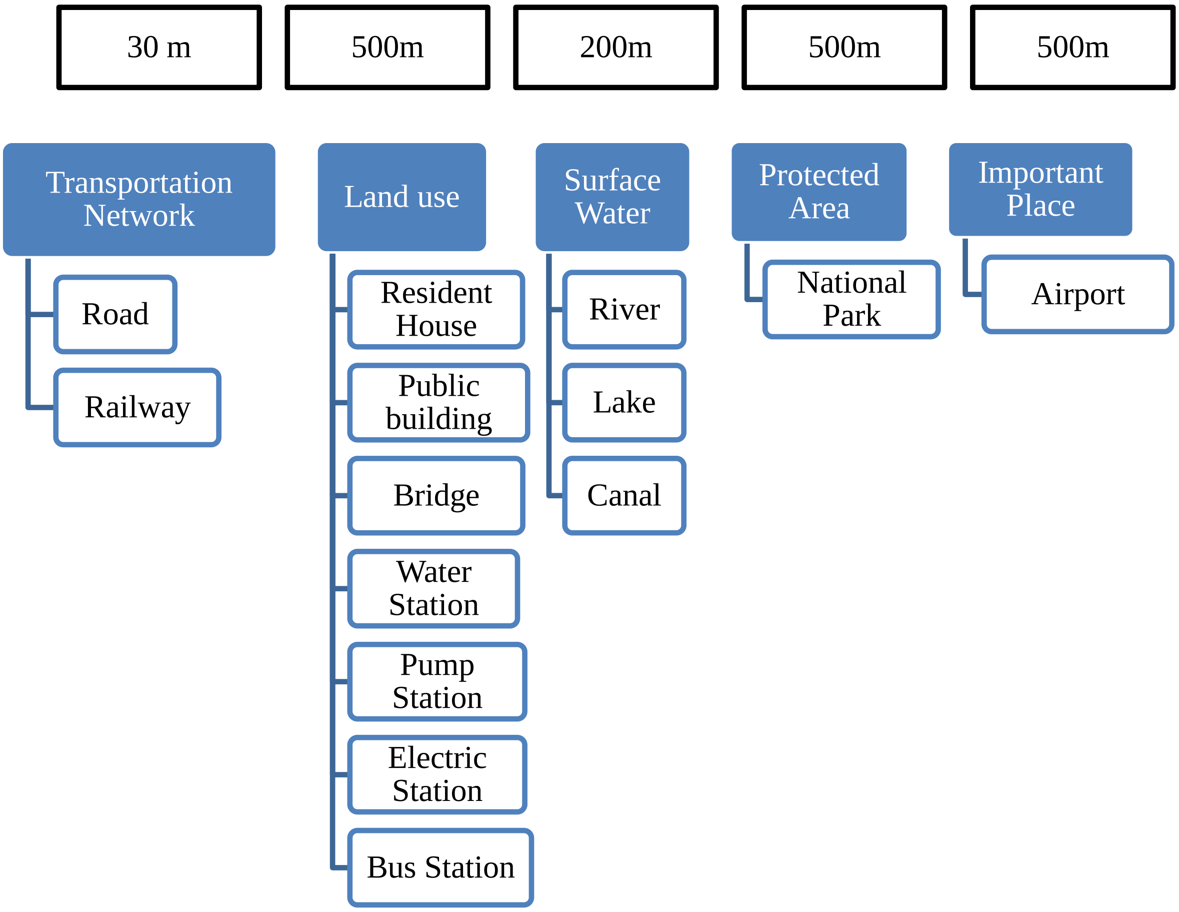

Figure 2.2. Restriction Factors for Suitability Analysis
Source: Developed by the author

Table 2.1 Buffering criteria for restricted places (in meters)

Reference	Transportation Networks (Roads, Railways)	Land use (Resident houses, Public building, Bridges, Stations)	Surface water (River, Lake, Canal)	Protected areas (National parks)	Important areas (airports)
[41]	30	1,000	200	500	1,000
[60]	-	500	200	-	-
[61]	30	1,000	200	500	-
[62]	100	600	500	500	500
[63]	100	300	200	-	300
[64]	100	2,000-5,000	500	500	-
This study	30	200	500	500	500

Source: Developed by the author [28]

respectively. The river's distance was distributed from 9,453 to less than 673 meters as best to worst value, respectively. For elevation, it was classified in five ranges of values from 0 to 19.59948 meters as best to worst value, respectively.

The weighted preferences are estimated based on the Analytical Hierarchy Process (AHP). The AHP introduced by Thomas Saaty [65] is a useful tool for a multiple-criteria decision-making process. Measures of judgment consistency are provided; accordingly, priorities among criteria and alternatives are given, and preference ratings among decision criteria using pairwise comparisons are simplified.

The AHP is conducted with the selectivity analysis, supporting the decision-maker to set priorities and make the best decision by calculating a series of pairwise comparisons and analyzed the synthesized results [28].

AHP has some necessary application steps [66,67]. Firstly, divide the issues into a hierarchy considering a set of evaluation criteria and alternative options. Firstly, the goal is set to find the best location for sitting the biogas plant. After discussions with stakeholders and experts on biogas production, three criteria, including collection efficiency, safety, and cost minimization, were chosen. Therefore, three alternatives, including road network, elevation, and flooding areas, are considered for the selectivity model. These factors are associated directly with the feasibility of the construction, operation, monitoring, and maintenance of biogas plants (Figure 2.3) and are objects to be weighted in AHP.

Secondly, based on a consultation's results with those experts and previous studies, the author identified the criteria' weights by several steps. Those steps are (i) making a pairwise comparisons matrix of alternatives for each criterion, (ii) normalizing the result matrix, (iii) estimating each row's average value to get the corresponding rate, (iv) computing the consistency ratio, and (v) assessing the consistency of judgments. The AHP mainly studies the scaling issue and the numbers used in scaling and correctly prioritizing in pairs [65].

The second and third steps with identifying the comparison's priorities (for each factor pair) are described with the fundamental scale in Table 2.2. The table expresses from 1 to 9 with a value from equal to significantly different. It means the higher number of the chosen factor, the more critical it is.

A 3×3 matrix in this study was built for three specific criteria (collection efficiency, safety, and cost minimization) and three alternatives (road networks, elevation, and flooding areas). It is based on the discussions with relative stakeholders and consultations with experts on biogas production as well as previous studies [28]. Afterward, the pairwise preferences were identified as matrices as in Equation (4).

$$A = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \quad (4)$$

where $A_{11} = A_{22} = A_{33} = 1$, $A_{21} = 1/A_{12}$, $A_{31} = 1/A_{13}$, $A_{32} = 1/A_{23}$

The author established Excel-based matrices were to identify each criterion's relative importance and alternatives concerning each other. For instance, to make a matrix for a criterion of collection efficiency, roads' significance is compared to the extent of roads, elevation, and flooding areas in the matrix's first line. The author applied the same rule to the remaining two lines. The matrix for safety and cost minimization criteria were set up similarly.

In the pairwise comparison matrix, A_{ij} is the value of row i and column j.

Follow this, the column sum is $A_{ij,}$ which is calculated by Equation (5).

$$A_{ij} = \sum_{i=1}^{n} A_{ij} \tag{5}$$

Normalization of the matrix is implemented by totaling the numbers in each column. Each entry in the queue is divided by the column sum to yield its normalized score as in Equation (6).

$$X_{ij} = \frac{A_{ij}}{\sum_{i=1}^{n} A_{ij}} = \begin{bmatrix} X_{11} & X_{12} & X_{13} \\ X_{21} & X_{22} & X_{23} \\ X_{31} & X_{32} & X_{33} \end{bmatrix} \tag{6}$$

Normalization of the matrix is by totaling the numbers in each column. The author divided each entry in the column by the column sum to yield its normalized score. In principle, the sum of each column in the matrix is 1.

Follow this, the author calculates the average value of each row as in Equation (7).

$$Y_{ij} = \frac{\sum_{j=1}^{n} X_{ij}}{n} = \begin{bmatrix} Z_{11} \\ Z_{12} \\ Z_{13} \end{bmatrix} \tag{7}$$

The consistency ratio is implemented in three necessary steps as follows:

Firstly, the author calculates the consistency measure for one criterion by following Equation (8).

$$\begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \times \begin{bmatrix} Z_{11} \\ Z_{12} \\ Z_{13} \end{bmatrix} = \begin{bmatrix} G_1 \\ G_2 \\ G_3 \end{bmatrix} \tag{8}$$

Afterward, we calculate the consistency index (CI) as Equation (9).

$$\mathrm{CI} = \frac{\lambda_{\mathrm{max-n}}}{n-1} \tag{9}$$

where λ_{max} is the consistency measure’s average value.

Lastly, the consistency ratio is calculated as Equation (10).

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{10}$$

where *RI* is Random Index

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

With n = 3, *RI* = 0.58 [28]

The author calculates the consistency ratio and checks the value to ensure that the original preference ratings were less than 0.1. A consistency rate of less than 10% is considered satisfactory [67].

Finally, the weight for the criteria and the pairwise matrix are calculated. The weighted score or the criteria's preferences are obtained by multiplying the weight vector and the score matrix, and the highest score judgments are chosen.

Therefore, for the selectivity analysis, once criteria were selected, weighted scores for criteria were obtained. Then, using the weighted overlay tools in the Arc toolbox, the input raster cells were multiplied by their weights for 3 alternatives (roads, elevation, and flooding areas) to create a suitability map. The final site's score ranks from most to least suitable and is reviewed with the best, good, medium, not good, and worst locations. ArcGIS Spatial analyst tools, including Euclidean distance and surface analysis and slope function, were used to analyze those criteria. Each of the criteria maps were converted to a raster. Those rasters were reclassified on a scale from 1 to 5, using the Reclassify tool in ArcMap. It refers to the best, good, medium, not good, and worst values for building a biogas plant. Afterward, the weighted overlay tool was used to carry out the spatial overlay of the maps.

2.2.3. Final Suitability Analysis for sitting biogas plants

A final suitability map is identified based on a combination of restriction and selectivity analyses using the Times function in Spatial Analysis tools.

2.3. Cluster Analysis of pig farms in Hanoi

For cluster analysis, the author first identified any cluster patterns using spatial statistic tools, analyzing patterns toolsets, and spatial autocorrelation functions. In this case, spatial autocorrelation based on feature locations and attribute values were measured based on applying the Global Moran's I statistic.

In theory, this tool evaluates characteristics of the pattern which is expressed clustered, dispersed, or random. Since the z-score or *p*-value indicates statistical significance, a positive Moran's I index value shows a tendency toward clustering. In contrast, a negative Moran's I index value indicates a trend toward dispersion. Second, the author identified distances where features have a neighbor using utility toolsets to calculate distance bands from the neighbor count. The average distance among neighbors will be found.

Third, the scale of the maximized cluster was identified using the analyzing patterns toolset. This allowed us to determine if there was any incremental spatial autocorrelation. Peaks can be defined as the distance band for hot spot analysis in the mapping clusters tool.

Finally, hot spot analysis in the Mapping Clusters toolset was used to perform cluster analysis and using the Getis-Ord Gi* statistic to determine the significant hot and cold spots where a high density of pig manure. This statistic visualizes the cluster areas and hot spots/cold spots.

In the analysis, the Gi_Bin field is considered as significant hot and cold areas statistically. Features with the value of the +/−3 bins, +/−2 bins, +/−1 bins imply statistical significance with 99%, 95%, 90% confidence level, respectively. In this study, the author selected only +2 (95% confidence level) features or +3 (99% confidence level) for consideration.

When the cluster analysis was complete, a map of spatially significant farm clusters with a high density of potential biogas production was made. The final suitability map and cluster map were intersected to show suitable areas with a high density of farms in the next step. Based on each farm's calculated capacity for biogas generation within their clusters in the intersected map, scenarios can be designed and suggested to identify the optimal location, number, and size of biogas plants.

2.4. Potential biogas capacity and GHG calculations

Potential biogas capacity was calculated basing on the methane generation from collected pig manure at farms. The formula followed the Revised 1996 and 2006 IPCC Guidelines on National Greenhouse Gas Inventories [68].

Methane emission from manure management was calculated as follow:

$$CH_4 = \Sigma_{ik}\ A_{ik} \times EF_{ik} \quad (11)$$

where

CH_4: Methane emissions from manure management (kg/yr)

A_{ik}: population of livestock (head) i by climate region k

EF_{ik}: emission factor for the defined livestock population i by climate region k (kg/head/yr)

i: livestock categories

k: climate region (temperate, warm)

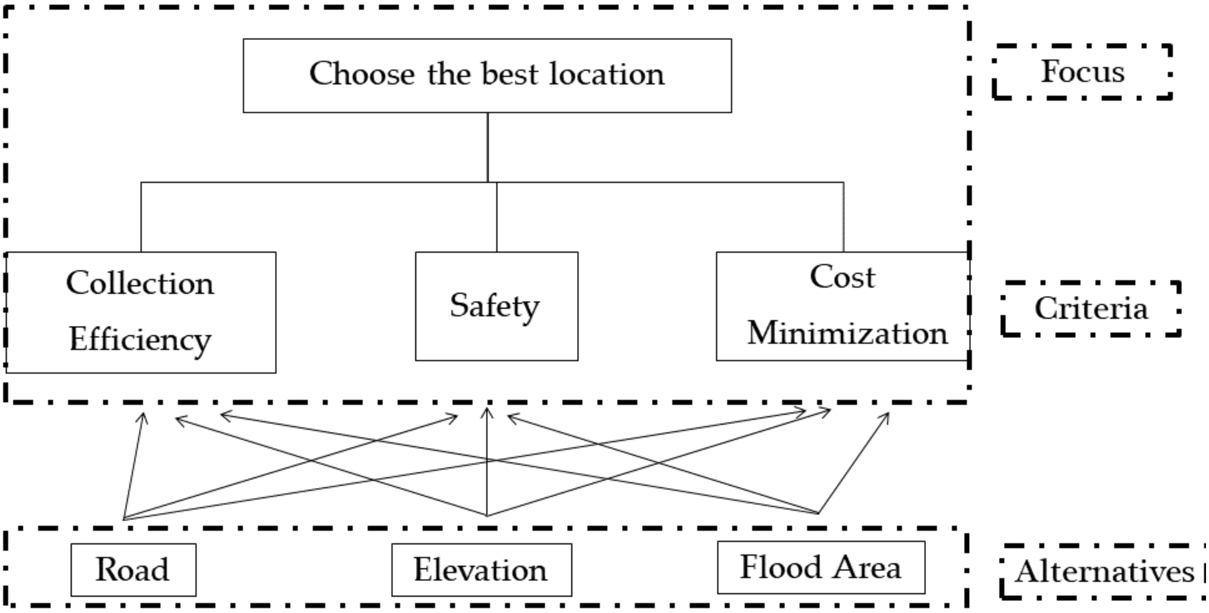

Figure 2.3. Analytic Hierarchy Process in choosing the best location
Source: Developed by the author

Table 2.2 Fundamental scale in AHP

The intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities/feature contribute equally to the objective
3	Moderate importance of one over another	One activity/feature is marginally favored over another
5	Essential or strong importance	One activity/feature is strongly favored over another
7	Very strong importance	One activity/feature is strongly favored, and its dominance is demonstrated.
9	Extreme importance	One activity/feature is of the highest possible order of affirmation over another
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed

Source: modified by the author based on [28, 64, 68, 69]

Emission factors for manure management were referred to as 408.3 kg CO_2 eq/head/year [29] based on the guidelines for calculating baseline farms' pig feces stored in anaerobic conditions UNFCCC (AMS-III.D, version 16). In the case of Hanoi, the author took values from the default values of the Revised 1996 & 2006 IPCC guidelines. Relative conditions are applied for only swine type (i) in Red River Delta Climate Region (k) with the annual average temperature from 15 to 25°C inclusive and application for biogas treatment as shown in Table B-6 of the guidelines.

