Master's Thesis: Evaluation of bioenergy resources in Egypt: case study for biogas production

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Affidavit

I hereby declare that I am the sole author of this work; no assistance other than that permitted has been used and all quotes and concepts taken from unpublished sources, published literature or the internet in wording or in basic content have been identified by footnotes or with precise source citations.

Vienna, 15th May 2020 signature

Ahmed Moetaz

Abstract

Previous studies have shown that utilization of biogas as an energy source is an effective possibility for the reduction of greenhouse gas emissions compared to energy production from fossil resources, and the electricity and heat from biogas can contribute to the substitution of fossil fuel. This study aimed to estimate the bioenergy potential from available biomass in Egypt, furthermore, studying the techno-economic analysis and the optimum size of biogas system: a case study for selected region in Egypt. The quantitative assessment of biomass resources was achieved through the intensive literature surveys. The EcoGas tool has been used for designing a biogas plant in the selected region in Egypt (Behera), moreover, to evaluate and demonstrate the potential of optimization measures in terms of economic as well as environmental efficiency.

The results of evaluation of the bioenergy potential in Egypt showed that the total production of biomass from municipal solid wastes, agricultural residues and livestock manure estimated in 2017 at 135 million tonnes per annum and the availability dry biomass estimated in 2017 at 18 million tonnes per annum. The total bioenergy potential produced using biochemical conversion via anaerobic digestion in Egypt estimated at 103 PJ/year. This potential could cover 7% of the total electricity consumption, as well as the thermic energy that can be used for external needs.

The results of evaluation of the biogas plant in Behera using EcoGas showed that the annual methane production was 3.6 million Nm^3, the electric capacity of CHP for 8,100 hours/year of operation, was 1,009 kW_{el}, the total investment will be about 4 million € and the balance between the revenue and the costs is 648 thousand €/year. The total costs per kWh_{el} and per Nm^3 CH_4 are 0.08 € and 0.29 €, respectively. With equity capital 550 thousand €, The biogas plant shows profit after 5 years. The reduction of CO_2 emission for biogas plant calculated as 3,758 tonnes/year.

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List of Abbreviations

Abbreviation	Description
AD	Anaerobic digestion
A_f	Availability factor
$AR_{av(i)}$	Total available amount of dry agricultural residue production
$AR_{tot(i)}$	Total agricultural residue production
Bbl	Barrel of oil
CCGT	Combined-Cycle Gas Turbine.
CHP	Combined Heat and Power
CO_2	Carbon dioxide
CPI	Consumer Price Index.
DB	Dry biomass
DNI	Direct Normal Irradiance
EJ	Exajoules
$EP_{AR(i)}$	Energy potential of agricultural residues per governorate
$EP_{LV(i)}$	Energy potential of livestock manure
$EP_{MSW(i)}$	Energy potential of municipal solid wastes
$EP_{MSW(i)}$	Energy potential of municipal solid wastes
€	Euro
FC	Fixed carbon
FM	Fresh matter
GCV	Gross calorific value
GDP	Gross domestic product
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GHI	Global Horizontal Irradiance
GW	Giga watt
GWh	Gigawatt hour
HHV	Higher heating value
HRT	Hydraulic retention time
J	Joule
Km	Kilometres
km^2	Square kilometres
KW	Kilo watt
KW_{el}	Kilowatt electric
KWh	Kilowatt hour
kWh	Kilo watt hour
$LHV_{average}$	Lower heating value
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
$LVM_{av(i)}$	Total available amount of dry livestock manure production
$LVM_{tot(i)}$	Total amount of livestock manure production
LV_{prod}	Number of livestock per governorate
M	Meter
m^2	square meter
m^3	Cubic meter
MC	Moisture content

