Geo-Spatially Based Analysis And Economic Feasiblity Evaluation Of Waste-To-Energy Facilities: A Case Study Of Local Government Areas Of Anambra State Of Nigeria

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GEO-SPATIALLY BASED ANALYSIS AND ECONOMIC FEASIBLITY EVALUATION OF WASTE-TO-ENERGY FACILITIES: A CASE STUDY OF LOCAL GOVERNMENT AREAS OF ANAMBRA STATE OF NIGERIA

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Abstract

Access to affordable clean energy source as stipulated in UN SDG goal number 7 is important for the development and socio-economic well-being of people, the need for proper assessment of resources to achieve this goal is indisputable. The goal of this study is to assess the economic feasibility of utilizing organic fraction of Municipal Solid Wastes (MSW_{of}) using a case study of 21 Local Government Areas (LGA) or Authority for Anambra State of Nigeria for waste to energy project. The quantity of organic fraction of MSW, energy recovery and optimum number of plants at the various LGAs was estimated. The result of the study indicates that about 198 tons maximum value of MSW_{of} can be generated daily in Aguata LGA, with electric energy potential value of 545MW. The number of plants for the LGAs ranged from 10 to 50 and from 3 to 12 for small and medium scale plants. A large scale plant of about 50m^3 can possibly be installed at all the LGAs, with a maximum of 4 plants in Idemili and Aguata LGA. The economic assessment based on Net Present Value (NPV) criteria shows poor economic feasibility for small scale plant, while NPV was positive for medium and large scale plants. The Internal Rate of Return (IRR) ranged from 0.32 to 0.94, with a general increase from small scale to large scale economic feasibility. It is suggested that the autonomy of the various LGAs in the country should serve as a major motivation in adopting bio-energy projects independently, and this study will serve as a decision toolkit in the appropriate scale to be adopted.

Key words: Geospatial model, economic factors, bioenergy plants, waste management, Nigeria

1. Introduction

Energy crisis is still plaguing many developing countries, as a result of poor utilization of natural resources within their reach. Recently a survey carried out in Nigeria by the National Bureau of Statistics in collaboration with World Bank, the study analyzed approximately 5000 nationally representative houses on the use and type of cooking methods. The study shows that about 25.8% of the population in South East of Nigeria depend on three stone or open fire cooking system, 18.6% on self-built biomass, 12.3% on manufactured biomass, 6.4 on LPG/natural gas, 36.5% on Kerosene, and 0.5% on electricity (National Bureau of Statistics, 2019). This indicates poor utilization of clean energy source for cooking in the region and therefore requires appropriate measures to reverse the trend. On access to electricity on a regional basis in Nigeria, the study also reported 47% access to electricity for North Central, 79.1%, 57.7%, 26.6%, 27.2% and 32.7%, for North East, North West, South East, South South, and South West respectively. With less than 50% access for the Southern region, the need for alternative sources of electricity is a paramount.

Analysis of waste characteristics and composition is vital in waste to energy projects. A number of studies in Nigeria have shown high content of organic matter in waste generated in Nigeria (Ezeudu et al., 2019). A survey on the composition of wastes of various household in Abuja reported about 63.6% of organic matter fraction (Ogwueleka, 2013), 56% was reported on the analysis of urban solid waste for Nsukka (Ogwueleka, 2003) and 51.27% in Ogbomoso (Afon, 2007). Solid waste management has been reported as one of the greatest challenges faced by many state and local government areas of developing countries (Okey-Onyesolu et al., 2020). Several researchers have asserted that utilization of organic fraction of municipal solid waste (MSW) will ensure a sound material-circle society, thereby establishing a circular economy (Palanivel and Sulaiman 2014). Further studies have reported that waste to energy technologies apart from providing circular economy; also have the potential of reducing the volume of waste generated by as much as 90% (Ezeudu et al., 2019). Studies have also shown that the organic fraction of MSW of developing countries is much higher when compared to developed countries, because of consumption pattern, this makes the utilization of organic MSW for waste-to-energy strategy, more viable for most developing countries (Ezeudu et al., 2019). The current trend towards the application of sustainable renewable energy systems globally calls for a systematic approach of assessing the energy potential of organic MSW and the development of a strategic approach for most developing countries.

Several biomass projects have been reported to be lacking in comprehensive planning, which often leads to the inability of projects to be sustainable as a result of the imbalance of demand-supply and cost-benefit (Wang et al, 2021). One of the biggest hurdles in utilizing waste-to-energy facilities is the determination of potential energy for organic MSW, estimation of the number of plants within a location and economic assessment of the project. Studies are therefore critical in the achievement of waste to energy system for a circular economy by utilization of organic MSW for most developing countries. Previous studies were limited to agricultural waste only as an energy source (Chukwuma et al, 2019; Manesh et al., 2020; Ozoegwu et al., 2017), other studies in the study area that considered organic waste source were limited to its characterization (Ogwueleka, 2013; Ezeudu et al. 2019). In addition, previous studies in the region have failed to consider the economic feasibility of waste to energy plants in the study area, this is critical in realization of a circular economy for any society; this study is therefore instrumental in achieving a circular economy. There is need to research on the viable number of waste to energy plants that are required in a location for successful implementation of waste to energy projects, this research gap is fundamental in economic assessment and therefore proves this study to be essential.

Several studies have assessed the economic feasibility of biogas plant. An investigation on the environmental and economic performance of thermophilic biogas production in Spain was conducted using Life Cycle Costing, Life Cycle and Cost Benefit assessment methodologies (Ruiz et al., 2018); Economic performance based on the actual operating data of 400kg-wet/day of biogas plant installed in Thailand was assessed for revenue from electricity sale and food waste disposal (Kiodo et al., 2018); the techno-economic prefeasibility studies of four bio-energy project comprising of incineration, gasification, anaerobic digestion and landfill gas was assessed for Colombia (Alzata et al., 2019); another techno-economic study evaluated the cost analysis and benefit of the operation performance of certain biogas project in Japan (Wang et al 2021); a feasibility study on the advantages and economic of biogas production using poultry manure was investigated in Iran (Manesh et al., 2020). Despite numerous economic attempts in assessing biogas technology by several researchers globally, there is scarcity of research on the economic feasibility of biogas technology in Nigeria. By virtue of being a major oil producer in Africa, studies that foster global adoption of renewable energy target should be a concern for all countries, especially for oil-producing nations for global interest and for the achievement of clean energy target of UN Sustainable Development Goal 7. Therefore critical data that will foster the adoption of renewable energy in developing countries should be a major concern for African researchers.

The law and regulations of countries are vital in the achievement of renewable energy target or project. In Nigeria for instance, the Federal Government laws and regulations promulgated to protect the environment include the Federal Environmental Protection Agency Act of 1988 and the Federal Environmental Protection Agency (FEPA), created in 1999 under the FEPA Act decrees that each state and local government in the country should set up its own environmental protection body for the protection and improvement of the environment within its jurisdiction, this makes municipal solid waste management a major responsibility of state and local government environmental agencies (Ogwueleka, 2009). It is therefore critical to provide waste to energy research project, at the levels of government for easy adoption. Previous studies on energy research have paid enormous attention in designing energy projects at national and state levels, while the LGA level, which is regarded to be closest to the people for grass root projects has been ignored totally. To the best of the knowledge of the authors, no study have considered providing energy generation potential of organic MSW and economic viability in the country at LGA level, despite the fact that it is critical in the adoption of independent clean renewable technology in the country. The objective of this study is to provide energy generation potential and economic viability of organic MSW using the 21 LGAs in Anambra state of Nigeria as a case study.

2. MATERIALS AND METHODS

2.1 Case Study Description

Anambra State is situated in the eastern part of Nigeria, for ease of governance the State is divided into 21 Local Government Areas with Awka as its state capital. The land mass of the state is estimated to be about 4,844 square kilometres. According to the figure given by the National Population Commission and estimated by National Bureau of Statistic in Nigeria, the population of the State stands at 5.5 million in 2016 with a population density of 1,500 to 2,000 persons living within every square kilometre. Figure 1 below shows map of Nigeria and the various LGAs on Anambra State map.