Follow this, methane converted from carbon dioxide equivalence by a division of 25 (over a period of 100 years). Energy generated from available pig manure in the case study was estimated as follow:

$$\text{Energy} = CH_4 \, x21.5x100/60/3.6/0.67 \text{ (kWh)} \quad (12)$$

The methane content, on average, makes up 60% of total biogas production. Therefore, to calculate energy from biogas production from pig waste, biogas (natural gas) production is converted to from kg in m^3 per year. At standard temperature and pressure, methane has a density of approximately 0.67 kg/m^3. The natural gas's heating value is 21.5 MJ/m^3 [69,70].

The power of biogas plants from available swine manure in the case study was calculated based on productivity of an average biogas plant operating 7,500 hours per year with the below formulation:

$$\text{Capacity} = \text{Energy}/7{,}500 \text{ (kW)} \quad (13)$$

Theoretically, at 100% capacity, a power plant with a 1 MW capacity will produce 8,760 MWh; however, power plants usually produce less power than their capacity depending on their maintenance, dependence on input materials, and other factors. The power plant is assumed to operate 7,500 h/year [40].

The potential methane was estimated differently depending on the collection rate of pig manure. Then energy generated from available pig manure was calculated from the heating value of the natural gas and methane content. Finally, the biogas plants' capacity from available swine manure was estimated based on the productivity of an average biogas plant functioning time in a year with the assumption that 90% of pig manure is collected for anaerobic digesters. The total capacity of farms within the same clusters was estimated by addition for the recommendation of biogas plants.

Improper management of large amounts of pig manure has caused severe adverse environmental impacts, including GHG emissions, mostly methane (CH_4) and nitrous oxide (N_2O). The author analyzes the potential reduction of GHG emissions (CH4 and N2O) compared to current pig farming practices within this research, including contributing to nationally produced electricity. It is worth noting that the remaining 10% of pig manure that is not collected for the anaerobic digesters could still release CH_4 and N_2O into the atmosphere and soil.

N_2O is generated during the storage and treatment of animal waste before it is released into the atmosphere or soil. While the manure is in storage, part of the nitrogen in the manure is converted into N_2O through microorganisms' activity.

N_2O emissions during manure management are estimated using IPCC default values with N-excretion/intake values and manure management systems usage data. It was calculated as follows [28]:

$$(N_2O - N)_{(mm)} = \sum_{(S)}\{[\sum_{(T)}(N_{(T)} \text{ x } Nex_{(T)} \text{ x } MS_{(T,S)})] \text{ x } EF_{3(S)}\} \quad (14)$$

where

$(N_2O\text{-}N)(mm)$: N_2O-N emissions from manure management (kgN_2O-N/yr)

N(T): Number of the head of livestock species per category T

Nex(T): Annual average N excretion per head of species per category T (kgN/animal/yr)

MS(T, S): Fraction of total annual excretion for each livestock species per category T in manure management system S

$EF_{3(S)}$: N_2O emission factor for manure management system S (kgN_2O-N/kg N in manure management system S)

S: Manure management system

T: Species/category of livestock [68]

In the case study of Hanoi, values are taken from the standard values from the Revised 1996 & 2006 IPCC guidelines, Table B-6, Asia for swine type (T) in Red River Delta Climate Region (k) with an average temperature from 15 to 25°C annually and applying for pasture, anaerobic lagoon, daily spread, aerobic treatment, anaerobic digester (S) as follows:

Nex(T): is the default value of "Asia and the Far East" in the Revised 1996 &2006 IPCC guidelines. Nex(T) for swine is 16kgN/head/yr Fraction of total annual excretion for the pig in biogas method.

MS for pasture, daily spread, anaerobic lagoon, anaerobic digester, aerobic treatment with values of 10; 2.3; 9.9; 16.4; 61.4%, respectively.

EF_3 for pasture, daily spread, anaerobic lagoon, anaerobic digester, aerobic treatment with 0.02; 0; 0.001; 0.001; 0.02 respectively (kgN_2O–N/kgN) [72]

Conversion of (N_2O–N) emissions to N_2O emissions is performed by applying a conversion factor of 44/28. After that, nitrous oxide was converted to carbon dioxide equivalence with an element of 298 in a period of 100 years.

Avoided carbon dioxide emissions from biogas electricity generation were also considered in this study's environmental benefits since the electricity from the conventional method is replaced by biogas electricity production. Avoided carbon dioxide emissions from biogas electricity generation by replacing traditional production of electricity per year were estimated based on average emission for electricity production from the biogas plant.

Avoided carbon dioxide emissions from biogas electricity generation from biogas could be estimated [28]as follows:

$$CO_2\ a = Energy \times 0.8795 \tag{15}$$

where

CO_2 a: avoided carbon dioxide emissions (tons/year)

0.8795: grid emissions factor for electricity production in Vietnam based on operating margin method (tons/MWh) [73].

Lastly, net GHG emissions from decomposing manure and replacing conventional electricity production per year were estimated with a total of 10% of methane and nitrous oxide emissions from uncollected pig manure and avoided carbon dioxide emissions from biogas electricity generation.

Net GHG emissions from manure decompose and a replacement of conventional electricity production per year was calculated [28]as follows:

$$T = CH_4 + N_2O + CO_2\ a \tag{16}$$

where

T: Net GHG emissions (ton/year)

CH_4: Methane in CO_2 equivalent (ton/year)

N_2O: Nitrous oxide in CO_2 equivalent (ton/year)

CO_2 a: Avoided carbon dioxide emissions (ton/year)

Chapter 3 Results

3.1. Restricted Map for eliminating factors affecting biogas plant development

This study made a restriction map for Hanoi's biogas developments, which excluded road networks, waterways, railways, land use (forest, buildings, resident area, park, and historical areas), rivers, airport, facilities, hotels, and buffers around these areas. The detailed restriction maps with those different layers are shown with examples in Annex 1.

Figure 3.1 is the overall restriction map, which combined the layers to obtain a map with restricted and available areas.

The available remaining areas are located in the north and west of Hanoi, which is mostly most rural areas with lower population densities and where other public services are located.

3.2. Weight for suitable analysis's criteria identified by AHP Analysis

The AHP calculation, including the normalization of matrices, the calculation of average values, and consistency indices and consistency ratios (CR), were conducted using Microsoft Excel. The CR values of the pairwise comparisons' judgments were less than 0.1 and thus, were determined to be consistent.

Four matrices were created based on discussions with stakeholders and experts on biogas production. Three matrices were used to compare road, elevation, and flooding area, and the final matrix was set up to compare among criteria.

The collection efficiency, safety, and cost minimization for prospective biogas plants after solving each matrix are shown in Table 3.1. Similarly, weight for criteria is obtained with a set of collection efficiency, safety, flood area. The weight of criteria compared with other criteria was calculated in the average column of the second table for each criterion in Annex 2.

The overall priority scale is analyzed by multiplying as follows:

$$\begin{bmatrix} 0.687729 & 0.073772 & 0.685294 \\ 0.234432 & 0.282839 & 0.093382 \\ 0.077839 & 0.643389 & 0.221324 \end{bmatrix} * \begin{bmatrix} 0.298126 \\ 0.069401 \\ 0.632473 \end{bmatrix} = \begin{bmatrix} 0.643580 \\ 0.148581 \\ 0.207839 \end{bmatrix}$$

Therefore, the highest priority was for road network proximity (0.643580), followed by distance from flood area (0.207839) and elevation (0.148581). The detailed AHP analysis process is given in Annex 2.

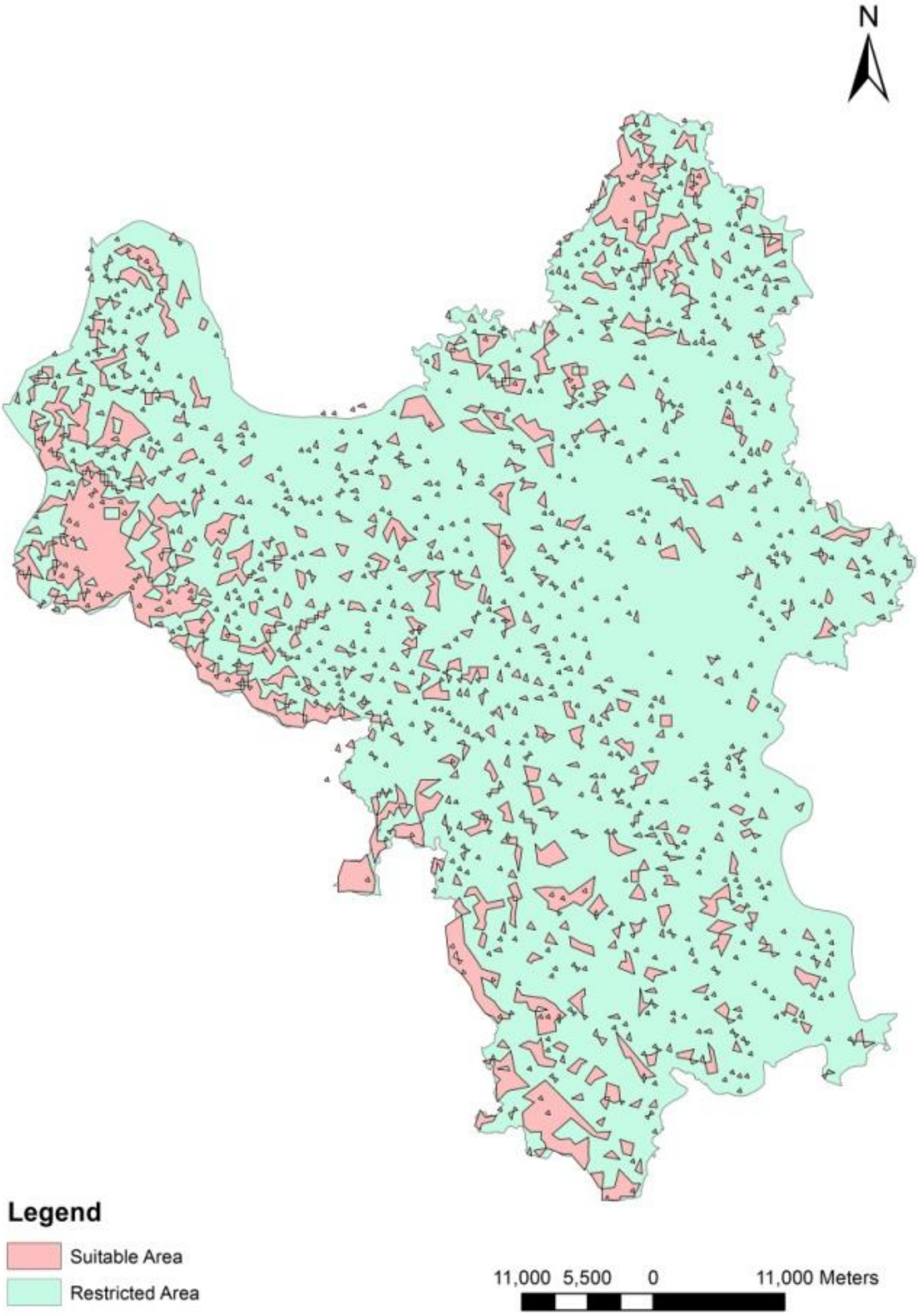

Figure 3.1. Restriction Map for biogas plants in Hanoi
Source: Developed by the author

Table 3.1. Weights preferences for suitability analysis

Criteria	Collection Efficiency	Safety	Cost Minimization
Road	0.687728	0.073772	0.685294
Elevation	0.234432	0.282839	0.093382
Flood Area	0.077838	0.643389	0.221323
Weighted preferences	0.298126	0.069401	0.632473

Source: The author’s calculation

3.3. Suitability Map for considering suitable criteria for sitting biogas plants

Since the calculation with AHP was done, thanks to Weighted Overlay tools in ArcTools box with the weights for three alternatives including road, elevation, and river are 64%, 15%, and 21% respectively, model builder for suitability analysis was illustrated in Annex 3.