M_{head}	Manure production per head of each livestock category per year
MJ	Mega joule
MSW	Municipal solid wastes
$MSW_{av(i)}$	Total available amount of dry biomass from municipal solid wastes
$MSW_{prod(i)}$	Total amount of municipal solid wastes
$MSW_{tot(i)}$	Total amount of wet biomass from municipal solid wastes
Mtoe	Million tonnes of oil equivalent
MW	Mega watt
MWh	Megawatt hour
M_{yield}	Methane yield
NCV	Net calorific value
Nm^3	Normal cubic meter
NREA	New and Renewable Energy Authority
OCGT	Open-Cycle Gas Turbine
OLR	Organic loading rate
OM_{rate}	Organic matter rate
PJ	Peta joule
$P_{prod(i)}$	Total plant production
RE	Renewable energy
$RPr_{(i)}$	Residue to product ratio
S	Second
SRT	Sludge retention time
TJ	Tera joule
TPES	Total primary energy supply
TPES	total primary energy supply
UASB	Upflow anaerobic sludge blanket
USD	United States Dollar
VFA	volatile fatty acids
VM	Volatile matter
VS	Volatile solid
W	Watt
W_f	Dry weight factor

1 Introduction

1.1 Background and Problem Statements

Renewable energy RE is almost a clean and natural energy which is gathered from renewable resources. They are naturally renewed on a human timescale, such as wind, sunlight, heat, rain, tides and waves. These sources can increase the system overall efficiency and decrease the environment problem such as emissions that occur because of traditional power generation based on fossil fuels [1]. It aims to ameliorate energy security, mitigate changing of the climate and create new and many opportunities to promote economic development [2].

Even though the consumption of fossil fuels has led to fast economic growth in industrial societies but has also caused global warming and climate change through increasing carbon dioxide in the atmosphere. Renewable energy resources are playing a largely and an important function to supply the world with their future energy needs and consequently should substitute fossil fuels [3, 4].The world total energy consumption in year 2018 was 13,730 million tonnes of oil equivalent (Mtoe) about 80% from fossil fuels and 20% from renewable energy resources with an increase rate 2.3% compared to year 2016 [5].

The modern renewable energy without traditional biomass contributed an estimated at 10.4% to total final energy consumption in 2017 with an increase rate 5.4% to 2016 and traditional biomass use for cooking and heating has been estimated at 7.8% with an increase rate 0.2%. the global new investment in renewable energy has been estimated at USD 279.8 billion in 2017, with an increase of 2% compared to 2016. The renewable energy sector employed 10.3 million people in 2017 with an increase rate 5.3% to 2016 [6].

Biomass appears an essential resource of renewable energy, it contains many various fuels with various chemical synthesis and burning properties [7]. Furthermore, biomass is an important alternative fuel to fossil fuels consumption. Theoretically, it has the potential to cover the global energy needs [3].

Bioenergy is almost a safe, vital, clean and authoritative resource of energy, it can be acquired from diversity of raw materials [8]. The global biomass contributed an estimated at 146 billion metric tonnes to global production. The global bioenergy from biomass contributed an estimated 13% (46.4 exajoules (EJ)) to total final energy consumption and power capacity 122 GW in 2017 [6].

Egypt is the largest oil and gas consumer on the African continent, with a daily production of 588 000 barrels. As of end-2014 stood at about 3.4 billion bbl were in the form of crude oil and about 11.4 billion as natural gas [9].

The Egyptian total primary energy supply according to utilization natural gas, oil, oil products and hydro, along with wind and solar, in 2016 with total production of 86.2 million tonnes of oil equivalent (Mtoe) and 44.8 Mtoe from natural gas 52% [10, 11]. The total electrical energy production and consumption amounted to 183.5 and 159.7 TWh, while imports and exports of electrical energy amounted to 0.54 and 1.16 TWh [12].

The Egyptian population is expected to reach 110 and 128 million by 2031 and 2051 respectively, according to the Cairo Demographic Centre. This fast population growth rate along with other environmental challenges is overriding the limited energy resources of the country [13, 14]. The growth of population leads to an increased request for energy which also support industrial development be content with the lifestyle's development and technological needs [15].