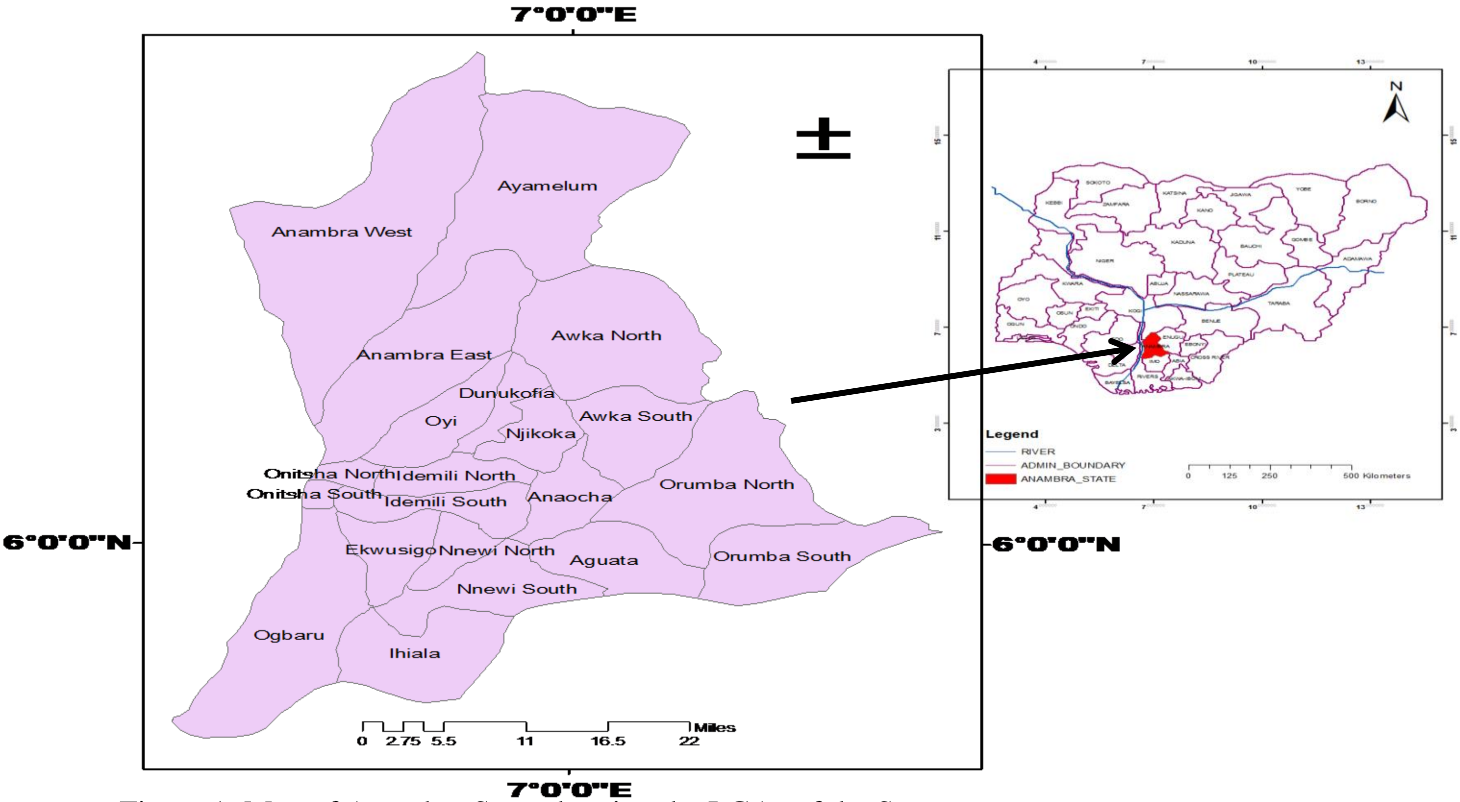


Figure 1: Map of Anambra State showing the LGAs of the State.

2.2 Waste characteristic and Management

The quantity and rate of solid waste generation in the various states of Nigeria depends on the population, level of industrialization, socio-economic status of the citizens and the kinds of commercial activities predominant. Food wastes (leftover food, vegetable wastes, leaves, etc.) constitute a significant proportion of the household-derived MSW, thus organic composition, and by extension the overall composition of MSW, should vary in Nigeria with food culture (Babayemi and Dauda 2009). The two major wastes that are of interest and major concern in the country because of the degree of mismanagement are agricultural waste and MSW. Wastewater from household is relatively managed properly using individual sewage tank. However, agricultural waste generated in various livestock farms and abattoirs are poorly managed. Though there is system to manage MSW, inefficient method of collection, inability to cover waste generation points timely, and littering of waste remain a serious challenge. The value of 0.307kg/capita/day of MSW$_{of}$ generation rate reported in a recent study was used for the study area (Ezeudu et al., 2019).

2.3 Estimation of Potential Energy

The estimation of potential energy recovered from waste is critical in assessing the economic viability of waste to energy project. The organic fraction of the MSW can be utilized and waste to energy conversion achieved using internal combustion engine. To convert the organic fraction of the MSW into biogas using an internal combustion, a conversion efficiency of $\eta = 0.4$ is used as done in previous studies (Yalcinkaya et al., 2020). Estimation of potential energy recovery was done using equation 1:

$$EP_{ice} = \sum_{i=1}^{n} N_i * M_f * R_m * \frac{Methane}{1000} * LHV * \eta \quad (1)$$

Where EP_{ice} is the energy potential (KWe), N_i is the population at LGA geospatial scale, M_f is the organic fraction of the municipal waste, R_m is the rate of generation of MSW, *Methane* indicates the unit Methane generation for organic MSW. LHV of 37.2MJ/m^3 was used.

Energy potentials recovery from agricultural waste such a livestock manure through anaerobic digestion was calculated using equation. The unit current electricity tariff price in Nigeria of \$0.15/Kw (N 62.33) was used. The Naira (N) to dollar conversion rate based on ATM bank charges of \$1 is to N415 was used in the study.

2.4 Estimation of the Number of Plants

Estimation of the cost of the project and optimum number of bioenergy plant(s) is essential to determine the profitability of the project. The general total cost for estimating any of the above listed waste to energy project is given by equation (2):

$$PT_c = \sum_{i=1}^{n} I_i + O_i + T_i \quad (2)$$

Where PT_c is the total cost of the project, I_i is the Investment cost for waste to energy plant I, O_i is the operational and maintenance cost, and T_i is the transportation cost.

Equation (3) is used to estimate the investment cost, Amigun and Blottniz (2010) determined investment cost relationship for small–large scale biogas system.

$$\frac{I_1}{I_2} = \left(\frac{C_1}{C_2}\right)^n \quad (3)$$

The study reported that the value of n for small scale plant as 1.21 and 0.8 for large scale biogas plant Where I_1 = cost of the item at size or scale C_1; I_2 = cost of the reference item at the size or scale C_2. n = scale exponent or cost capacity factor. This study considered three scenarios, which include the use of small, medium and large scale plants of $4m^3$, $16m^3$ and $50\ m^3$, the scales were chosen since a good number of such capacities already exist in the continent with capital investment costs, and this will provide good comparative advantage (Amigun and Blottnitz, 2007). Various studies have shown that relationship exist between the investment cost and the operation and maintenance cost of a project, Alzate et al., (2019) used 16% of investment cost for the operation and maintenance cost in evaluating the techno-economic scenarios of MSW for anaerobic electricity generation in Colombia, while Adeoti et al., (2000) arrived at 14.4%, from a study of engineering design and economic evaluation of family-sized biogas project in Nigeria. Since the work of the latter is geographically economically similar, 14.4% of the investment cost was used in this study as the operational and maintenance cost.

The transportation costs to the plants is given by equation (4)

$$T_c = 2 \times F_c \times F_p \times \sum_{i=1}^{m} \sum_{j=1}^{n} d_{ij} \times \frac{Q_i}{V} \quad (4)$$

Tc is the transportation cost, 2 is return trip multiplier, F_c is the fuel consumption per km (L/km); F_p is the fuel price (N/Km), d_{ij} is the distance between the waste source i to any of the energy to waste plants j. Qi is the waste generation rate and V is the capacity of the vehicle. \$0.8/L/km transportation cost was used for fuel consumption, while the current fuel price of \$0.421 (N 165) was used. The current situation in collection of wastes in the state indicates that the use of different capacities of vehicle such open load of $5m^3$, rear loading compactor ($7.5m^3$) and container truck ($15m^3$) is in place. The

$5m^3$, $7.5m^3$ and $15m^3$ capacity vehicles designated for the small, medium and large scale plants respectively. Since no specific location has been decided for the study area, an economic maximum distance of 40km based on previous work was taken for the large scale plant, while 10km and 20km were used for the small and medium plants respectively. This is based on a study that reported a maximum transportation distances for raw materials varying from 10 to 40 km (Höhn et al., 2014). In the present study, the upper end was used to estimate the collection area. The total project cost is therefore:

$$PT_c = \sum_{i=1}^{n} \frac{C_1}{C_2} = (\frac{Q_1}{Q_2})^n{}_i + 0.144 I_i + 2 \times F_c \times F_p \times \sum_{i=1}^{m} \sum_{j=1}^{n} d_{ij} \times \frac{Q_i}{V_i} \quad (5)$$

The total waste (TW_{msw}) for waste to energy conversion = Population of the LGA × Waste generation rate × Organic Fraction of MSW.

$$\text{Number of facilities needed (LGA)} = \frac{Total\ Waste\ generated}{The\ plant\ scale\ or\ capacity} \quad (6)$$

2.5 Cost Analysis of Waste to Energy Plant

The application of techno-economic analysis tools to engineering projects is worthwhile; it is aimed at identifying the best choice between alternative projects. The best project depends on a locality and cannot be generalized without further economic assessment. This study used Internal Rate of Return (IRR) and Net Present Value economic indices to analyse the best bioenergy plant scale project for the various LGA. IRR is regarded as the discount rate that equates the present value of the expected cash outflows with the expected value of the cash inflows. Waste to energy plant with several years of economic benefits X is given by:

$$\frac{X_1}{(1+i)} + \frac{X_2}{(1+i)} + \frac{X_3}{(1+i)} + \cdots \frac{X_n}{(1+i)^n} - I = 0 \quad (7)$$

$$IRR = \sum_{t=1}^{n} \frac{X_t}{(1+i)^t} - I = 0 \quad (8)$$

Where I it the discount rate, I=the cash outflows, n the number of years.