The suitability map was modeled with five levels, including the best, good, medium, not good, and the worst area as criteria mentioned in section 2.2.2 (Figure 3.2). The best suitable areas are areas in the proximity of the road networks due to convenient transportation of manure from farms to collection points/ biogas plants with appropriate elevation and far from the flooding areas because the principal environmental conditions are within the optimum range. Medium suitable areas have some factors that are not within the optimum condition levels, but only within its acceptable range of distance from road networks, flooding areas, and medium elevation. In these areas, changes in environmental conditions such as further distance from the road, nearer distance from flooding areas, the higher level of slope compared to the best areas. Similarly, the worst suitable areas are areas where all conditions are adverse for sitting biogas plants due to insufficient proximity to road networks and high flood risk, and unfavorable elevation to collect manure. Good and not good values are in the middle of the best and medium and medium and the worst value**.**

The available areas considered as best, good, medium obtained from the suitability map are located in the North, East, and West of Hanoi. They are areas with the appropriate land slope with a suitable distance to avoid flooding risks and connect to road networks. The other unsuitable areas are in the Western South of Hanoi.

3.4. Final Suitability Map for sitting biogas plants

The restriction map and suitability map were combined into the final suitability map to eliminate all existing purposes using area and consider important influencers on selecting locations for proper biogas plants such as elevation, roads, and rivers. The Times tools in the ArcTools box were used to create the Final Suitability Map (Figure 3.3).

All the restricted zones and suitable zones were identified in the final suitability map. Suitable zones include best, good, medium, not good, and the worst area. The best, good, and medium zones were considered appropriate for building biogas plants, whereas other zones are unsuitable. In the final suitability map, areas located in the North East and West of Hanoi where are suitable areas for sitting biogas plants with appropriate land elevation, a convenient distance to connect to road networks and minimize flooding risks, as well as the distance from existing constructed buildings, facilities, and other environmental natural objects. The remaining areas are problematic areas for building biogas plants.

The final suitable map is used for integration with cluster analysis and scenario designs in this study.

3.5. Optimized location Map of high-density pig farms

Cluster Analysis was applied by using Arcgis 10.6 to determine the optimized locations for developing biogas plants in Hanoi.

Follow this, the distance at which any farm had at least one neighbor was estimated using the utility function with "Calculate the Distance Band from neighbor count". It is found that the maximum distance was 4,991.7 meters. Afterward, the study applied the Incremental Spatial autocorrelation in the Analyzing patterns function to identify what scale the cluster is maximized. As shown in Figure 3.4, the peak was 5 km, which was an appropriate distance between farms in Hanoi's situation.

Then another supporting analysis, namely Hot Spot Analysis (GETIS-ORD GI), was used to produce a high-density pig farm map in Hanoi with a distance band of 5 km. As a result, 495 farms get a robust spatial correlation (Figure 3.5).

By selecting a Gi_Bin value at over 1, we obtained a map of optimal locations of high-density pig farms with 95% of confidence. Thanks to the selection, it was possible to reduce the number of potential farms from 495 to 96 farms with strong spatial correlation. This step helped identify the farms with the highest potential to install biogas plants and feasibility on transportation cost.

3.6. Proposed Scenarios in the study area

After producing a map of optimal locations in high-density pig farms, there is an intersection of this map with the final suitable map. Thanks to the available number of pigs per farm, each farm's potential biogas capacity were estimated based on the mathematic formulation in 3.3 with the assumption that 90% of pig manure is collected for anaerobic digesters. The results helped us understand the total capacity of strong spatial farm clusters for biogas plants.

According to Zambon [74], biogas plants with a power capacity of 250 kW or more are economically viable and attractive investments. Therefore, biogas plants with capacities below 250 kW capacity were not taken into consideration in this study. Farms in clusters with strong spatial correlations and potential generating power capacity of 250 kW or higher were selected as suitable areas for biogas plants. It was assumed that the biogas plants would be used for electricity generation purposes only.

The study designed a baseline scenario and three other scenarios based on pig farms' potential capacity for electricity production. Scenarios 1, 2, and 3 were proposed for large, medium, and small-sized farms, with the number of pigs per farm being more than 1,600

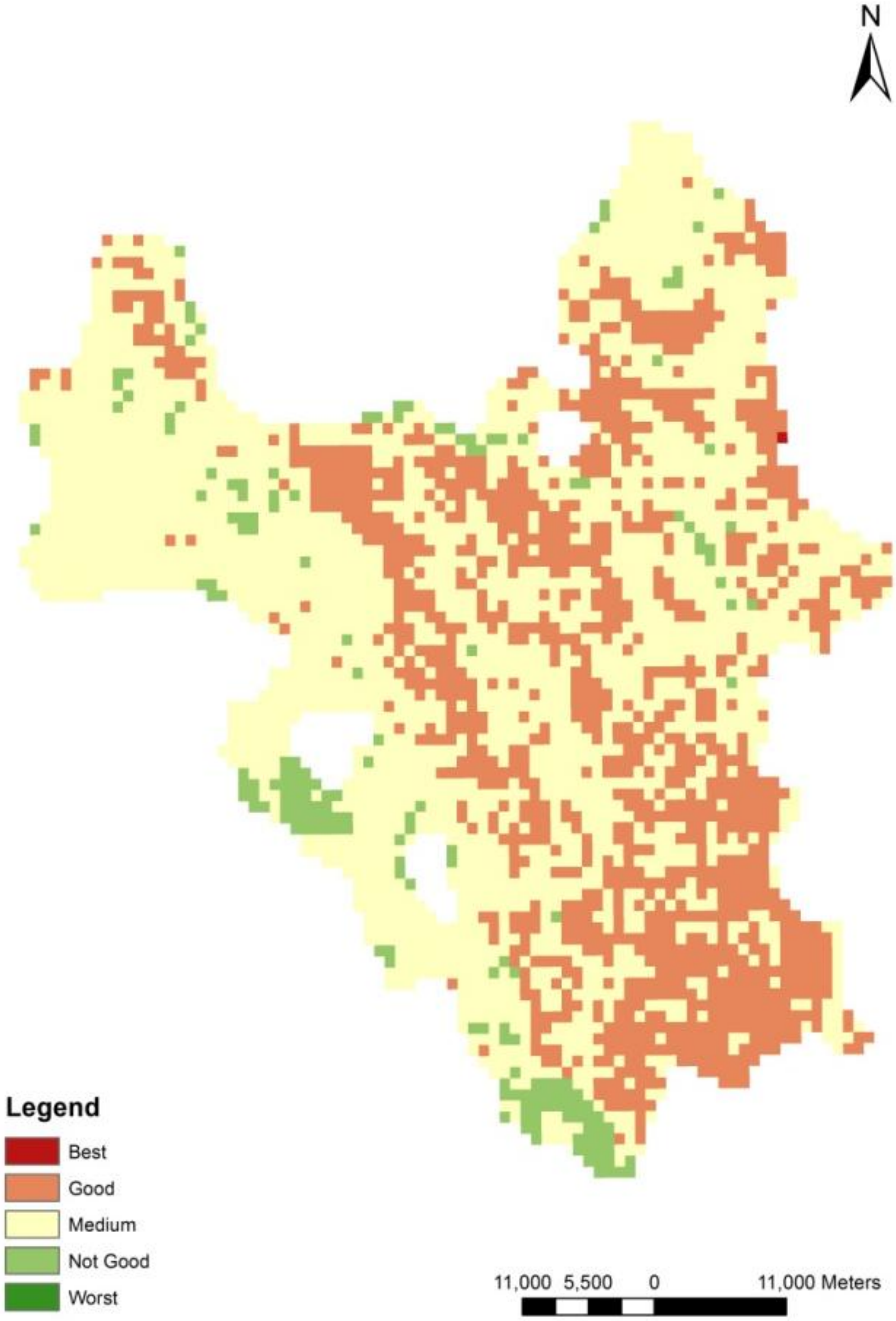

Figure 3.2. Suitability Map for biogas plants in Hanoi
Source: Developed by the author

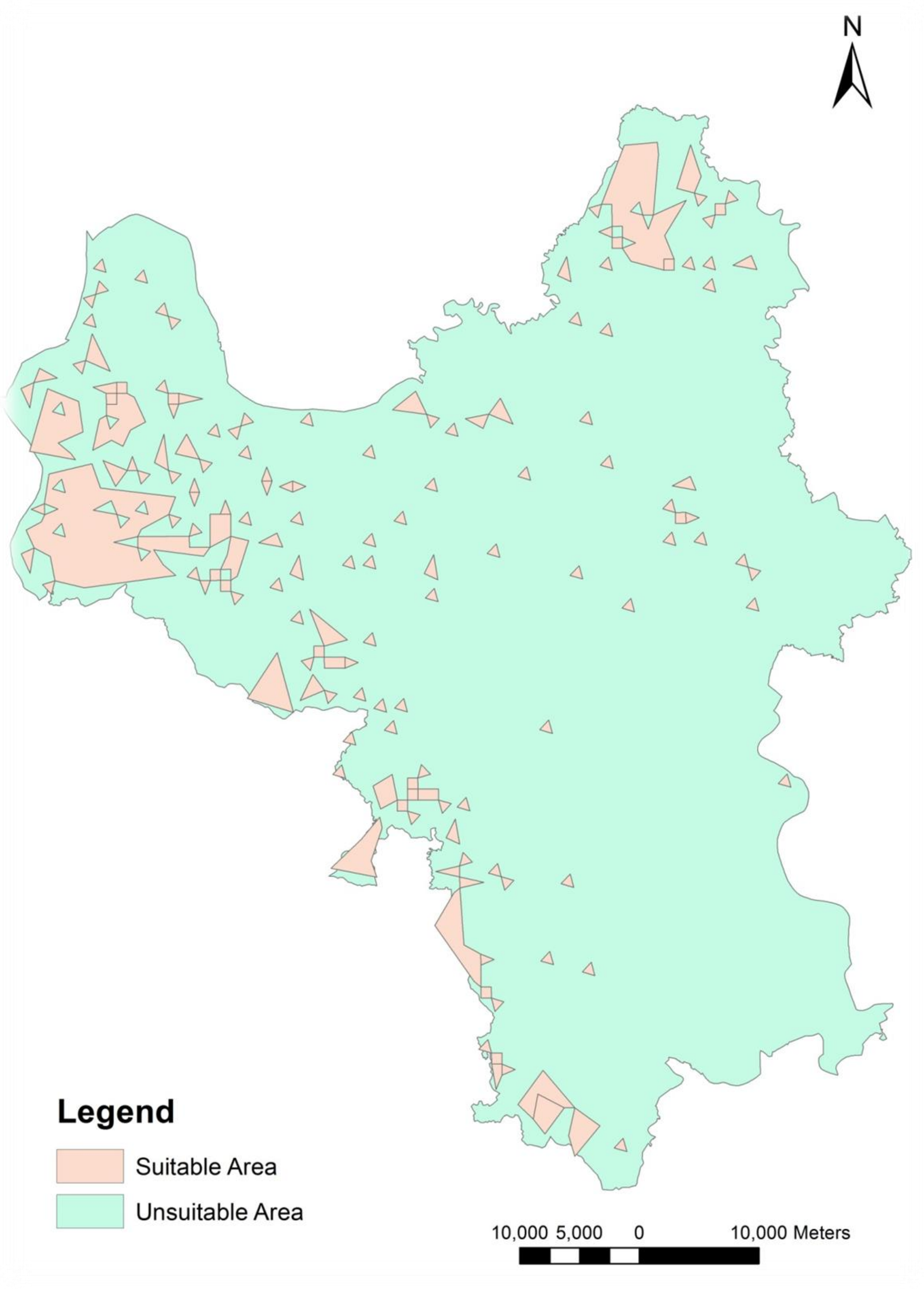

Figure 3.3. Final Suitability Map for biogas plants in Hanoi
Source: Developed by the author

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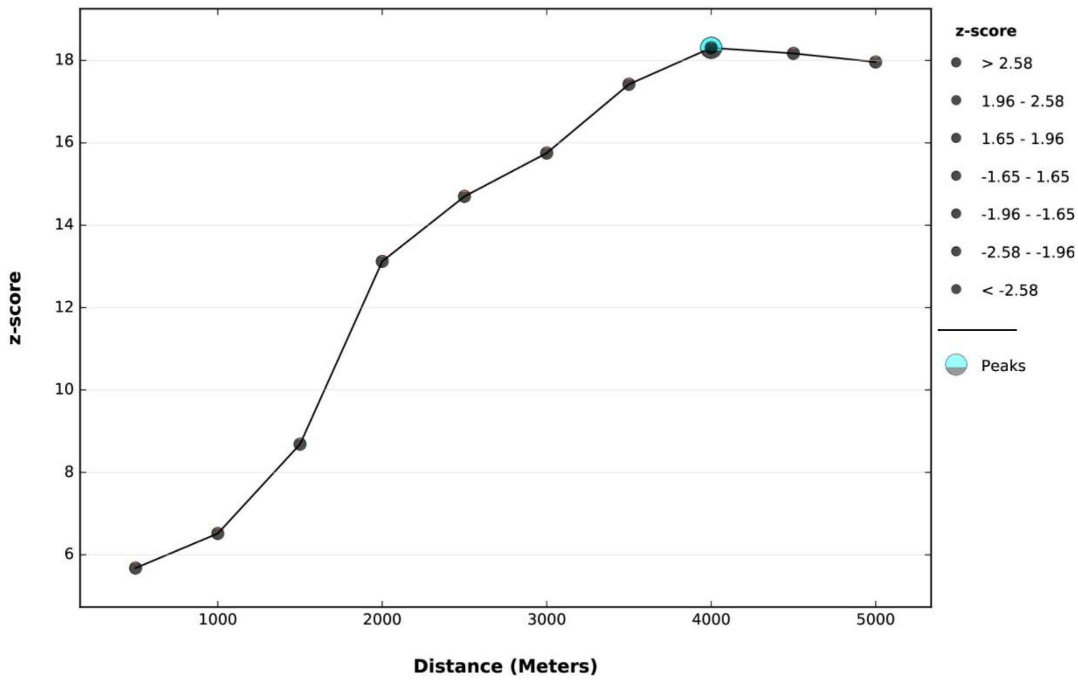