Due to its location, topography and climate, Egypt has vast potential of renewable energy resources such as wind, solar and biomass [16, 17].

The total energy generated from hydro-power plant has been estimated in 2018, at 12.7 TWh [18].

The Egyptian wastes has been estimated in 2016, at 90.76 million tonnes/year. About 80% of these wastes has been disposed in public and random landfill [19]. The most common method to dispose of agricultural residues is open burning directly in the fields, about 52%. Egypt contributed an estimated 0.57% to the global greenhouse gas (GHG), therefore Egypt is one of the eleven fastest growing countries in the world in greenhouse gas emissions (GHG) [20, 21]. The carbon dioxide (CO_2) emissions has been increasing in the year 2017 accounted for 217.3 million tonnes CO_2 equivalent with an increase rate 32% compared to 2006. The energy sector accounted for 59.4% to greenhouse gas emissions [9, 19].

The renewable energy (wind, solar) in Egypt has grown at an average annual rate of 30.4%. The total national hydro capacity has been estimated in 2018, at 2.83 GW, with an increasing 1.1% compared to year 2017. Egypt has the potential to supply 53% of its electricity mix from renewables (wind, solar and hydro) by 2030. With a reduction in total energy costs of USD 900 million annually in 2030.

The renewable energy targets according to the Egyptian government strategy to achieve 20% renewable energy (wind 12%, hydro 6% and solar 2%) by 2020 and 42% (solar 25%, wind 14% and hydro 2%) by 2035.

The Egyptian government strategy to access their policies:

- Private level, governmental directives encourage the Build, Own and Operate system.
- On the governmental level, the New and Renewable Energy Authority (NREA) fulfilled some projects for wind farms, PV plans and hydro-power plant [22, 23].
- In 2015, plans to build a 2 400 MW pumped storage hydroelectric plant in Attaqa were initiated, due for completion in 2022 [22, 23].

Although Egypt has vast potential biomass, more recent studies have argued for solar and wind energy and few studies have argued for bioenergy [20]. However, biomass–based electricity production also offers an opportunity to give added value to biomass residues, participating in the renewable energy matrix. Therefore, it's important to increase interesting in bioenergy to reducing GHG emissions; better management of residues; mitigation environmental impacts; biodiversity; restoration of degraded lands; long-term security of energy supplies; producing electricity; supplying employment opportunities and reduce costs and increase conversion efficiencies [24]. In this study, anaerobic digestion used as the main method to convert biomass into energy and to compare the results, the potential bioenergy using incineration has been analysed.

1.2 Research Objectives

According to conclude the above-mentioned researches and results from different research, this study purpose to beat the above-mentioned sectoral focus on solar and wind in Egypt. Therefore, it is important to increase the interest in bioenergy. This leads to many benefits like better management of residues, mitigation of climate change, healthier environmental benefits with decreasing the emissions, promising a new, diverse and clean term of energy with a reduction in total energy costs and supplying many employment opportunities [25, 26].

The specific objectives are as follows:

- Evaluation of potential biomass from production and availability of residues for each residues type (municipal solid waste, agricultural residues and livestock manure): estimation of the total quantity of residues generated as a result of type production at governorate level and displayed the results in a geographic map by ArcGIS Desktop 10.6.1 Software[1].

- Evaluation of potential bioenergy from potential availability of dry biomass for all residue's types: estimation of the total bioenergy that could actually be accessed from potential biomass at governorate level and displayed the results in a geographic map by ArcGIS Desktop 10.6.1 Software.

- Simulation, dimensioning and performance the economic analysis of the case study biogas plant for treatment of biomass from one governorate in Egypt by EcoGas (Version 07-E1) Software[2].

[1] ArcGIS is a geographic information system (GIS) for working with m.aps and geographic information maintained by Esri.