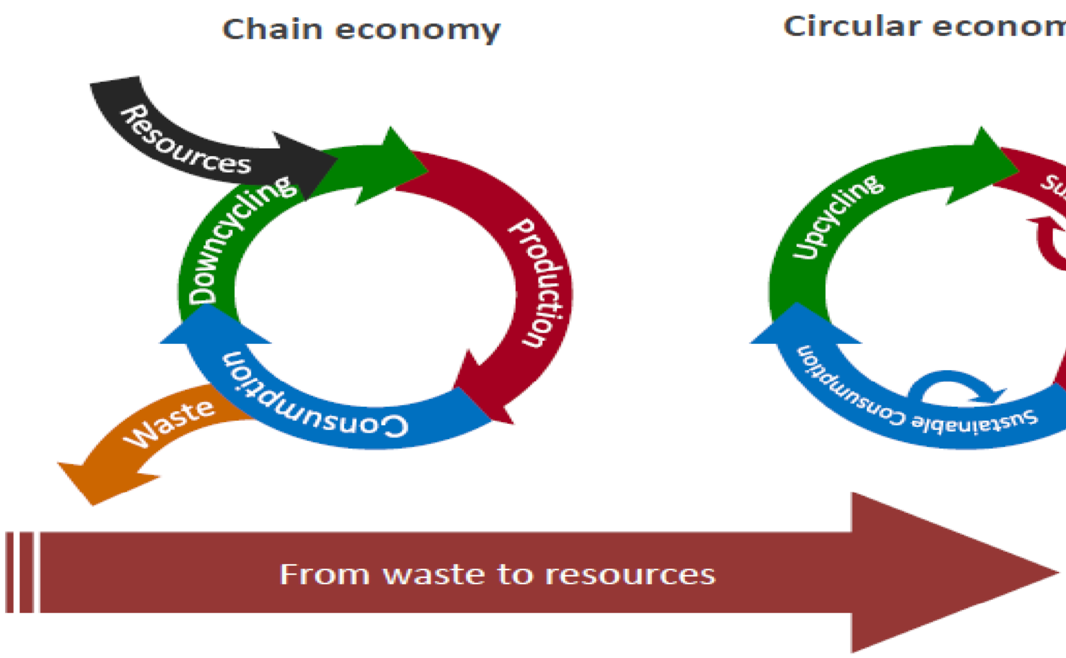
The NPV is used to compute and compare streams of cash flows that will accrue in the future. It is defined as the difference between the present value of the project future cash inflows and its initial investment. It is given as:

$$\text{NPV} = \sum_{t=1}^{n} \frac{X_t}{(1+i)^t} - I = 0 \quad (9)$$

A project is profitable when NPV is positive.

2.6 Data Management and Circular Economy

ArGIS version 10.1 was used to geospatially model the data in this study. The data for the population of the various LGA was obtained from the official website; the population growth rate of 2.6% as reported by the National Population Commission was used to project the population figure to the current year. Data of the population of each of the LGAs is shown in the Appendix. The Waste to energy projects and circular economy should be the current economic pathway for developing countries and study area in particular, against chain economy in managing MSW.



[Source: https://www.valueloops.eu/index.php/circular-economy-2/]

Biomass wastes take up a large proportion of waste generation in developing countries. Thus, exploiting biomass waste as a recyclable resource is of pronounced benefit in the promotion of a cycle-oriented society. The proposed waste to energy to be adopted in the State to achieve a circular economy should comprise of sustainable food production to minimize waste by adopting food processing technologies that prevent food waste especially at the peak harvesting time of the year. A situation where either the local government authority, interested companies, farmers' co-operative society etc decide to finance and operate the plant has long been sought for. Sustainable consumption and upcycling through the utilization of organic MSW is essential in achieving circular economy in the study area.

3.0 Result and Discussion

3.1 Estimated Waste and Energy Potential

Assessment of energy potential from biomass source is critical in the development of waste to energy project. The energy potential was estimated for each LGA based on equation 1. Figure 3 (a) shows the waste generation capacity (in tons) of the various LGA, while Figure (3b) shows the estimated energy potential (MW) of the various LGAs. A maximum waste generation potential of about 198 tons was identified in two LGAs, while a minimum range of 40 to 50 tons was observed in four LGA areas that were clustered in the central region of the study area. Two LGAs located in the South West of the region had a value of estimated waste generation capacity that were about 102 tons to 138 tons. The organic fraction of waste from the various LGAs is substantial for waste to energy projects. A previous study that utilized 400kg/day of bio-waste on a small-scale bio-methane production was asserted to be successful (Kiodo et al., 2018). It, therefore, follows that the availability of waste in the study area will ensure the success of bio-energy project when adopted.

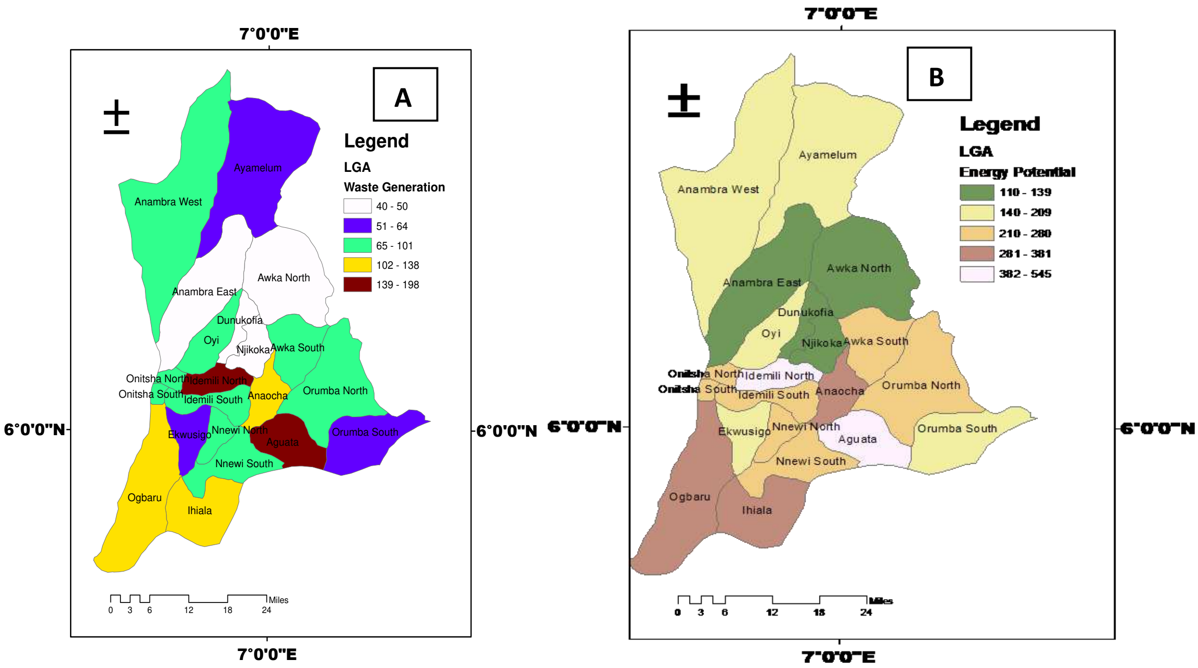


Figure 3: (A) Waste and (B) energy generation potential from Organic MSW for the LGAs

Spatial model of the estimated energy potential (MW) indicates that a maximum value of 545MW was recorded for Aguata LGA, this shows the enormous untapped energy potential that would be available for electricity when waste to energy technology is adopted in the LGA. Similarly, Idemili North LGA, also indicated high potential for energy potential among all the LGA, the location of this LGA in the central region of the study, provides it with opportunities to access wastes from nearby LGA. A similar study on energy potentials reported that about 4000 MW was generated through the application of biomass resources in Iran in 2005 (Manesh et al., 2020). In addition a similar study on the assessment and estimation of energy potential from biogas plant reported that 2000 MWh/yr of power could be generated in a biogas facility in Spain by processing 26,000 t/yr of biowastes (Ruiz et al., 2019). Considering the waste generation capacity of 75tons daily for Anambra West LGA for instance, approximately 27,375t/yr of bio-waste could be generated in the region annually, this is slightly higher than the estimate of Ruiz et al., (2019), and indicates the energy potential that could be assessed in the adoption of renewable in the various LGA. The ability to adopt waste to energy system based on the relative high value of energy potential is a good prospect for LGA within the study area.