Figure 3.4. Incremental spatial autocorrelation by distance for pig farms in Hanoi
Source: Developed by the author

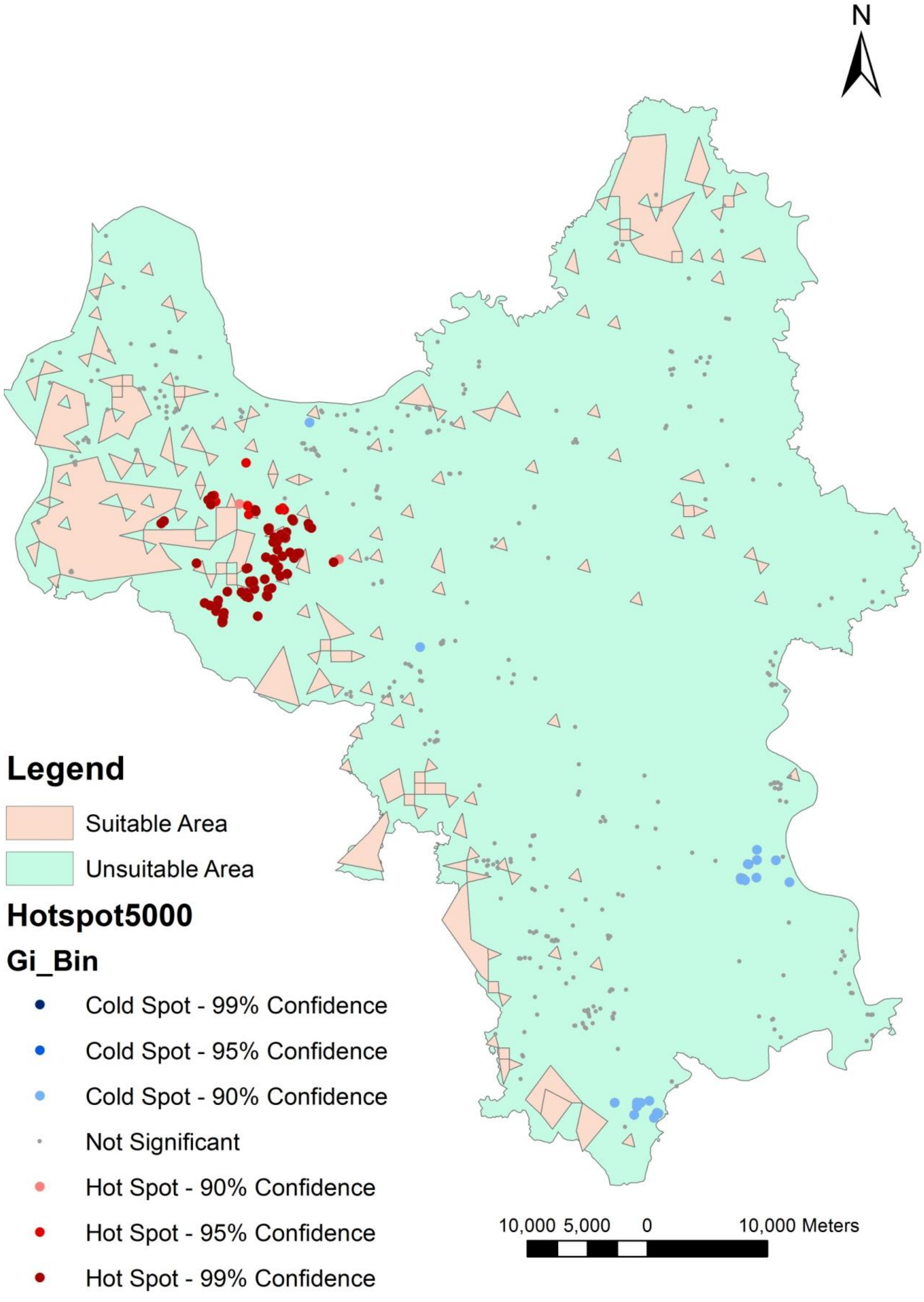

Figure 3.5. The Hot Spot Analysis of pig farms in Hanoi
Source: Developed by the author [28]

heads, 650 to 1,600 heads, and less than 650 heads, respectively to determine what would be the potential of biogas plants at different scales.

3.6.1. Baseline Scenario

The baseline scenario was considered as a reference scenario of this research. It represents the current situation of all selected pig farms after clustering analysis. In this scenario, all of the pig farms discharge their pig manure directly to the environment, such as into pastures/ranges/paddocks, ponds, water channels surrounding pig farms, sewer channels, anaerobic lagoons, or daily spreads as fertilizers, without any treatment or utilization for the generation of renewable energy. Therefore, there was no biogas plant in this scenario, and all GHG from pig manure (mostly CH_4 and N_2O), emits completely into the natural environment with non-treatment. This scenario is the baseline scenario, which can be compared to identify net GHG emission with other scenarios.

3.6.2. Scenario 1: large-scale farms

The first scenario was designed to promote large-scale farms and generate electricity for local demand. After carrying out the intersection analysis and capacity estimation, the author found 2 possible clusters with enough potential biogas for installing biogas plants (Figure 3.6) with capacities of 1,218 and 1,350 kW/year, meeting 1.06% and 0.59% of the expected local electricity demand for Son Tay and Thach That district, respectively, in 2025. Details of the farming clusters in scenario 1 are presented in Annex 4. With the total number of pig heads at 89,500, the full power generation capacity for scenario 1 is 2,568 kW/year.

3.6.3. Scenario 2: medium-scale farms

The second scenario was designed to boost medium-scale farms. After the intersection analysis and capacity calculation, three clusters were found. However, only 2 clusters with a capacity of more than 250 kW per year were considered; the other one with a capacity less than 250 kW per year was taken out for analysis. Therefore, for scenario 2, there are 2 potential biogas plants with a capacity of 476 and 363 kW per year in Son Tay and Thach That district, respectively (Figure 3.7). It can meet 0.416% and 0.159% of those two districts' expected electricity demand in 2025. Annex 5 presents details of farming clusters in scenario 2. With the pig number of 29,225 head, the total power generation capacity in a year of scenario 2 is 839 kW.

3.6.4. Scenario 3: small-scale farms

The third scenario was designed to promote small-scale farms. After the intersection analysis and capacity estimation for pig farms, three clusters were obtained for the analysis. However, only 1 cluster, with a capacity of 308 kW/year in Son Tay (Figure 3.8), met the 250 kW/year threshold. This plant could meet 0.269% of the expected electricity demand of Son Tay district in 2025. Detailed calculation on the farming clusters in Scenario 3 is presented in Annex 6. With the total pig heads at 10,747, the total power generation capacity for Scenario 3 is 308 kW/year.

In total, there are 2 possible biogas plants with capacities over 1 MW and 3 with capabilities over 250 kW. The obtained results showed that biogas could be used to meet some of the demand of electricity in Son Tay and Thach That districts, with 1.75% and 0.76% of the expected electricity demand for 2025 being met, respectively, using plants from all 3 scenarios.

3.7. GHG emission comparison

A baseline scenario was designed with the GHG emission from the current farming situation without electricity from the national grid. A hundred percentage of CH_4 and N_2O were estimated based on the equations in Section 2.3. As a result, the CH_4 and N_2O emissions in the baseline scenario were 52,863 and 14,108 tons carbon dioxide equivalent (CO_2eq) /year, respectively. In total, the baseline scenario emitted 66,971 tons CO_2eq /year.

For scenario 1, 2, and 3, the assumption that 90% of pig manure were collected for an anaerobic digester, it meant that 10% of untreated manure releases together with GHG emissions (CH_4 and N_2O) to the atmosphere. Therefore, 10% of CH_4 and N_2O emissions were calculated. Also, avoided CO_2 emissions from electricity generation from biogas plants in scenarios were estimated. Using the equations in Section 3.3, the GHG calculations yielded results as shown in Table 4 as follow:

Scenario 1 has CH_4 and N_2O emissions of 3,654 and 975 ton CO_2 eq/year, respectively. The amount of avoided CO_2 emission from electricity generation from biogas plants is -16,936 tons CO_2 eq/year. Therefore, the net GHG emission of scenario 1 was -12,307 tons CO_2 eq/year.

Similarly, in Scenario 2 and 3, net GHG emissions were -4,021 and -1,478 tons CO_2eq/year, respectively (Figure 3.9). Detail of GHG calculation for Scenario 1, 2, and 3 can be referred to at Annex 4, 5, and 6.

All three scenarios with the implementation of the biogas plants got a negative value for GHG emission. In contrast, the baseline scenario without manure utilization for generating power received a positive GHG emission value. The GHG emission gap between those scenarios was 84,777 tons CO_2 eq/year (Table 3.2). Therefore, in comparison with the baseline scenario as a baseline, it is noticed that renewable energy production from pig manure avoids the GHG emissions from manure decomposition and conventional electricity production from biogas significantly.

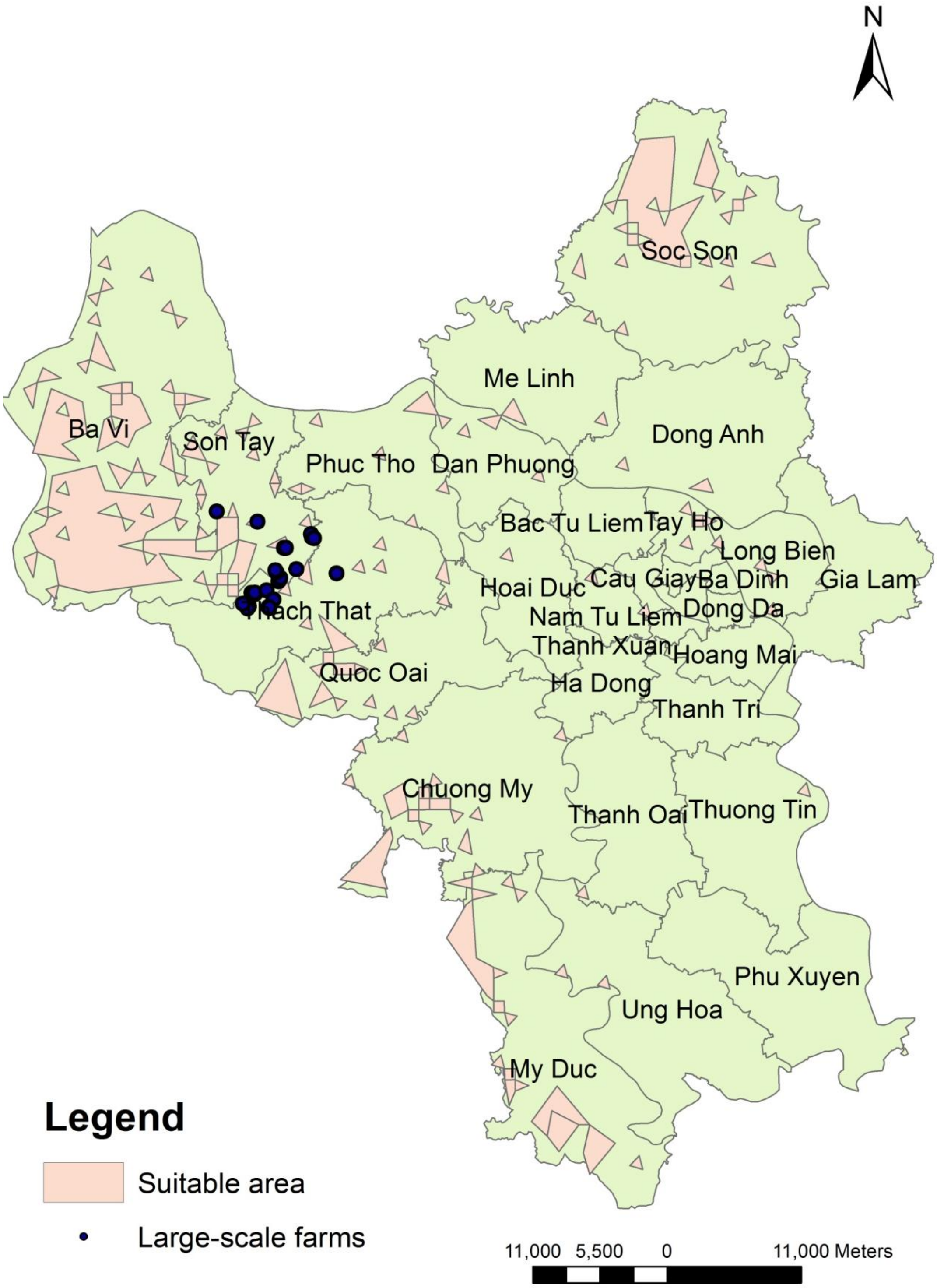

Figure 3.6. Selection of large scale farms in Hanoi
Source: Developed by the author