[2] EcoGas (Version 07-E1) Software, which has been developed in BOKU – Vienna – is part of a comprehensive and inclusive toolkit comprising technological, economic, social, environmental and cultural dimensions of development. This software uses powerful search algorithms to identify potential trade-offs among factors such as cost, performance and reliability.

2 Fundamentals

2.1 Biomass

Biomass is a complex organic biological solid which is derived from living or deceased and naturally occurring organisms [27, 28]. All of the earth's total biomass exists in a tiny fraction on the earth's surface, the biosphere. This biomass stores an enormous potential of chemical energy which is continuously replenished by the sun's energy through photosynthesis, of which the energy content exceeds two to five times the world's total primary energy supply (TPES) [27]. Photosynthesis typically converts less than 1% of the energy from sunlight into chemical energy used for biomass building blocks. When the chemical energy stored in biomass is released through either biological or chemical processes, CO_2 and water is formed, thereby making the process cyclical because the CO_2 is now available for uptake in new biomass [29].

The process for photosynthesis is represented by the chemical equation [27]:

$$6CO_2 + 6H_2O + \text{Light Energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

2.1.1 Biomass Classifications

Two classification methods based on biomass properties and origin are generally scientifically considered. The first is one in which biomass can be divided into four primary classes [30]:

1. Primary residues: these are the byproducts of agricultural crops and products of forestry namely straw, wood, cereals, maize, etc.
2. Secondary residues: these are the byproducts of biomass during the processing of food products or materials from biomass namely industries from food and beverages, paper and sawmills, and fruit seeds, etc.
3. Tertiary residues: there are the byproducts of discarded biomass commodities namely, construction waste and demolition plywood, etc.
4. Energy crops: these are products grown for the purpose of biofuel production.

A second classification is based on biomass physical properties [27, 31]:

1. Woody fuels: hard and softwood, demolition wood.
2. Herbaceous fuels: grasses, straws, and stalks, etc.
3. Wastes: refuse-derived fuels (municipal and industrial wastes), sewage sludge etc.
4. Derivatives: waste from food and paper industry, etc.
5. Aquatic: kelp, etc.
6. Energy crops: especially cultivated for energy.

A further, recent classification system is the “European Standards for Fuel Specification and Classes of Solid Biofuels” (CEN TC 335) based on the origin and source of biofuel [32]:

1. Wood biomass: pellets, sawdust, logs, wood chips, etc.
2. Herbaceous biomass.
3. Fruit biomass.
4. Blends and mixtures biomass.

Most of the world's biomass is found in the first two categories; woody forested areas and a variety of agricultural crops and application of these two are typically the most used for energy production throughout the world, and therefore are a more significant focus of research [28]. Biomass derived from the other wastes also have potential; however, these are not the focus of this study.

2.1.2 Biomass Characteristics

Selection of biomass for energy production is dependent on its physical and chemical properties, which can vary significantly depending on biomass. Subsequent selection of the conversion process is also dependent on the feedstock properties. Several important chemical and physical properties are the [29, 33, 34]:

- Carbohydrate and Elemental content
- Cellulose to Lignin ratio
- Calorific value (CV)
- Fixed carbons (FC) and volatiles proportions (VM)
- Moisture content (MC)
- Alkali metal content
- Ash/Residue Content
- Bulk Density

2.1.2.1 Carbohydrate and Elemental content

The elemental content is an ultimate analysis of biomass and it is done based on ASTM D5373. The samples are combusted at high temperature (~1000 °C) in a furnace (oxidation), and the resulting products (CO2, H2O, N2, and SO2) are separated and analyzed by a thermal conductivity detector (TCD) [35].

2.1.2.2 Cellulose to Lignin Ratio

Structurally vital components of woody biomass which have high molar masses are oligomers and carbohydrate based long chain polymers, or polysaccharides, which make up 65 - 75% of chemical structure as well as lignin which makes up 18 - 35% of chemical structure.