3.2 Estimated Number of Waste to Energy Plants

Determination of the optimum number of plants is imperative in the economic assessment of bio-energy project. This operation was performed and the number of plants required to be set up for small, medium and large scale plants respectively for each of the LGA using equation (6) was established. This is presented in Figure 4 to 6. Since spatial density and distribution of MSW is directly proportional to the population of a given area. Figure 4 indicates that the maximum number of small scale waste to energy plants is to be constructed and installed in Idemili North and Aguata LGAs. The study indicates that based on the quantity of organic MSW generated in the areas, 48 and 49 small scale plants are required in Idemili North and Aguata LGAs respectively to successfully maximize the generated waste. Ogbaru, Ihiala and Aniocha LGAs are classified as zones that need the range of 26 to 35 plants to strategically handle the MSW in the area, Ogbaru, Ihiala and Aniocha LGAs need a precise number of 33, 31 and 34 plants respectively based on this study.

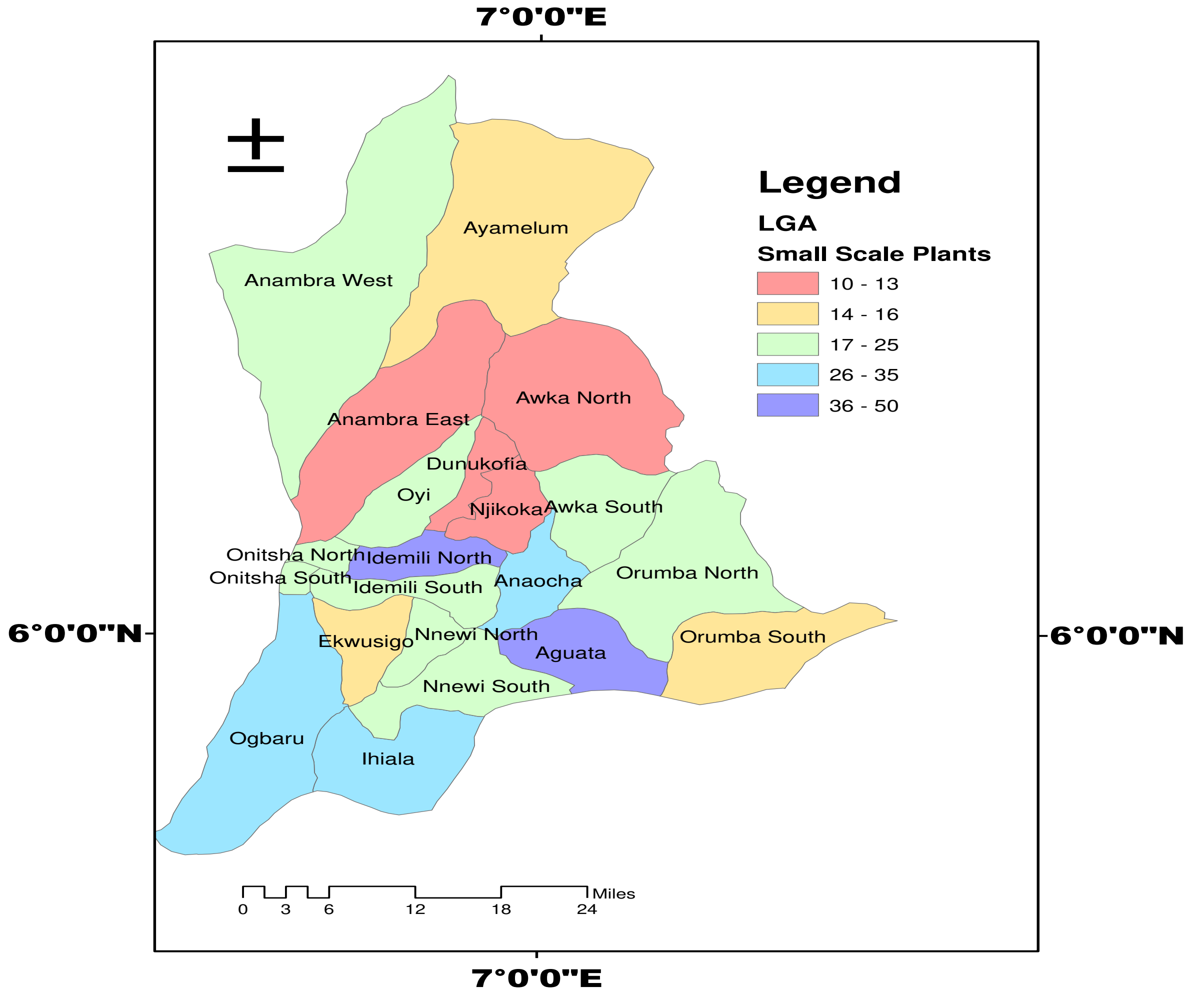


Figure 4: The number of small scale plants in the LGA

The majority of the LGAs (about 9 in total) fall within the places where an average number of plants that should range from 17 to 25 should be installed. Further on the number of plants required to manage organic MSW generated within the various LGAs, it is worthy to note that a minimum of plants ranging in the number of 10 to 13 is required in about four LGAs namely: Anambra East, Awka North, Dunukofia and Njikoka LGA. It is suggested that properly dispersed plants taking into cognizance the population density of the area should be able to cater for the waste generated in the area. From the data, it shows that about 2 LGAs and 3 LGAs are designated as places that need a maximum and minimum number of plants respectively, and 9 LGAs in the middle of the class, it shows without detailed statistical analysis, that the number of plants to be installed in the State follows a normal distribution, this is a natural phenomenon. Owing to the economics of scale and preferences in the adoption of scales of bio-energy plants, the spatial model of medium scale of plants required in each of the LGAs was equally provided; this is represented in Figure 5. From the Figure, it is observed that the maximum number of plants to be installed in the study area, should a medium scale plant of about 16m^2 be the preference, will be about twelve in Idemili and Aguata LGAs.