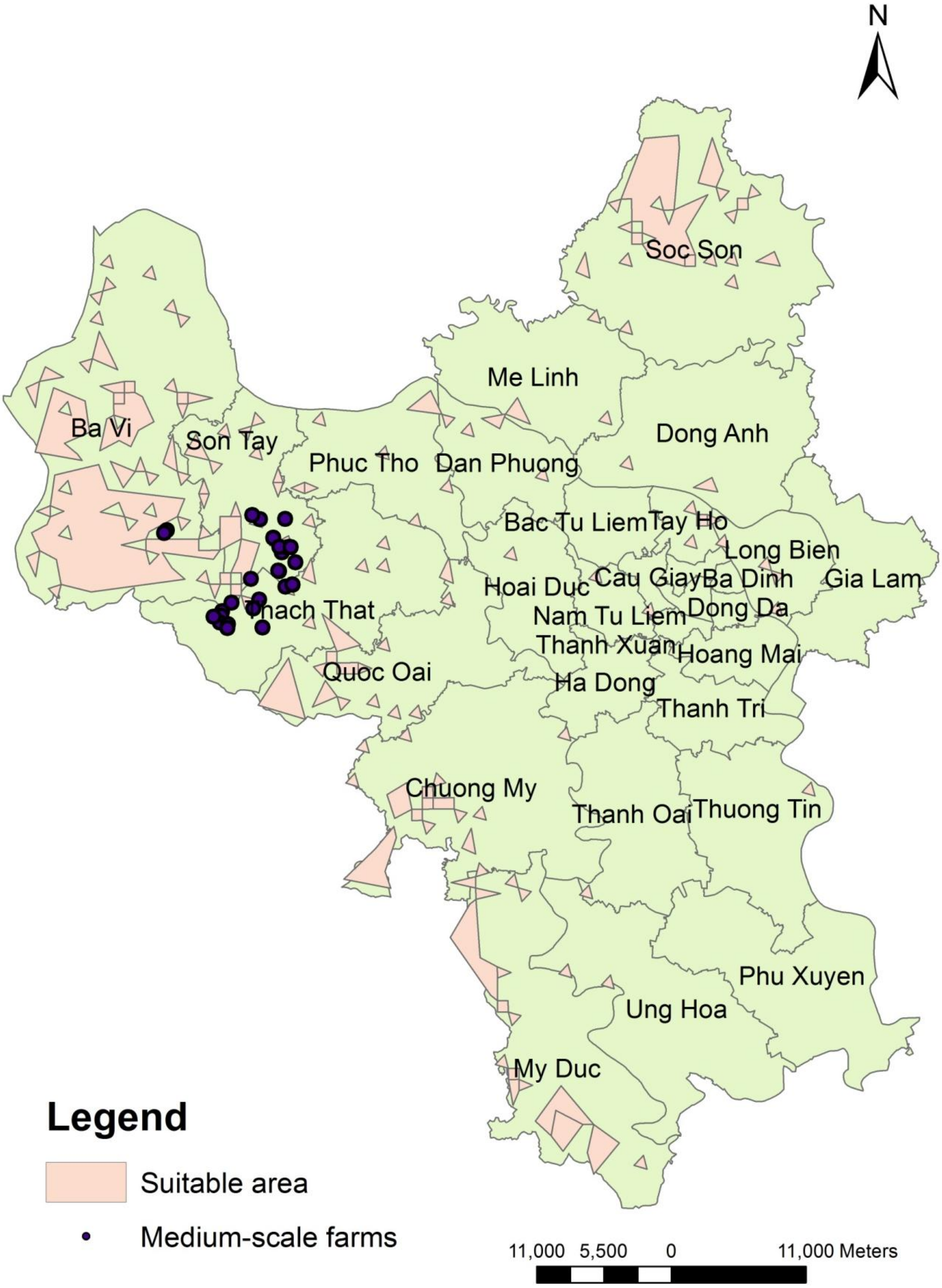

Figure 3.7. Selection of middle-scale farms in Hanoi
Source: Developed by the author

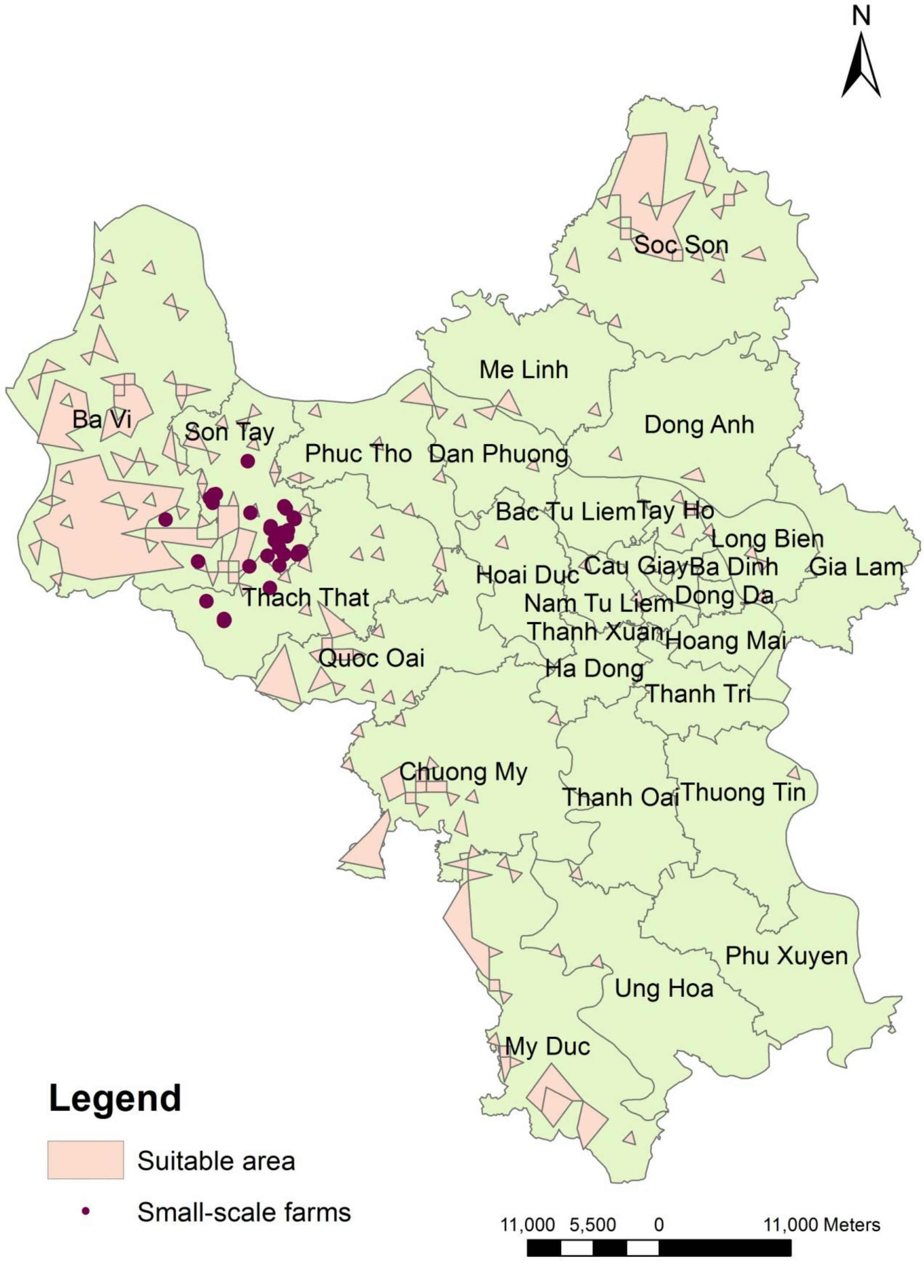

Figure 3.8. Selection of small-scale farms in Hanoi
Source: Developed by the author

Table 3.2. Summary of results of four scenarios

	Baseline scenario*	Scenario 1** (Large-scale farm)	Scenario 2** (Medium-scale farm)	Scenario 3** (Small-scale farm)
Assumed number of pig (heads)	129,472	89,500	29,225	10,747
Assumed collection rate (%)	0	90	90	90
Number of plants	-	2	2	1
Plant ≥ 250 kW	-	0	2	1
Plant ≥ 1MW	-	2	0	0
CH_4 emissions (ton CO_2 eq/year) [a]	52,863	3,654	1,193	439
N_2O emissions (ton CO_2 eq/year) [b]	14,108	975	318	117
Total power generation (kW_{el})	-	2,568	839	308
Avoided CO_2 emission from generating biogas -electricity (tons/year) [c]	-	−16,936	−5,532	−2,034
Net GHG emission from electricity power generation from biogas and manure decomposition (tons CO_2 eq/year)	66,971	−12,307	−4,021	−1,478

[a] Calculations were based on Equation 11. The emission factors for manure management are referred to as 408.3 kg CO_2 eq/head/year [29] based on the guidelines for calculating baseline farms' pig manure stored in anaerobic conditions of the UNFCCC (AMS-III.D, version 16). [b] Calculations were based on Equation 14. N_2O releases into the environment (pastures/ranges/paddocks/paddy fields as fertilizers, anaerobic lagoons, anaerobic digesters, aerobic treatment) [72]. [c] The estimation was made by Equation 15 using the grid emissions for electricity production from biogas generation in CO_2 emissions equivalent. This estimation was only applicable to Scenarios 1, 2, and 3. The grid emission for electricity production based on the operating margin method was 0.8795 ton/MWh [73].

* For the baseline scenario, 100% of the manure was considered for assessing CH_4 and N_2O emissions into the environment. **For scenarios 1, 2, and 3, 90% of pig manure is assumed to collect for an anaerobic digester, and 10% is not collected but emitted as CH_4 and N_2O into the environment.

Source: Developed by the author [28]

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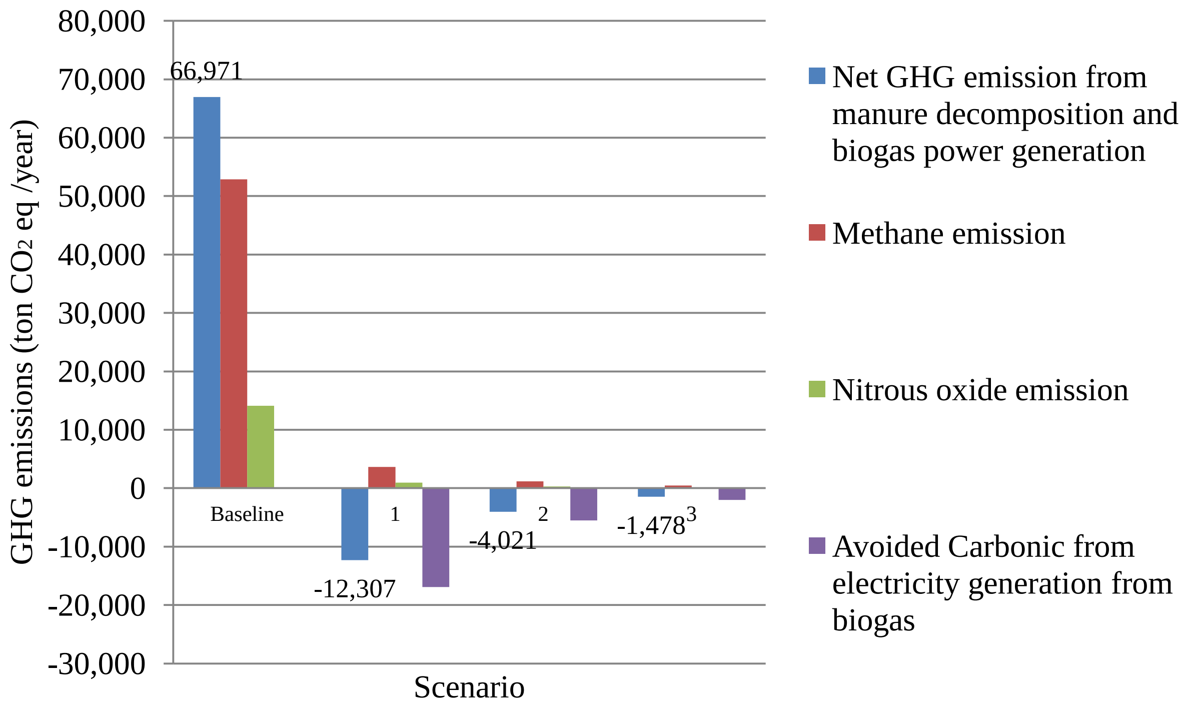

Figure 3. 9. GHG emissions from pig manure in Hanoi
Source: Developed by the author

Chapter 4 Discussion

This study had implications for manure management's academic and practical applications to reduce negative impacts and stimulate positive outputs. Based on the spatial analysis of pig manure and calculations of its environmental impacts presented in this study, discussions can be had on methodologies, simulations of GHG emissions reduction, ability to transfer the research results to policymakers, and the impacts of GHG reductions in line with national policies for renewable energy and climate change combat.

The proposed methodology can be applied to determine and select optimal livestock manure management locations and clusters in other livestock-intensive areas. For instance, it can be implemented in other areas with high densities of pig manure, such as provinces in the Red River Delta, Midland and Northern Mountain, North Central and Central Highlands, and the Mekong River Delta, Dong Nai, Thai Binh, Bac Giang, etc. This method is also applicable for other types of manures, such as cows, buffalos, chickens, ducks, and many different kinds of agriculture residue and by-products. It can also be applied to sludge and food waste, which contain organic matter, for bioenergy and utilize waste for environmental pollution reduction. The research’s methodology also can be used in many fields, including renewable resources such as wind, solar, urban waste, thermal, hydro energy, if we have good enough GIS data for natural and specific features in those areas.

The method developed in this study is useful for finding out the potential biogas generated from manure and other waste based on the total input of livestock manure, agriculture residues, and other organic wastes, as well as for calculating the total net GHG emissions reduction from energy generation and avoided carbon dioxide from replacing fossil energies.

Spatial data is necessary to be collected. Those data are related to many fields such as the administration, the geography, natural, or socio-environmental features of the province. They include road networks, hospitals, parks, rivers, livestock farms or agriculture fields where animal manure or agriculture residues are available, wastewater treatment plants where sludge is available, or markets, restaurants, and hotels where food waste is available. Those data are categorized in GIS into groups of related functionalities. Understanding the categories will help to identify particular proper tools. Using the Spatial Analyst toolbox and depending on the research objectives, all data are analyzed with geoprocessing to produce specialized output maps. The simulation for calculating potential biogas capacity and GHG emissions followed the Revised 1996 and 2006 IPCC Guidelines on National Greenhouse Gas Inventories. Therefore, the accuracy of the simulation is considered acceptable for calculation.

To improve the proposed methodology, the author could include GHG emissions from manure transportation in the spatial analysis. However, this would require an up-to-date and detailed GIS file for the road network for conducting network analysis. Integrating environmental costs into the production costs will improve the competitiveness of technologies with high financial costs but are more environmentally friendly [75]. Moreover, spatial distribution data of other waste such as sludge, food waste, or other substrates such as local crops could be collected and integrated into the analysis to enhance biogas production. It is also possible to create a roadmap for the collection and transportation of manure or other wastes in the study areas, including forecasting any changes in logistics that will be needed if the production of manure changes due to shifts in livestock numbers. Therefore, with the overall goal of utilizing waste for environmental pollution reduction and the generation of energy, the proposed method can be applied to identify critical spatial waste areas and offer appropriate solutions that incorporate socioeconomic conditions, logistics, and public health policies.