2.1.2.3 Calorific Value

The calorific, or heating, value of a substance is a measurement of the energy content released through combustion. The energy content per unit measurement is expressed by MJ kg^{-1} for solids, MJ l^{-1} for liquids, and MJ/m^3 for gases [29]. Fuels are usually quoted with two varying calorific values which give their heat output when combusted, the lower heating value (LHV), also called the net calorific value (NCV), and the higher heating value (HHV), also called the gross calorific value (GCV). Biomass, coal, oil, and industrial wastes are normally given an LHV, which assumes that the produced water vapor is uncondensed. However, in the case that water vapor is condensed, then the HHV is more appropriate. For coal and oil, the difference between HHV and LHV is negligible; however, in the case of natural gas, the difference can exceed 10% [27]. When providing a heating value, the moisture content (MC) should also be provided as any moisture present proportionally reduces the energy content [29]. Generally, an increase of 10% MC reduces the LHV by about 11%. Condensation of all the H_2O in biomass can increase the output of heat by 50% or more [27]. Raw biomass feedstock typically has roughly half the calorific value of lignite or bituminous coal.

2.1.2.4 Fixed Carbons and Volatiles Proportions

Chemical energy is primarily stored in two forms, in volatile matter VM and fixed carbon (FC). The VM is measured as the portion of feedstock which is released as gas, including moisture, at a temperature of 950°C and a residence time of 7 minutes as outlined in the ASTM International (ASTM) standard E872-82 [29, 36]. The FC is the mass which remains after the release of volatiles, excluding MC and ash. The VM, ash, and MC in the biomass are determined in laboratory tests while the FC is calculated by difference during the proximate analysis. Biomass with high VM has a lower calorific value, and, therefore, a low VM is more desirable. Alternatively, biomass with high FC has a higher calorific value and is of better quality (SVCE 2010).

2.1.2.5 Moisture Content (MC)

One of the major obstacles to widespread adoption of lignocellulosic biomass for thermochemical conversion is its high MC. Moisture present during thermochemical processes has a detrimental effect due to the high energy needed during the process of vaporization. This may lead to a decrease in process temperature and depression of the product calorific value. In general, feedstocks undergoing thermal conversion require low MC, usually under 50%; otherwise, the conversion processes energy balance is negatively affected. This is the main reason dry woody and herbaceous plants with low MC are the most widely used feedstocks for thermal conversion to fuels [29]. The MC affects biomass decay rate, so drier biomass can be stored for a longer length of time whereas wet biomass will decay quickly [27].

2.1.2.6 Alkali metal content

The alkali metal content of biomass i.e. Na, K, Mg, P and Ca, is especially important for any thermo-chemical conversion processes [29].

2.1.2.7 Ash/Residue Content

Ash is the solid residue after full oxidation of a biomass fuel. Ash is the mass which remains after release of volatiles, MC and FC. The ash content of biomass affects both the handling and processing costs of the overall, biomass energy conversion cost [29].

2.1.2.8 Bulk density

The bulk density of a material is its mass per unit bulk volume. Most agricultural residues have low bulk densities, that leads to complicate their processing, transportation, storage and firing [34].

2.2 Anaerobic digestion treatments

The aim of this chapter is to describe the anaerobic digestion process, the reasons for selection of this treatment, its requirements and problems for biomass treatment, its products and the technology used.

2.2.1 Why anaerobic digestion?

Alongside the environmentally friendly benefits of anaerobic digestion technology such as reduced greenhouse gas emissions, mitigation of global warming and reduced pollution potential in wastewater, the anaerobic digestion has relatively inexpensive and simple reactor designs and operating procedures. The utilization of anaerobic digestion for biogas production is a promising option for a renewable and sustainable energy source. Furthermore, biogas sludge can be used as fertilizer on arable land can provide nitrogen, phosphor, and other valuable nutrients to agricultural production, or for recovery of degraded lands, as well as for the reclamation of polluted soil. This recycling of nutrients is regular with development of a circular economy and sustaining soil organic carbon concentrations. In addition to the above, AD provides socioeconomic benefits for the society as a whole as well as for the involved farmers, such as waste management, job creation, low water inputs, and additional income for the farmers involved [26, 37-39].