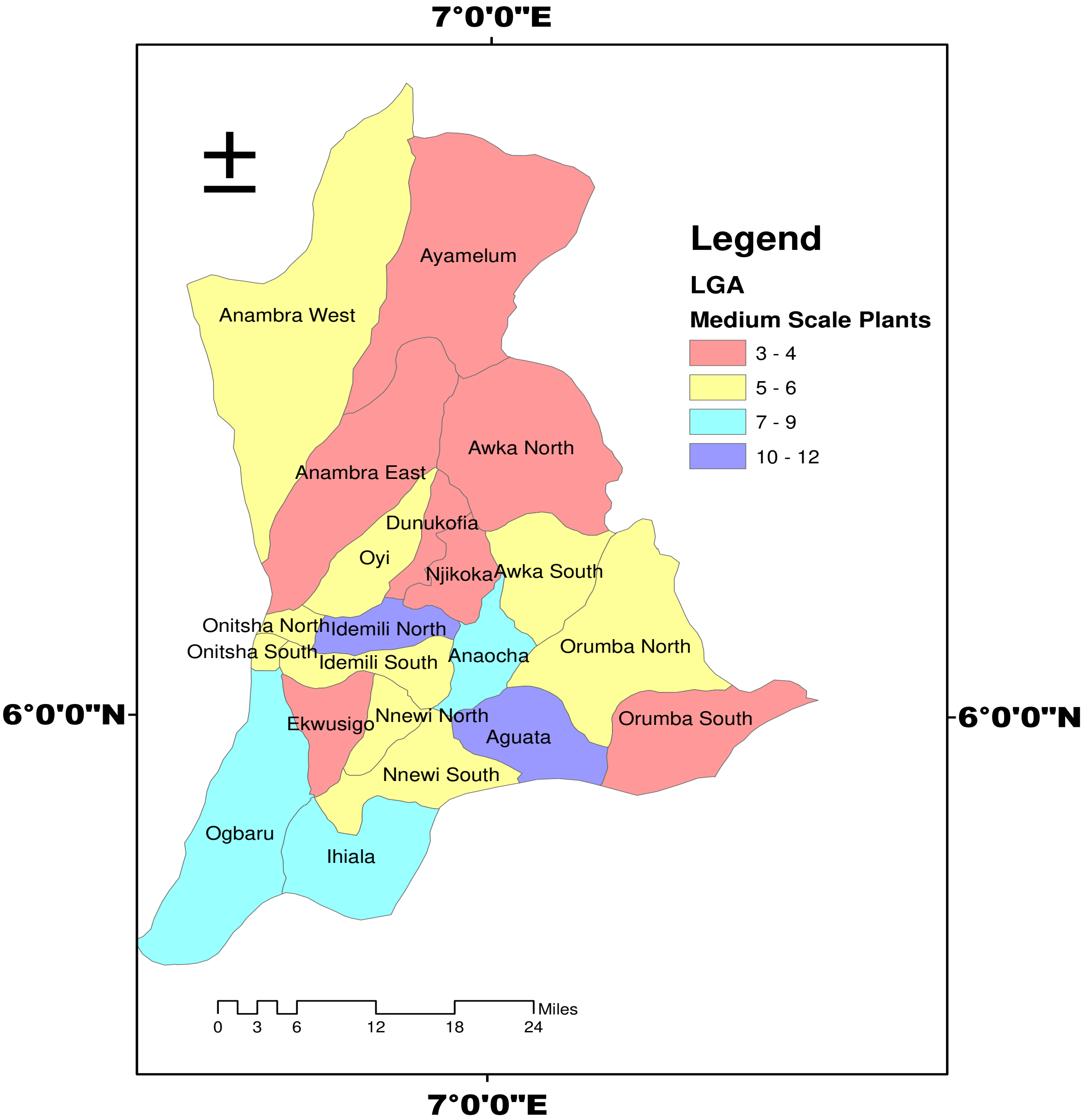


Figure 5: The number of Medium Scale Plants

This also seems to coincide with the two LGAs that have the maximum number of small scale plants: Idemili North and Aguata. Similar to the required number of small scale plant shown in Figure 4, Ogbaru, Ihiala and Anaocha LGAs were all classified under the same zone that required about 7 to 9 medium bioenergy plants. However, the number of LGAs that needed about 5 to 6 number of medium-scale plants seem to be the highest. The Figure also shows that about 7 LGAs need about 3 to 4 medium-scale bioenergy plants, this study obviously indicates that every LGA needs a minimum of 3 medium-scale plants. This seems to contradict a recent study by Chukwuma et al (2021) that considered agricultural waste only in GIS bio-waste assessment and suitability analysis for biogas power plant in the same study area. The study based on agricultural bio-waste estimation, eliminated the possibility of installation of biogas plants in Anambra West and Ayamelum LGAs owing to low agricultural waste generation capacities of both LGAs. However, based on the use of organic fraction of MSW in this study, the possibility of for adoption of waste to energy project is feasible for both LGAs. Figure 6 shows the number of large scale bioenergy plants that is required for each of the LGAs.

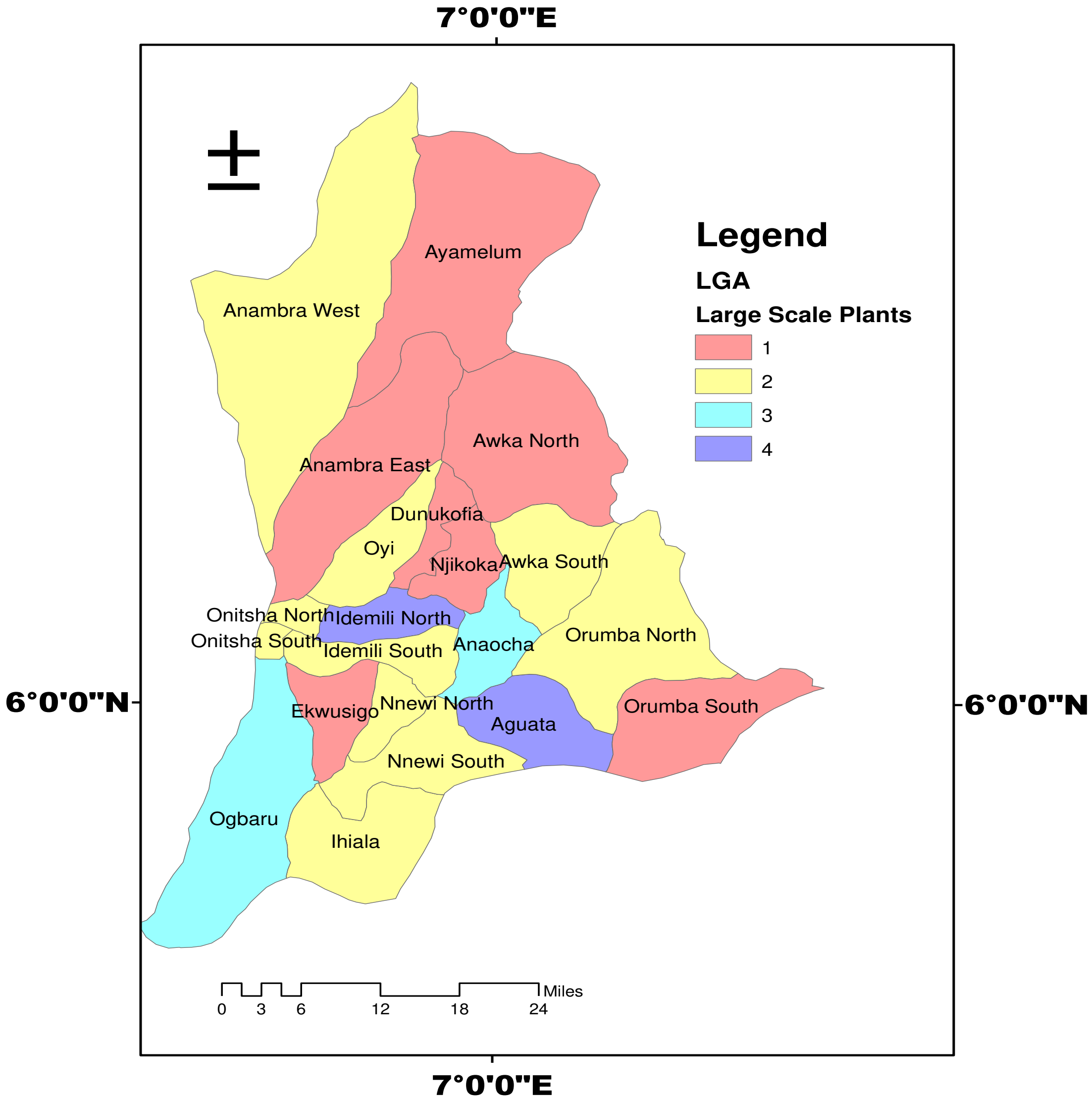


Figure 6: The Number of Large Scale Plants Estimation for the LGAs

Large scale bioenergy plants have been asserted to have economy of scale; however the investment cost is usually high (Carlini et al., 2017). The inclusion and presentation of spatial model of large scale bioenergy plant of about $50m^3$ is essentially for independent decision by LGAs that have the economic muscle to prefer or chose the project. From Figure 6, it shows that the maximum number of large plant scale of 4 is required in two LGAs; Idemili North and Aguata, while a minimum of one large scale plant is required in 7 LGAs. The majority of the LGAs (9) would be able to install 2 large scale plants. The presentation of various scales as opined here is critical in decision making, since the financial capacity of the various LGAs is not the same, and also the priority of these government jurisdiction to invest in renewable energy source usually differ. It is suggested that adoption of the number of plants as done in this study is a prerequisite in allocation of fund for investment in waste to energy project.

3.3 Profitability Analysis of Waste to Energy Plant

Economic models when applied to engineering project are designed to serve as analytic tools, aimed at identifying the best choice between project alternatives. This study considered three bioenergy plant scales to ascertain the appropriate project alternative for the various LGA in the study area. Table 1 shows the result of the economic feasibility studies on the NPV values and IRR values for 5 years. From Table 1, virtually all the LGAs will be at economical loss using the NPV economic criteria, only three LGAs viz; Aguata, Anaocha and Idemili North had a positive NPV value.

Table 1: Economic Assessment of the various Plants

LGA	NPV $ (Small Scale Plant)	NPV $ (Medium Scale Plant)	NPV $ (Large Scale Plant)	IRR (Small Scale Plant)	IRR (Medium Scale Plant)	IRR (Large Scale Plant)
Aguata	110338.82	437726.93	390951.38	0.33	0.57	0.94
Anambra East	-133529.15	90437.24	95372.54	0.32	0.52	0.42
Anambra West	-79054.19	168014.42	161398.62	0.32	0.54	0.64
Anaocha	18433.96	306846.23	279558.60	0.33	0.56	0.84
Awka North	-130552.85	94675.74	98979.95	0.32	0.52	0.43
Awka South	-56060.41	200759.61	189268.10	0.32	0.55	0.71
Ayamelum	-103823.56	132740.63	131377.04	0.32	0.54	0.56
Dunukofia	-122298.11	106431.23	108985.06	0.32	0.52	0.48
Ekwusigo	-100253.68	137824.46	135703.89	0.32	0.54	0.57
Idemili North	101417.67	425022.42	380138.55	0.33	0.57	0.93
Idemili South	-63028.09	190837.02	180822.97	0.32	0.55	0.69
Ihiala	-3952.05	274966.55	252425.75	0.32	0.56	0.81
Njikoka	-117532.05	113218.53	114761.74	0.32	0.53	0.50
Nnewi North	-66286.03	186197.42	176874.20	0.32	0.55	0.68
Nnewi South	-38205.22	226186.99	210909.38	0.32	0.55	0.75
Ogbaru	9012.04	293428.57	268138.80	0.33	0.56	0.83
Onitsha North	-66186.13	186339.69	176995.28	0.32	0.55	0.68
Onitsha South	-51133.86	207775.45	195239.29	0.32	0.55	0.72
Orumbah North	-59456.27	195923.60	185152.16	0.32	0.55	0.70
Orumbah South	-96477.56	143201.99	140280.71	0.32	0.54	0.59
Oyi	-78153.18	169297.54	162490.68	0.32	0.54	0.65