GIS analysis in this study produced maps showing suitable locations for biogas plants, which consider potential biogas production, capacity and size of energy generation plants from farms, and possibilities of GHG emission reductions. These maps could be used to guide and support policymakers for manure and GHG management. These outputs can assess the current situation and forecast future scenarios if inputs vary and give directions on the collection, transportation, and coordination of manure and GHG management for achieving sustainable development.

Using GIS requires large data sets that need to be systematized and organized into unified focal points for easy management and sharing online with policymakers and organizations. Policymakers can use the data to manage overall manure development, evaluate investment progress, and share assessments of operation indicators with stakeholders. They also can easily query, search, and aggregate data on manure, farms, biogas potential, and clusters and produce exports, including charts and tables to report to local authorities. The monitoring of these indicators can track and help avoid problems in manure and GHG management. Therefore, it will help local and sector authorities in decision-making through a much less labor-intensive process than dealing with sizeable manual data sets.

Using this method for manure and GHG emission in Vietnam is significant because efforts are being made to transform major urban centers such as Hanoi, Ho Chi Minh, and Da Nang into smart cities. Solving environmental problems from agricultural pollution by building a comprehensive and intelligent waste treatment service system can be considered a vital phase in building a smart and sustainable city.

The scenarios are not exclusive, but the potential of biogas plants at different scales was determined. It is possible to implement two or three scenarios at the same time. Moreover, the scenario setting was conducted assuming the strictest conditions regarding manure availability and transportation access. It is meaningful since there are no mid or large-scale biogas plants in the case study and surrounding regions. These research results are also crucial since it is forecasted that from 2020 to 2024, there will be a severe shortage of electricity in Vietnam since the power transmission infrastructure has not been completed as scheduled [76].

This study is an essential step in making policies that support local decision-makers in Vietnam in utilizing valuable bio-energy sources from pig manure, contributing to Nationally Determined Contribution (NDC) with the target to reduce greenhouse gas emissions [77]. It also has significant implications in developing strategies for biogas development and GHG emissions reduction from pig waste management in the area and the whole country.

The government of Vietnam has been recently paying attention to environmental issues and renewable energy solutions. This is reflected in the government's consideration of biogas production for generating electricity for reducing GHG emissions and promoting the efficient and sustainable use of natural resources. The National Energy Development Strategy describes the energy sector strategy, including renewable energy up to 2020 with an outlook to 2050; the target for renewable energy generation was set at 5% by 2020 and 11% by 2050. Besides, the seventh Power Development Plan (PDP 7) issues the targets for renewable electricity increase from 4.5% in 2020 to 6.0% of total electricity generation and imported energy in 2030 [78]. Along with these targets, the government has issued several financial policies to incentivize investment [79]. These are the initial policies promoting renewable resources in Vietnam; however, there are still many challenges to achieving the targets.

The lessons and experiences learned from other countries that have successfully utilized renewable energy, including biogas production and biogas electricity generation, are valuable for Vietnam. Biogas' contribution in the EU countries towards total bioenergy production has increased from 2.7% in 2005 to 7.8% in 2015 and grown at the highest pace in the bioenergy sector over the last decade [80]. The EU accounted for 72.5% (58 GWh) of the global electricity generation from biogas in 2014. Generally, the success of increasing renewable energy production in the region is attributed to the more than 200 incentives in place, including manure for biogas generation [81]. China has also introduced financial support and improvements of biogas service systems to promote the number of new biogas units in every province since 2003. Many solutions, including direct investment and encouraging international cooperation, were used, such as developing global carbon trade systems [82]. These experiences can provide useful guidelines for Vietnam in promoting biogas production and boosting electricity generation.

The not in my backyard (NIMBY) phenomenon is also an aspect to consider when evaluating a community's willingness to accept and maintain potential biogas plants. Residents nearby proposed sites could create opposition groups to fight the development of biogas plants. Even though new plants could generate clean energy to power towns and improve the local economic situation, the new facility's concern would be too close to their homes and maybe potentially hazardous to their health can outweigh the more abstract benefits. Biogas plants could create noise, pollution, and traffic and could obstruct their views. These concerns are not without merit. First, the biogas industry is relatively new, and a fear of the unknown is expected. Besides, with the technology available, building a biogas plant in a neighborhood would likely mean noise, traffic, and pollution. Nevertheless, with modern technology and strict government regulations, the inconvenience caused by any development can be minimized. A solution to nimbyism is to gain the support of locals by identifying those in favor and those against through polls or surveys, asking supporters to communicate the benefits of biogas production to those who are against, organizing social media campaigns to reach the community, and considering the local residents' interests and taking them in the participative procedures [83].

To gain stakeholders' cooperation in adopting biogas production, policymakers need to determine the factors affecting the development of joint biogas production projects. It was found that the number of livestock; the age of farm owner; the level of education; distance to the source; crop production; credits, loans, and subsidies; income; gender; water availability; and awareness are all factors that have statistical significance on the rate of adoption [84][85]. Studies also found fundamental barriers to adopting biogas technologies, such as a lack of proper technical services provided by organizations and insufficient governmental support [86]. Awareness of consequences, responsibilities, and environmental problems all influence the personal behavior of farmers. As a result, subjective norms affect farmers' intentions towards adopting biogas technology [87].

According to experiences in Germany, factors affecting the success of power generation from biogas are grid connection and feed-in tariff mechanisms. In developing countries, more conditions for the legal framework supporting the development of biogas for power generation are required. As long electricity generation from biogas is not a priority condition of the legal framework for power generation, it will remain limited to a few pilot applications [88].

It should also enhance awareness of biogas opportunities, increase possibilities of access to finance, build and improve local capacity for project design, construction, operation, and maintenance, and enhance legal framework conditions to promote alternative energy production and commercialization.

Chapter 5 Conclusion

Biogas digestion is already addressing the health, energy, and environmental challenges Vietnam faces while creating and supporting a sustainable commercial sector in the country. The use of alternative energy such as biogas has already contributed to reducing greenhouse gas emissions and provide benefits to health, environment, helping Vietnam to achieve the target raised in Vietnam's s NDC for the agriculture sector.

This research applied suitability analysis and AHP to optimize the spatial distribution and amount of potential biogas produced from pig manure by considering different variables. Suitable areas for biogas plants were identified through a combination of avoiding existing objects and infrastructures, selecting areas near road networks with appropriate elevation and far from flooding areas, and identifying areas with a high density of pig manure for input material. The method developed in this research work has based on a combination of statistical and spatial practices.

The study analyzed and identified the optimum location, number, and scale of biogas plants with their potential for biogas production from pig manure in Hanoi. Cluster analysis helped designing out three scenarios of grouping different feedstock sources were proposed. The results showed that for Scenario 1, which looked at large-scale farms, there were 2 potential biogas plants with capacities of 1218 and 1350 kW located in Son Tay and Thach That district, respectively. For Scenario 2 of medium-scale farms, 2 potential biogas plants with capacities of 476 and 363 kW were identified in Son Tay and Thach That district, respectively. For Scenario 3 of small-scale farms, 1 potential biogas plant with a capacity of 308 kW was identified in Son Tay district. The results show that biogas could help meet 1.75% and 0.76% of the anticipated demand for electricity in Son Tay and Thach That districts in 2025, respectively, by utilizing waste from approximately 8% of the total pigs in Hanoi.

The GHG emissions reduction from the development of biogas plants is significant. The net GHG emissions of Scenarios 1, 2, and 3 were −12,307, −4,021, and −1,478 tons of CO_2 eq/year, respectively, whereas the baseline scenario was 66,971 tons CO_2 eq/year of net GHG emissions. The GHG emissions gap between the 3 scenarios and the baseline is 84,777 tons of CO_2 eq/year.

This study's results highlight the importance of identifying the potential amount of biogas at nearby spatial clusters and identifying the optimum location, scale, and the number of biogas plants meeting the electricity demand in Hanoi rural areas and contribute to GHG emission reductions.

This research's value comes from (i) highlighting the importance of renewable energy resources in GHG emission reductions and power generation and (ii) recommending optimal options for the utilization of pig manure, which is currently poorly treated and contributes to GHG emissions. This research carried out a case study and recommended sites for building five biogas plants. This initiative could be applied for similar initiatives across the country, further reducing GHG emissions and promoting energy production from renewable resources.

To achieve this goal, the author plans to assess the biogas potential at the national level to realize the government's renewable energy targets in future work. Moreover, a similar method can be applied to make plans for managing other wastes, including agriculture residues, municipal solid waste, and sludge from wastewater treatment plants to optimize the output of biogas plants and energy recovery.

In the next few years, the enormous market potential for domestic biogas will be opened in Vietnam. The country's animal husbandry sector is vibrant, expanding, and largely dominated by family-owned farms. Farmers and the government embrace solutions, including biogas plants, to reduce the sector's environmental load. Alternatives that can replace inefficient conventional domestic fuel sources are welcome, as are opportunities to improve the fields' nutrient management.

To encourage people to construct biogas digesters for treating livestock waste, the government should develop policies and incentive mechanisms to support livestock farms and fund research centers to study modern biogas technologies appropriate for Vietnamese conditions.

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APPENDIX

Annex 1: Examples of Restriction Maps

a b c

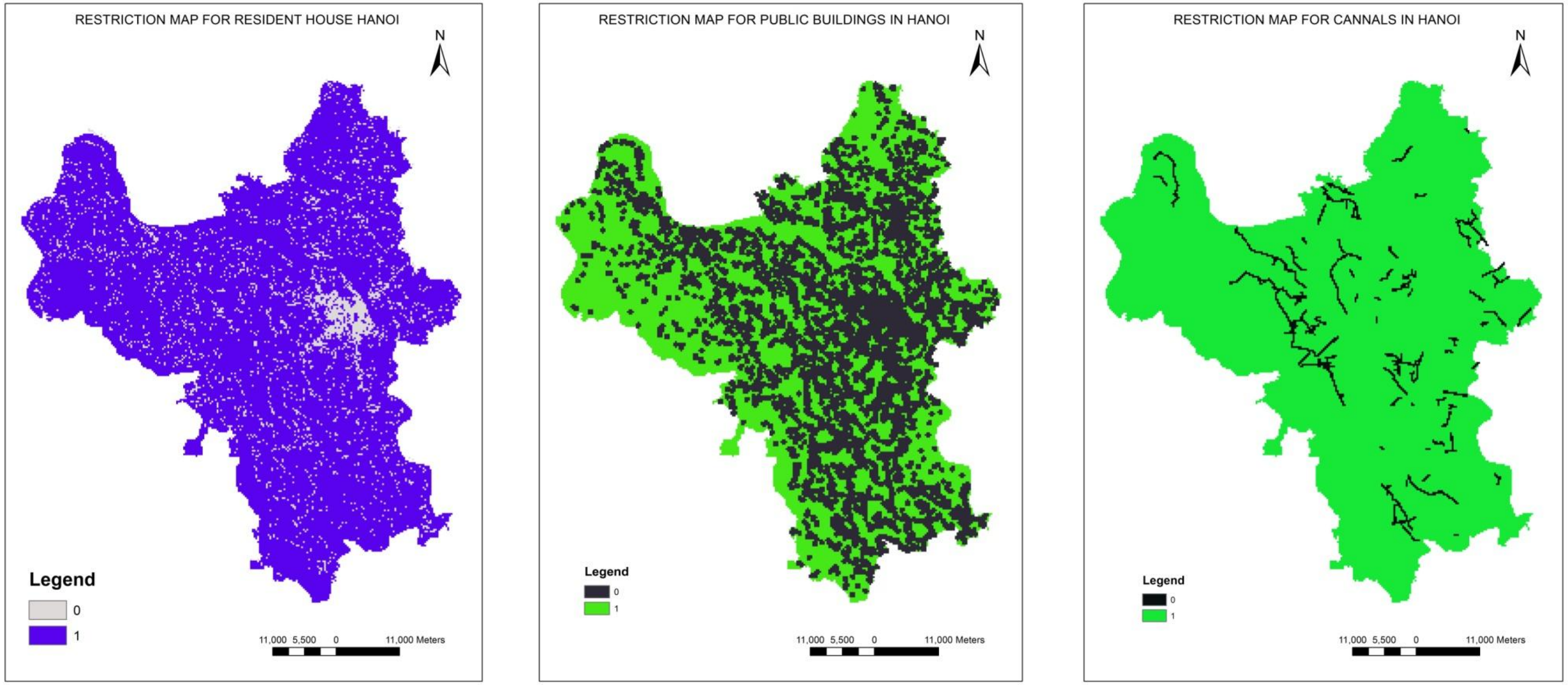

Figure A1.1. Restriction Maps for sitting biogas plants in Hanoi for factors: a. Resident houses, b. Public buildings, c Canals