2.2.2 Anaerobic digestion process

Anaerobic digestion (AD) is a sequence of processes used for treatment of organic matter by micro-organisms in the absence of oxygen for biogas production. It can be used to treat different wastes such as agricultural waste, animal manure, landfill sites or sewage treatment plants. Biogas is a combustible gas and consists of methane (50-70%), carbon dioxide (30-50%) and trace elements like nitrogen and hydrogen sulphide [40]. The AD process of complex of organic matter divided into four stages or reactions with specific microorganisms each: hydrolysis, acidogenesis, acetogenesis and methanogenesis as shows in Figure 2-1. The four reactions take place at the same time[41].

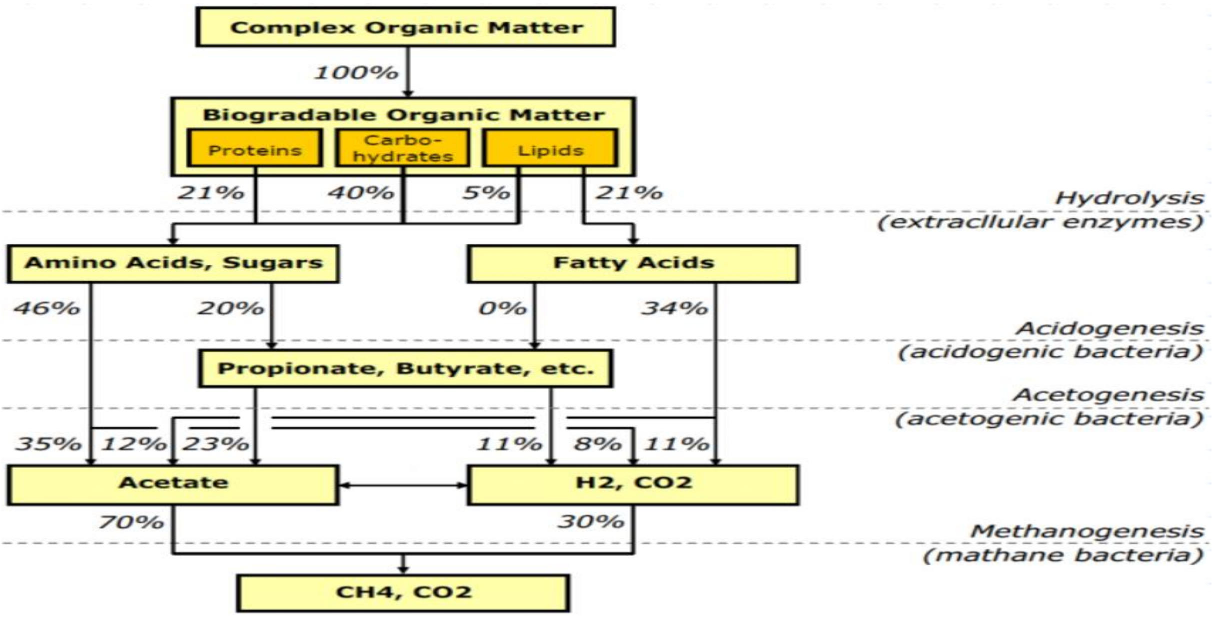

Figure 2-1: Different stages of anaerobic digestion [40]

2.2.2.1 Hydrolysis

This process is carried out by bacteria, where the complex polymeric matter (insoluble), such as cellulose, is hydrolysed to monomer (soluble molecules), such as sugars amino acids, and fatty acids, by extracellular enzymes, so the bacteria can use it. The time for this reaction depends on the characteristics of the substrate [42].