The medium-scale plant indicated a positive NPV value as well as the large scale plant. This corresponds to a previous study by Sarker et al., (2020) on the economic feasibility of biogas technology adoption in Bangladesh. The study reported an increase in the annual benefits for fuel, labour and fertilizer substitution as the size of biogas plant increases. This study however contradicts a study on economic evaluation of small-scale or household plants in Nigeria by Adeoti et al, (2000) that reported a positive NPV at 6.6 years of the project. The possible reason for the contradiction could be linked to the difference in a payback period of 6.6 years, since this study was conducted for just 5 years. The negative NPV as obtained in this study for small scale plant is similar to a study by Cucchiella et al., (2019), the study investigated on the economics of different plant scale of several typologies of animal residues for biogas and biomethane plants using NPV, the research indicated negative NPV values for all 100 kW plants, positive NPV for all 200 kW plants (with the exception of cattle substrates), and positive value for all the 300 kW plants. The IRR value seems to be low for investment in the plants. The study however shows an increase in the IRR value from small-scale to large-scale plants. This indicates the economy of scale as have been reported by various researches on the economy of bio-energy plants. A study on the techno-economic assessment of biogas plants in Japan reported that an optimal scenario of IRR within the range of 1.31% and a simple payback period of 26.9 years (Wang et al, 2021). Ruiz et al. (2020) reported IRR of 10.2%, this seems to be higher when compared with this study, the higher values however could be attributed to the inclusion of other revenue from the energy production process. Another study on the economic evaluation of Bio-based products from fruit trees and crops in Germany indicated negative values for NPV and IRR (Tabe-Ojong and Habiyaremye, 2017). This indicates that the substrate plays a major role in the profitability of the bioenergy project.

4.0 Conclusion

This study investigated the energy generation potential and economic viability of organic MSW using LGAs in Anambra state of Nigeria as a case study. The estimation of potential energy recovery from waste is critical in assessing the economic viability of the waste to energy project as well as the profitability of the project. This study applied Internal Rate of Return (IRR) and Net Present Value (NPV) economic indices to analyse the best bioenergy plant scale project for the various LGAs in Anambra State. The result of the study implies that a maximum waste generation potential of about 198 tons could be achieved in one of the LGAs, while the spatial model of the estimated energy potential (MW) indicates that a maximum value of 545MW could be produced in Aguata LGA. The study also shows that based on the quantity of organic MSW generated in the areas, 48 and 49 small-scale plants are required in Idemili North and Aguata LGAs respectively to successfully maximize the generated waste. The minimum numbers of plants ranging in the number of 3 to 12 are required for the medium installation of biogas plant for the study area. A large scale plant of about $50m^3$ can possibly be installed at all the LGAs, with a maximum of 4 plants in Idemili and Aguata LGAs. The economic assessment based on Net Present Value (NPV) criteria shows poor economic feasibility for small scale plant, while NPV was positive for medium and large scale plants. For the IRR, a low value of 0.32 to 0.94, with a general increase from small scale to large scale economic feasibility was observed.

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Appendix

Table 2: Population data for all the 21 LGAs

LGA	2005	2006	2007	2008	2009	2021
Aguata	424,037	436,037	448,377	461,066	474,114	645,135
Anambra East	85,618	88,041	90,533	93,095	95,730	130,261
Anambra West	161,214	165,776	170,468	175,293	180,253	245,273
Anaocha	296,499	304,890	313,519	322,391	331,515	451,098
Awka North	89,749	92,289	94,901	97,587	100,348	136,545
Awka South	193,123	198,589	204,208	209,988	215,930	293,819
Ayamelum	126,841	130,431	134,122	137,918	141,821	192,978
Dunukofia	101,204	105,068	107,013	110,041	113,156	153,973
Ekwusigo	131,796	135,525	139,361	143,305	147,360	200,515
Idemili North	411,836	423,491	435,475	447,800	460,272	626,300
Idemili South	183,454	188,645	193,984	199,474	205,119	279,109
Ihiala	265,435	272,946	280,671	288,613	296,781	403,835
Njikoka	107,818	110,870	114,007	117,234	120,551	164,035
Nnewi North	178,932	183,996	189,203	194,557	200,064	272,230
Nnewi South	217,900	224,067	230,408	236,928	243,634	331,517
Ogbaru	283,425	291,446	299,694	308,175	316,896	431,206
Onitsha North	179,071	184,139	189,351	194,709	200,219	272,441
Onitsha South	199,960	205,619	211,438	217,422	223,574	304,221
Orumba North	188,411	193,743	199,226	204,864	210,661	286,650
Orumba South	137,035	140,914	144,901	149,002	153,219	208,487
Oyi	162,464	167,063	171,790	176,652	181,651	247,175
Total	**4,125,822**	**4,243,585**	**4,362,650**	**4,486,114**	**4,612,868**	**6,276,815**

Source: https://www.nigerianstat.gov.ng/pdfuploads/Statistical%20Year%20Book%202010.pdf

Figures

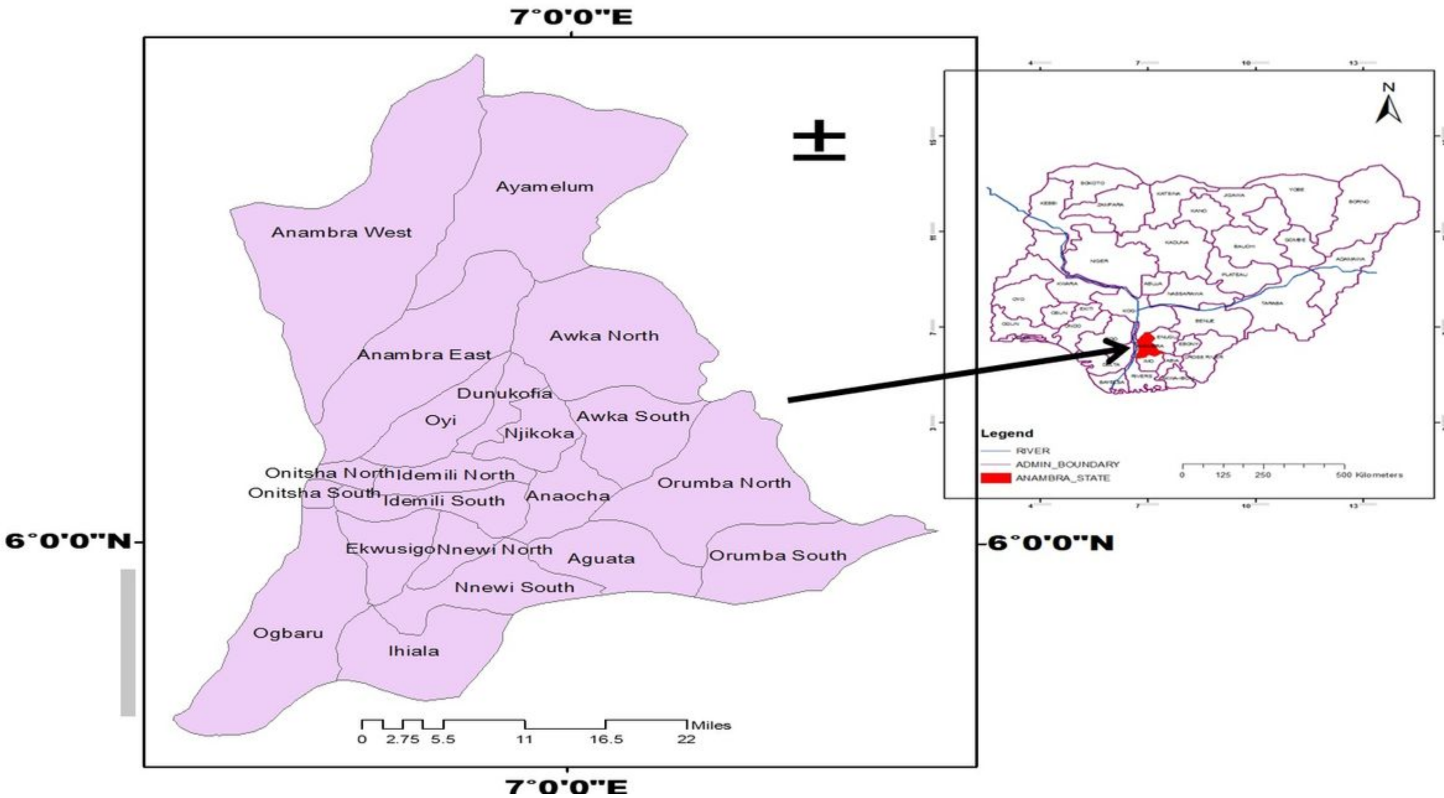

Figure 1

Map of Anambra State showing the LGAs of the State.