a b c

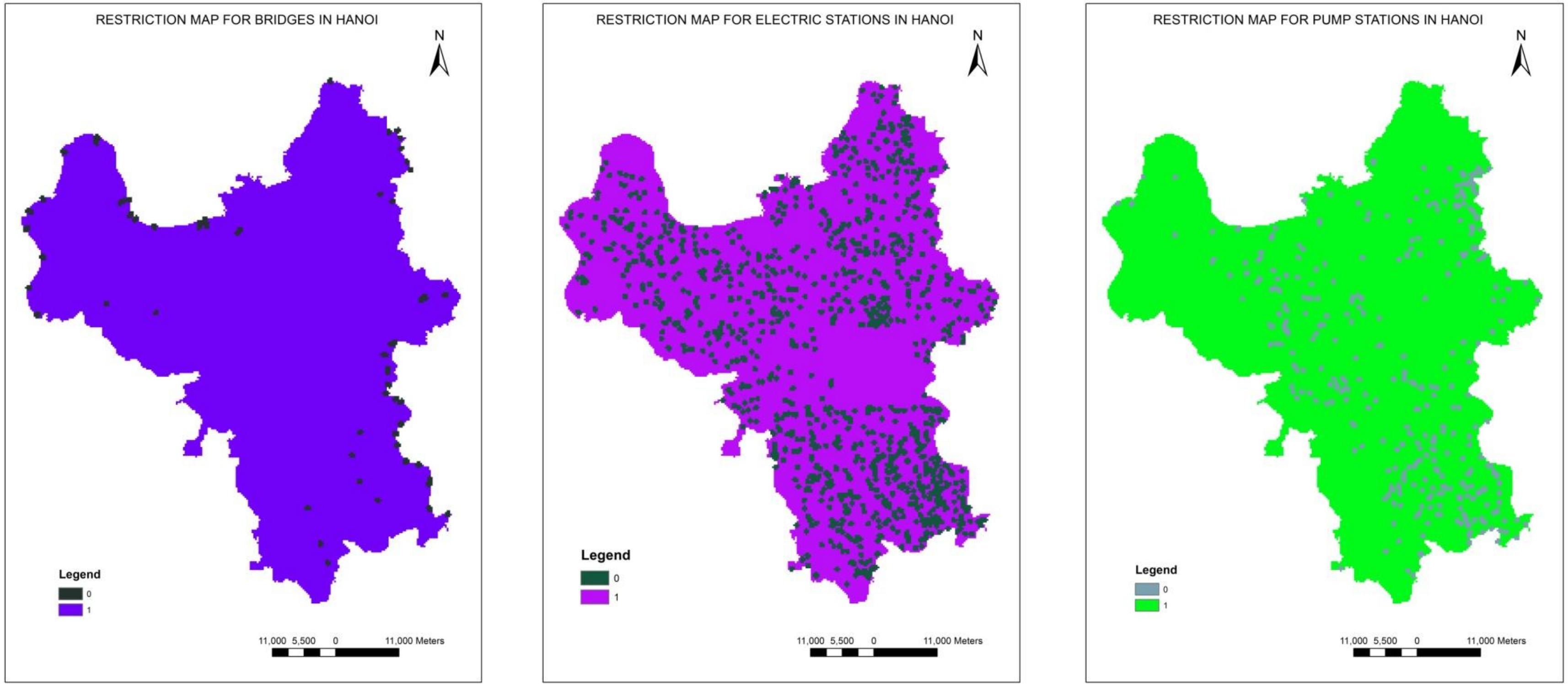

Figure A1.2. Restriction Maps for sitting biogas plants in Hanoi for factors: a. Bridges, b. Electric stations, c Pump stations

a b c

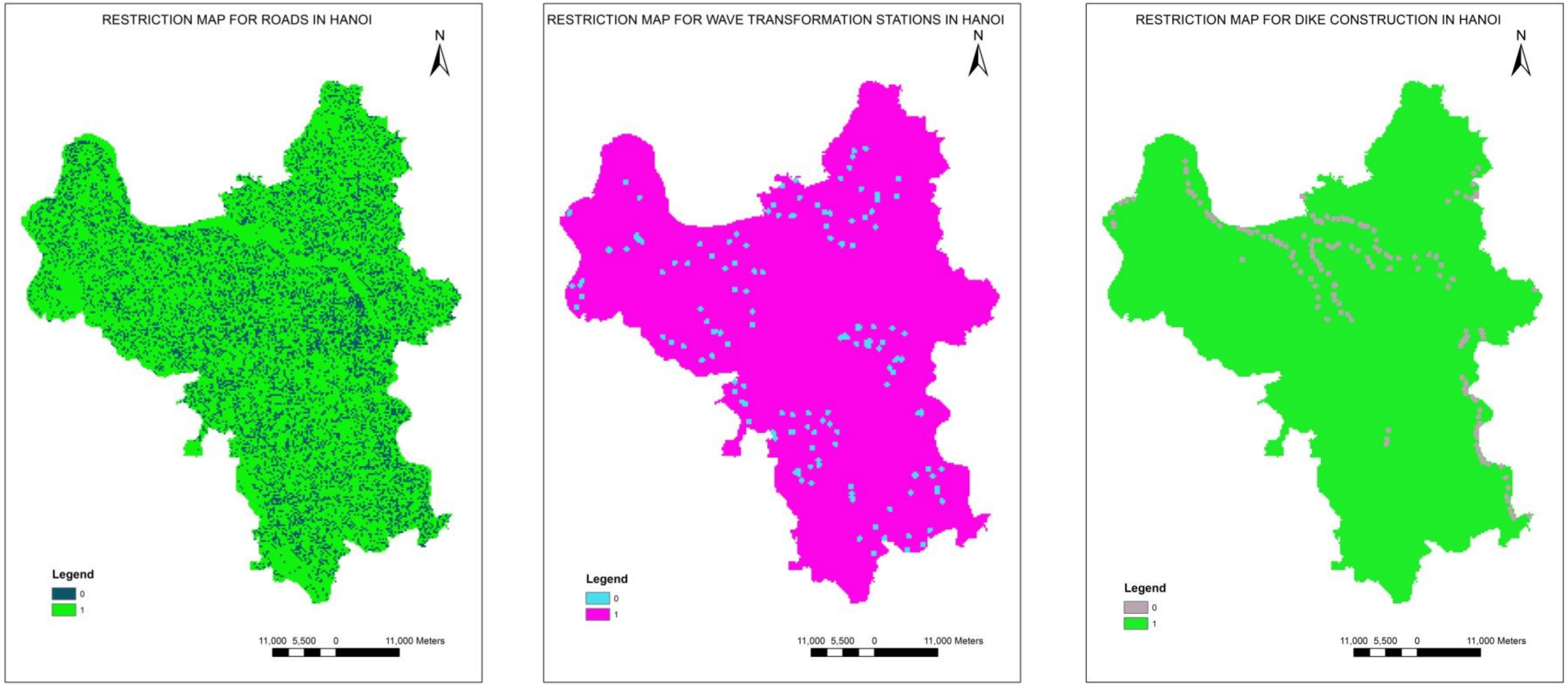

Figure A1.3. Restriction Maps for sitting biogas plants in Hanoi for factors: a. Roads, b. Wave transformation stations, c. Dike Construction

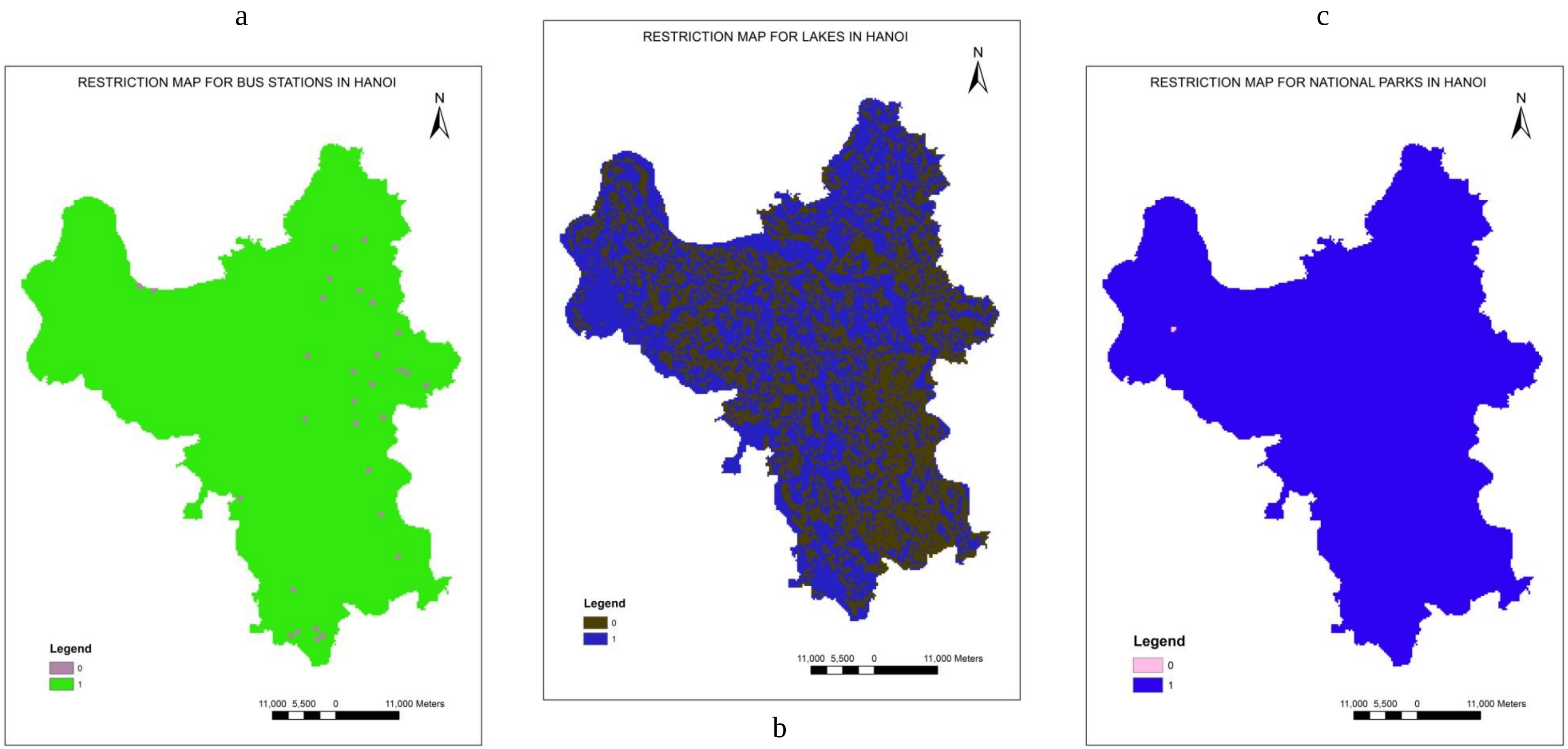

Figure A1.4. Restriction Maps for sitting biogas plants in Hanoi for factors: a. Bus stations, b. Lakes, c. National Parks

a b c

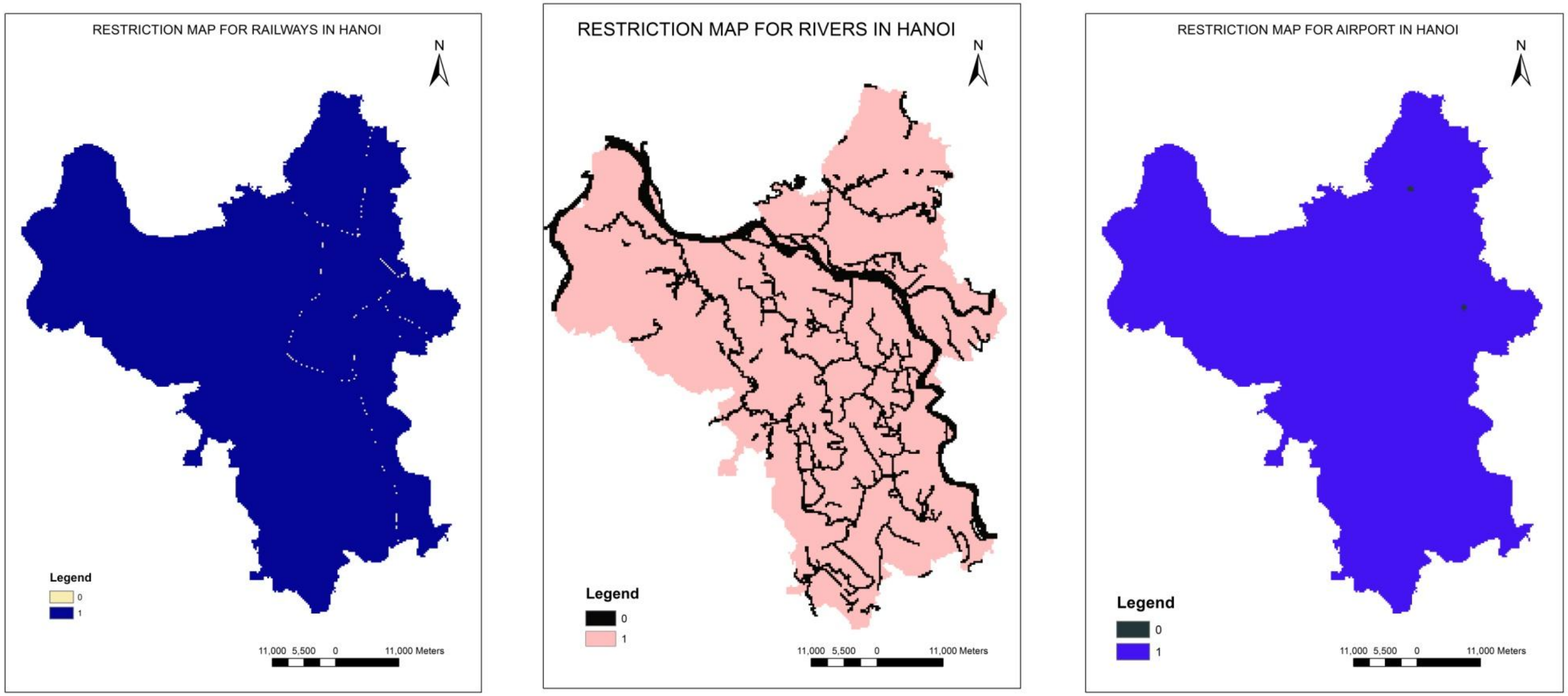

Figure A1.5. Restriction Maps for sitting biogas plants in Hanoi for factors: a.Railways b. Rivers, c. Airports

Annex 2: AHP process analysis

In Table 2A.1, 2A.3, 2A.5, 2A.7, the priority values of the comparison for each factor pair are placed based on Table 2. With scale from 1 (equal value) to 9 (extremely different). In which a higher number means the chosen factor is considered more important in a greater degree than other factors being compared with (Table 2). The calculations are based on Equations 4 and 5.

In Table 2A.2, 2A.4, 2A.6, 2A.8, normalization of the matrix is implemented following the equation 6 and 7. The consistency measure is estimated by equation 8. The consistency index (CI) is calculated by equation 9. The consistency ratio (CR) is estimated based on the following equation 10.