2.2.2.2 Acidogenesis

Acidogenic bacteria ferment and transform the products of the hydrolysis stage into carbon dioxide, hydrogen, ammonia, and organic acids. Acetic acid, propionic acid, butyric acid, and ethanol are the main products for this stage. In a balanced system, the most of organic matter is converted into acetate, hydrogen, and carbon dioxide, that facilely available for methanogenic microbes, but approximately 30% of organic matter is transformed into short chain fatty acids or alcohols [42].

2.2.2.3 Acetogenesis

The part of organic matter, that is transformed into short chain fatty acids or alcohols in the acidogenesis stage, converted in this stage into acetate, hydrogen, and carbon dioxide by acetogenesis bacteria [42].

2.2.2.4 Methanogenesis

The last stage of AD, where the methane is produced by bacteria in two ways: either from acetates, where acetic acid cleavage to generate carbon dioxide and methane (70% of total methane production) or carbon dioxide and hydrogen reduced (30%) [42]. This reaction is the slowest in the whole AD process [41].

2.3 Bioenergy in Egypt

2.3.1 Geography and Climate in Egypt

The Arab Republic of Egypt located in the north-eastern of Africa and south-western of Asia. Egypt is the world's 31st-largest country with an area of over 1 million square kilometres (km^2). Approximately 95% of the population lives within 20 km concentrated along the narrow Nile Valley and Delta [22, 43]. It is meaning that about 98% of Egyptians live on 3% of the territory [44]. It is bordered by the Mediterranean Sea to the north, the Red Sea to the east, Sudan to the south and Libya to the west, and is therefore at the crossroads between Europe, the Middle East, Asia and Africa. The population exceeded 97 million inhabitants with median age 23.9 (male: 23.6 years and female: 24.2 years) (2017), with those aged between 15 and 29 years represent 27% of the population. Egypt is the most populous country in North Africa and the Arab region and the 14th most populous in the world. The population growth rate 2.45% (2017), it occupies 22nd-ranked worldwide. Egypt lies primarily between latitudes 22° and 32°N, and longitudes 25° and 35°E. With climate desert, hot, dry summers with moderate winters [22, 43]. The gross domestic product (GDP) depends in the services, industrial and agricultural sectors. The unemployment rate reached 12% in mid-2016. The total population lived in 2015 below the national poverty line is 28% [45].

Egypt is divided into 27 governorates and 5 regions. Figure 2-2 shows a map of Egypt with the respective governorates and regions, while Table 2-1 lists these [46].