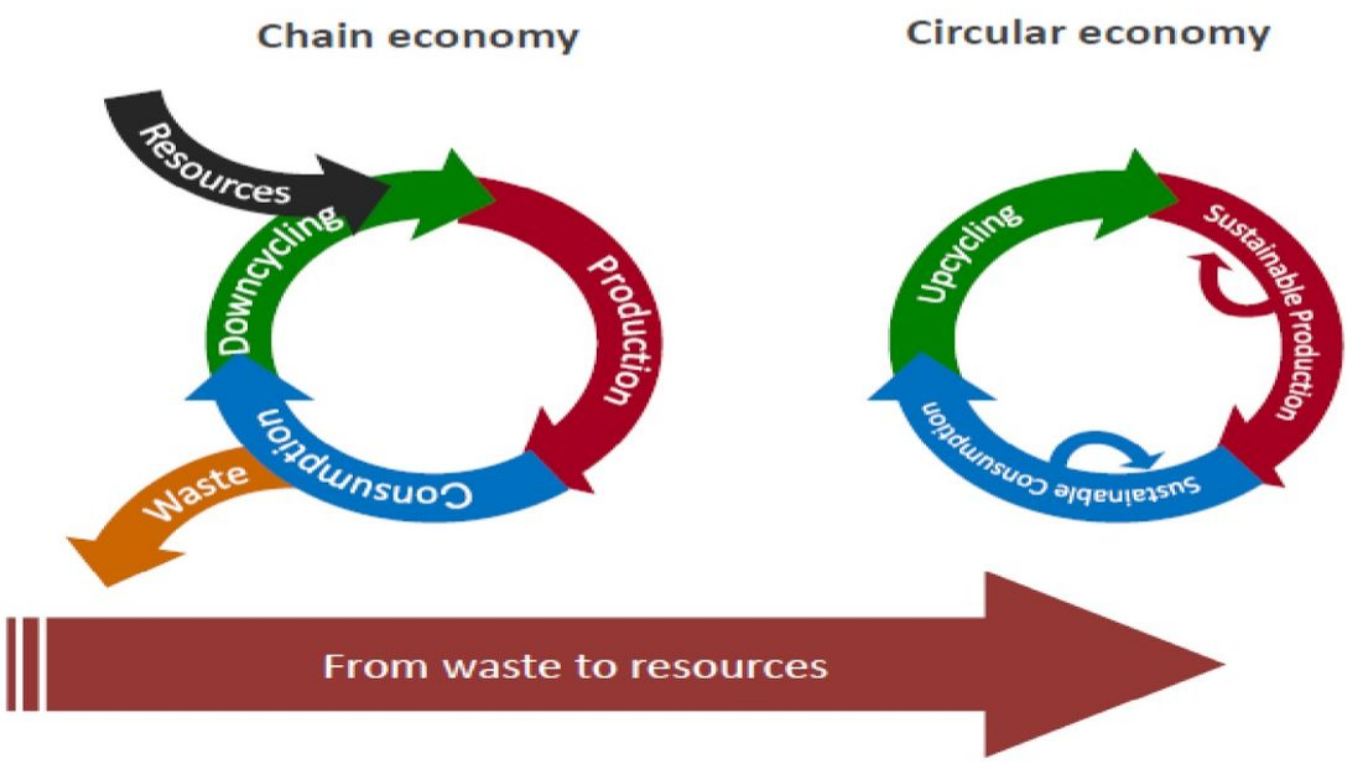

Figure 2

[Source: https://www.valueloops.eu/index.php/circular-economy-2/]