Table 2A.10 is the result of multiplying the weight for criteria and the pair-wise matrix in Table 2A.9, which syntheses from three average columns of three criteria.

1. Collection Efficiency

Table 2A.1. Matrix for Collection Efficiency criteria

	Road	Elevation	Flood Area
Road	1.00	4.00	7.00
Elevation	0.25	1.00	4.00
Flood Area	0.14	0.25	1.00
Total	1.39	5.25	12.00

Table 2A.2. Normalization of Matrix and Weight vector (Collection Efficiency criteria)

	Road	Elevation	Flood Area	Total	Average	Consistency Measure
Road	0.717948	0.761905	0.583333	2.063187	0.687729	3.155792
Elevation	0.179487	0.190476	0.333333	0.703297	0.234432	3.061523
Flood Area	0.102564	0.047619	0.083333	0.233516	0.077839	3.015126
					CI	0.038740
					RI	0.58
					CR	0.066793

2. Safety

Table 2A.3. Matrix for Safety criteria

	Road	Elevation	Flood Area
Road	1.00	0.20	0.14
Elevation	5.00	1.00	0.33
Flood Area	7.00	3.00	1.00
Total	13.00	4.20	1.47

Table 2A.4. Normalization of Matrix and Weight vector (Safety criteria)

	Road	Elevation	Flood Area	Total	Average	Consistency Measure
Road	0.076923	0.047619	0.096774	0.221316	0.073772	3.012691
Elevation	0.384615	0.238095	0.225806	0.848517	0.282839	3.062386
Flood Area	0.538461	0.714286	0.677419	1.930167	0.643389	3.121456
					CI	0.032755
					RI	0.58
					CR	0.056475

3. Cost Minimization

Table 2A.5. Matrix for Cost Minimization criteria

	Road	Elevation	Flood Area
Road	1	6	4
Elevation	0.16	1	0.33
Flood Area	0.25	3	1
Total	1.41	10	5.33

Table 2A.6. Normalization of Matrix and Weight vector (Cost Minimization criteria)

	Road	Elevation	Flood Area	Total	Average	Consistency Measure
Road	0.705882	0.6	0.75	2.055882	0.685294	3.109442
Elevation	0.117647	0.1	0.0625	0.280147	0.093382	3.013123
Flood Area	0.176470	0.3	0.1875	0.663971	0.221324	3.039867
					CI	0.027072
					RI	0.58
					CR	0.046676

4. Weight for criteria

Table 2A.7. Matrix for Weight for criteria

	Collection Efficiency	Safety	Cost Minimization
Collection Efficiency	1	6	0.33
Safety	0.16	1	0.14
Cost Minimization	3	7	1
Total	4.16	14	1.47

Table 2A.8. Normalization of Matrix and Weight for criteria

	Collection Efficiency	Safety	Cost Minimization	Total	Average	Consistency Measure
Collection Efficiency	0.24	0.428571	0.225806	0.894378	0.298126	3.103909
Safety	0.04	0.071429	0.096774	0.208203	0.069401	3.017854
Cost Minimization	0.72	0.5	0.677419	1.897419	0.632473	3.182209
					CI	0.050660
					RI	0.58
					CR	0.087346

5. Synthesis

Table 2A.9. Weight for criteria and the pairwise matrix

Criteria	Collection Efficiency	Safety	Cost Minimization	Weighted preferences
Road	0.687728	0.073772	0.6852941	0.298126
Elevation	0.234432	0.282839	0.0933823	0.069401
Flood Area	0.077838	0.643389	0.2213235	0.632473

Table 2A.10. Final priority for criterion

Criteria	Final Priority
Road	0.64358
Elevation	0.148581
Flood Area	0.207839

Annex 3: Model Calculation for Suitability Weight

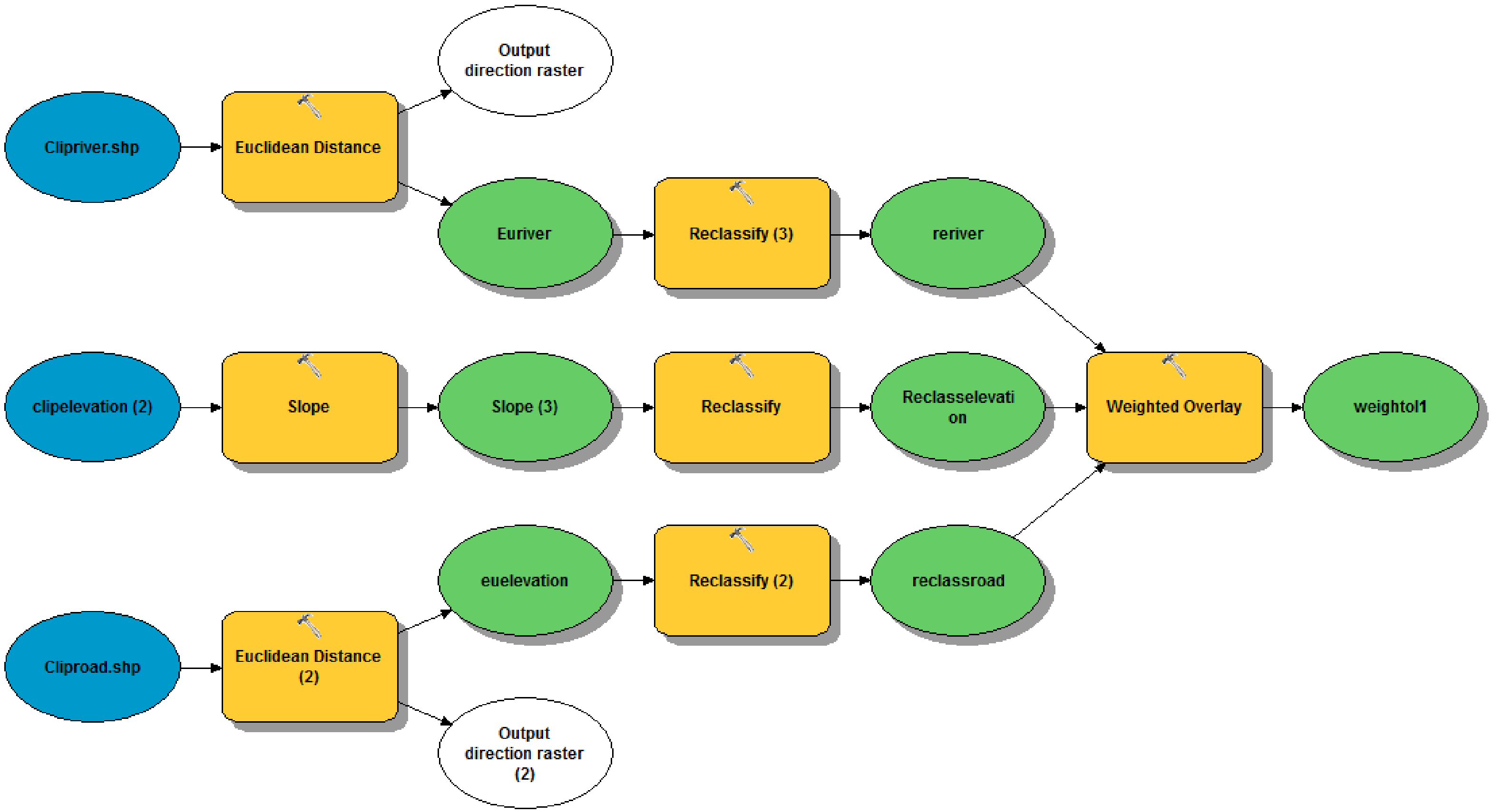

Figure 3A. Model Calculation for Suitability Weight

Annex 4: Calculations for Scenario 1

FID	Pig (head/ farm)	Gi _Bin	CH_4 generation per year (kg/year)	Energy per year (MJ/year)	Capacity Per year (kW)	Area	Total Capacity per year (kW/year)	Total CH_4 emission per year (ton CO_2 eq/year)	Total N_2O emission per year (ton CO_2 eq/year)	Total CO_2 emission per year (ton/year)
0	2000	3	29398	430316	57	Son Tay	1,218	1,733	462.55	8,032.88
1	5000	3	73494	1075790	143	Son Tay				
2	4000	3	58795	860632	115	Son Tay				
3	2000	3	29398	430316	57	Son Tay				
4	2500	3	36747	537895	72	Son Tay				
5	3050	3	44831	656232	87	Son Tay				
6	1600	3	23518	344253	46	Son Tay				
7	2000	3	29398	430316	57	Son Tay				
8	2500	3	36747	537895	72	Son Tay				
9	10700	2	157277	2302192	307	Son Tay				
10	1600	3	23518	344253	46	Son Tay				
11	2000	3	29398	430316	57	Son Tay				
12	3500	3	51446	753053	100	Son Tay				

13	2250	3	33072	484106	65	Thach That	1,350	1,921	512.68	8,903.34
14	1600	3	23518	344253	46	Thach That				
15	2400	3	35277	516379	69	Thach That				
16	2400	3	35277	516379	69	Thach That				
17	2000	3	29398	430316	57	Thach That				
18	2000	3	29398	430316	57	Thach That				
19	5000	3	73494	1075790	143	Thach That				
20	6000	3	88193	1290949	172	Thach That				
21	1600	3	23518	344253	46	Thach That				
22	2000	3	29398	430316	57	Thach That				
23	3200	3	47036	688506	92	Thach That				

24	2000	3	29398	430316	57	Thach That				
25	3000	3	44096	645474	86	Thach That				
26	4600	3	67614	989727	132	Thach That				
27	3000	3	44096	645474	86	Thach That				
28	4000	3	58795	860632	115	Thach That				
Total							2,568	3,654	975	16,936.22

Annex 5: Calculations for Scenario 2

FID	Pig (head/ farm)	Gi _Bin	CH_4 generation per year (kg/year)	Energy per year (MJ/year)	Capacity Per year (kW)	Area	Total Capacity per year (kW/year)	Total CH_4 emission per year (ton CO_2 eq/year)	Total N_2O emission per year (ton CO_2 eq/year)	Total CO_2 emission per year (ton/year)
0	1000	3	23935	857671	32	Ba Vi	112			
1	1000	3	23935	857671	32	Ba Vi				
2	1500	3	35902	1286488	48	Ba Vi				
3	1500	3	35902	1286488	48	Son Tay	528	476	180.75	3,137.28
4	800	3	19148	686137	25	Son Tay				
5	1000	3	23935	857671	32	Son Tay				
6	1500	3	35902	1286488	48	Son Tay				
7	1100	3	26328	943420	35	Son Tay				
8	1475	3	35304	1265060	47	Son Tay				
9	1100	3	26328	943420	35	Son Tay				
10	1200	3	28722	1029205	38	Son Tay				
11	1200	3	28722	1029205	38	Son Tay				
12	1200	3	28722	1029205	38	Son Tay				
13	1200	3	28722	1029205	38	Son Tay				
14	650	3	15558	557495	21	Son Tay				
15	900	2	21542	771922	29	Son Tay				
16	1000	2	23935	857671	32	Son Tay				
17	750	3	17951	643244	24	Son Tay				

18	750	3	17951	643244	24	Thach That				
19	1000	3	23935	857671	32	Thach That				
20	1200	3	28722	1029205	38	Thach That				
21	1000	3	23935	857671	32	Thach That				
22	1100	3	26328	943420	35	Thach That				
23	1200	3	28722	1029205	38	Thach That	404	363	132.95	2,394.37
24	1000	3	23935	857671	32	Thach That				
25	1000	3	23935	857671	32	Thach That				
26	1000	3	23935	857671	32	Thach That				
27	1000	3	23935	857671	32	Thach That				
28	1500	3	35902	1286488	48	Thach That				
29	900	3	21542	771922	29	Thach That				
Total							839	1,193	975	5,532

Annex 6: Calculations for Scenario 3

FID	Pig (head/ farm)	Gi _Bin	CH_4 generation per year (kg/year)	Energy per year (MJ/year)	Capacity Per year (kW)	Area	Total Capacity per year (kW/year)	Total CH_4 emission per year (ton CO_2 eq/year)	Total N_2O emission per year (ton CO_2 eq/year)	Total CO_2 emission per year (ton/year)
0	600	3	14361	514602	19	Ba Vi	32			
1	400	3	9574	343068	13	Ba Vi				
2	202	3	4835	173254	6	Son Tay	308	439	117	2,034
3	105	3	2513	90049	3	Son Tay				
4	600	3	14361	514602	19	Son Tay				
5	600	3	14361	514602	19	Son Tay				
6	550	3	13164	471710	17	Son Tay				
7	315	3	7540	270183	10	Son Tay				
8	250	3	5984	214427	8	Son Tay				
9	400	3	9574	343068	13	Son Tay				
10	600	3	14361	514602	19	Son Tay				
11	600	3	14361	514602	19	Son Tay				
12	500	3	11968	428853	16	Son Tay				
13	130	3	3112	111513	4	Son Tay				
14	420	3	10053	360232	13	Son Tay				
15	580	3	13882	497438	18	Son Tay				
16	120	3	2872	102913	4	Son Tay				
17	165	3	3949	141506	5	Son Tay				
18	400	3	9574	343068	13	Son Tay				

19	600	3	14361	514602	19	Son Tay				
20	400	3	9574	343068	13	Son Tay				
21	120	3	2872	102913	4	Son Tay				
22	120	3	2872	102913	4	Son Tay				
23	360	3	8617	308776	11	Son Tay				
24	110	2	2633	94349	3	Son Tay				
25	210	2	5026	180098	7	Son Tay				
26	600	2	14361	514602	19	Son Tay				
27	600	2	14361	514602	19	Son Tay				
28	400	3	9574	343068	13	Son Tay				
29	130	2	3112	111513	4	Son Tay				
30	110	3	2633	94349	3	Son Tay				
31	450	3	10771	385961	14	Son Tay				
32	200	3	4787	171534	6	Thach That	71			
33	600	3	14361	514602	19	Thach That				
34	450	3	10771	385961	14	Thach That				
35	500	3	11968	428853	16	Thach That				
36	500	3	11968	428853	16	Thach That				
Total							308	439	117	2,034