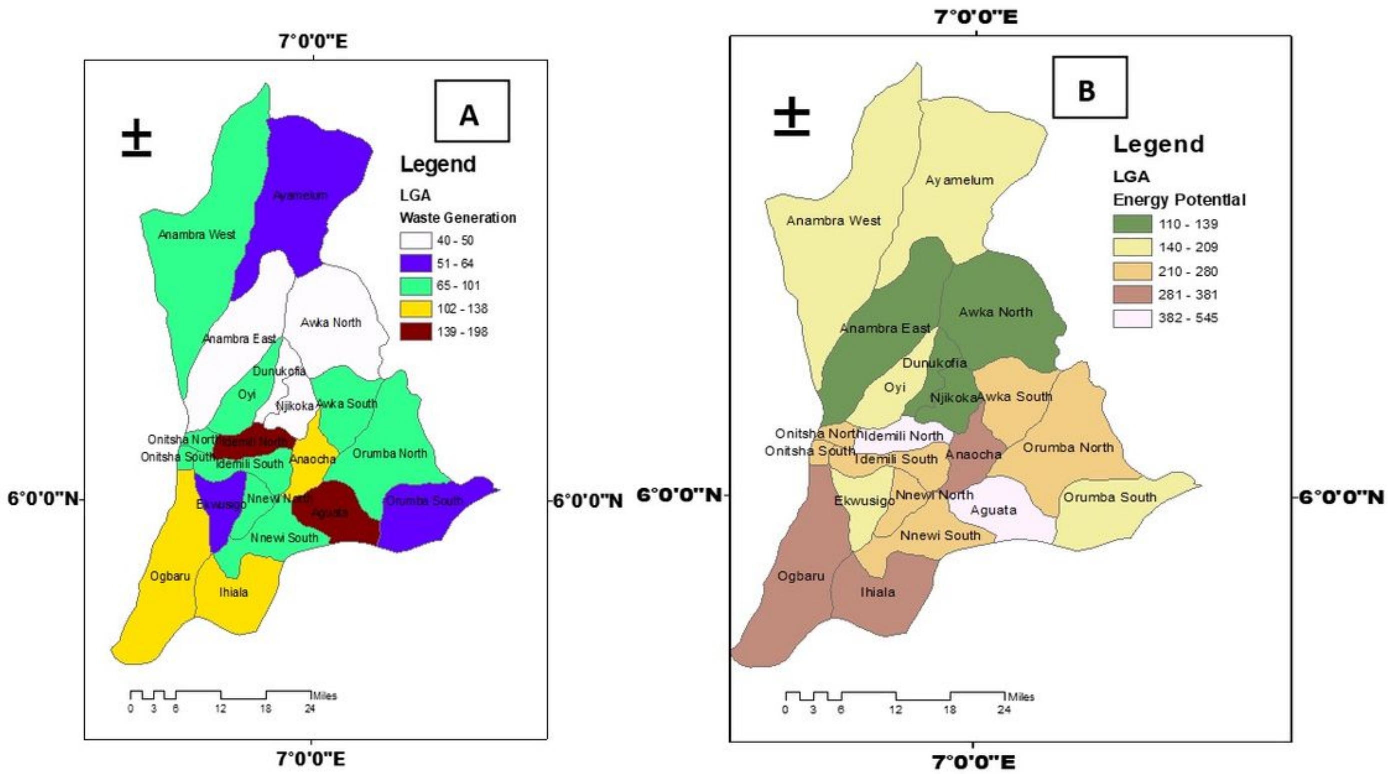

Figure 3

(A) Waste and (B) energy generation potential from Organic MSW for the LGAs

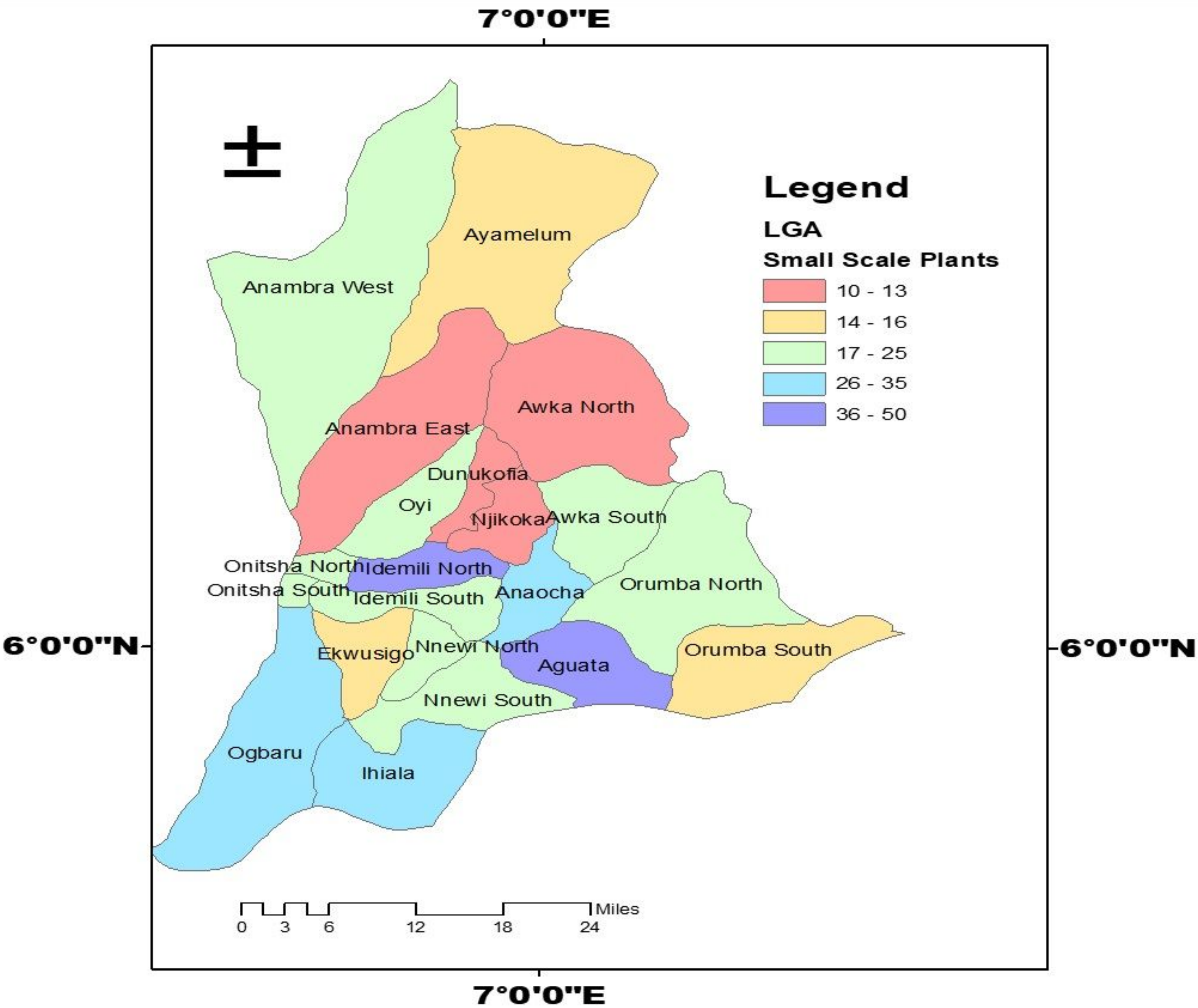

Figure 4

The number of small scale plants in the LGA

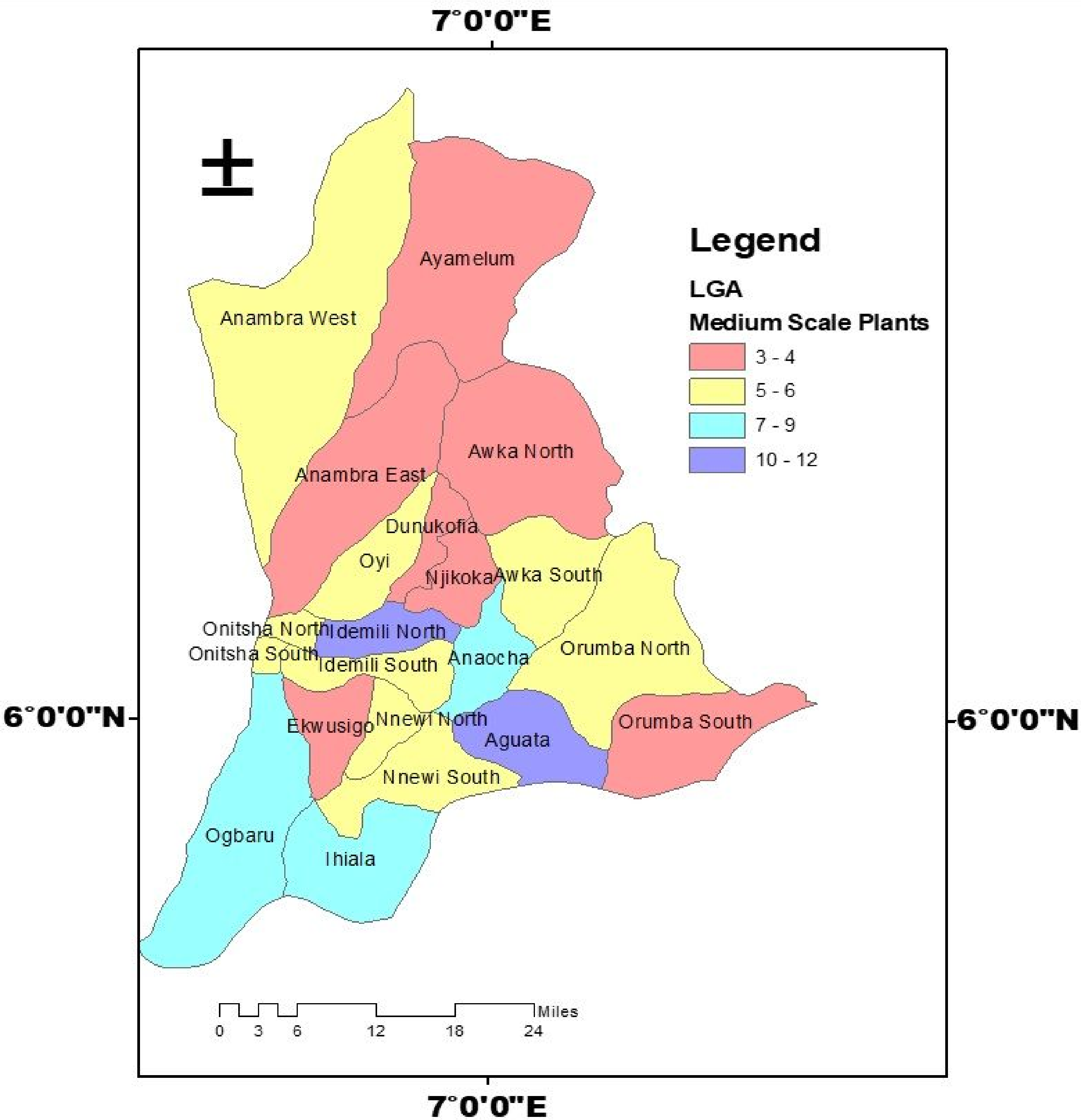

Figure 5

The number of Medium Scale Plants

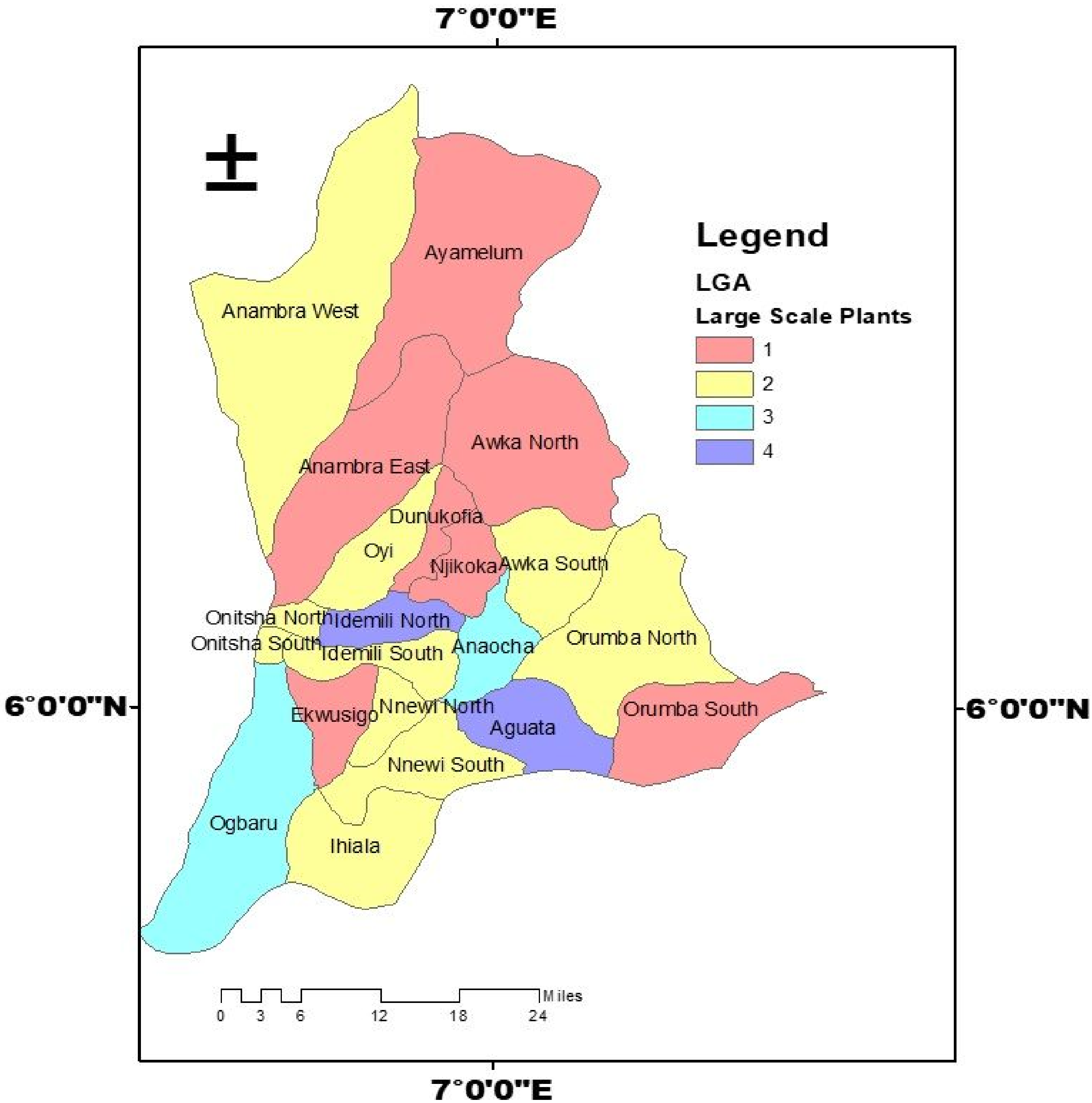

Figure 6

he Number of Large Scale Plants Estimation for the LGAs