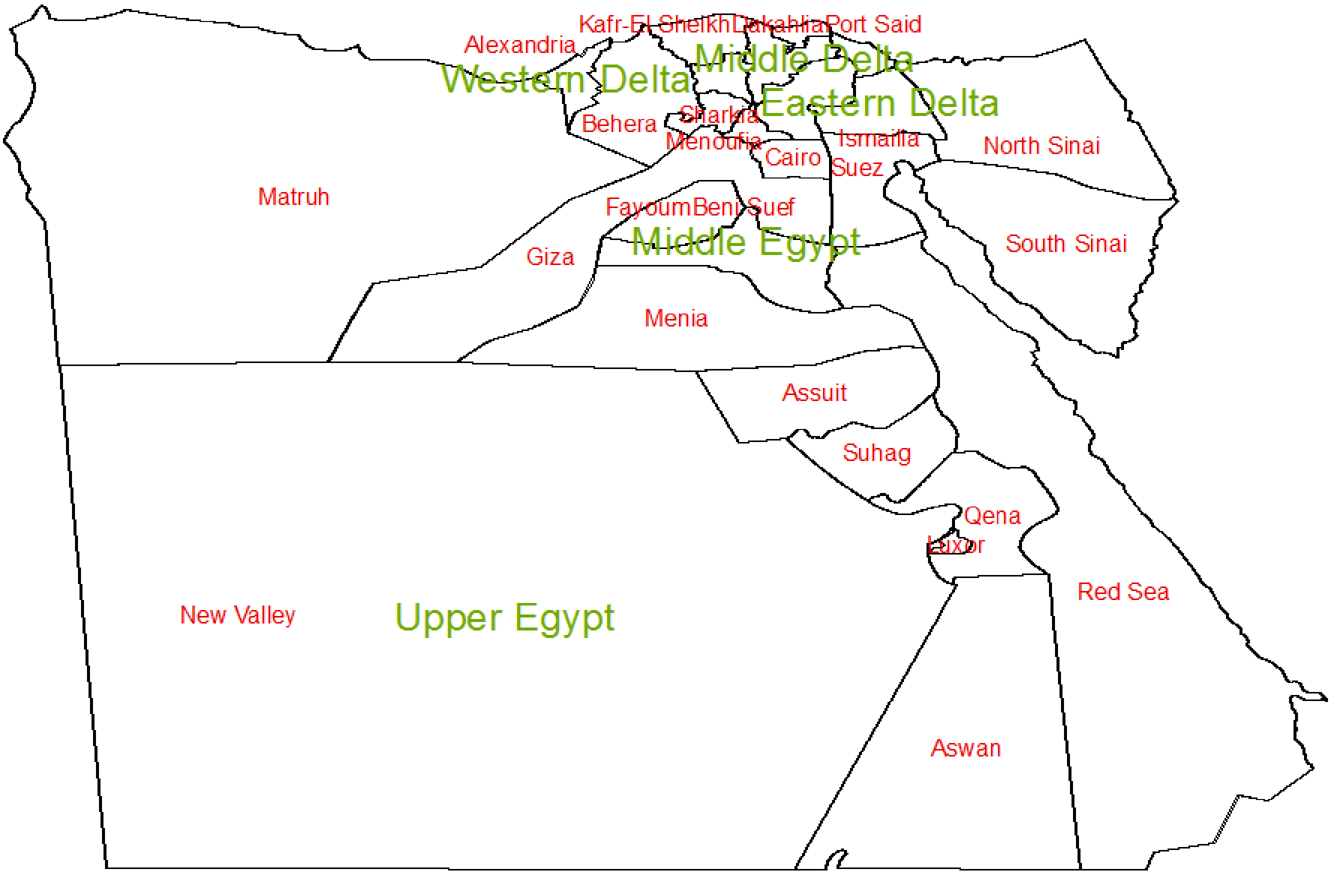

Figure 2-2: ArcGis map of Egypt: Governorates and regions [44]

Table 2-1: Regions and governorates in Egypt [46]

Region	Governorate
Middle Delta	Gharbia
	Kafr-El Sheikh
	Dakahlia
	Damietta
	Menoufia
	Qalyoubia
Eastern Delta	Sharkia
	Ismailia
	Port Said
	Suez
	North Sinai
	South Sinai
Western Delta	Alexandria
	Behera
	Matruh
Middle Egypt	Cairo
	Giza
	Beni Suef
	Fayoum
	Menia
	Assuit
Upper Egypt	Suhag
	Qena
	Luxor
	Aswan
	New Valley
	Red Sea

The sustainable development strategy: ‘‘Egypt Vision 2030’’ was declared from the ministry of planning. The real growth of the gross domestic product (GDP) exceeded 4% by 2016 and will be reached at 10% and 12% by 2020 and 2030 respectively. The GDP depends in the services, industrial and agricultural sectors, with their respective contributions of 55%, 33% and 12%, and therefore Egypt is a lower-middle income country. The energy sector was shared of GDP at 13% by 2016 and expect to reach at 20% by 2020 and 25% by 2030. The renewable was shared in primary energy and electricity production at 1% for both and expect to reach at 8% and 21% by 2020 and 12% and 32.5% by 2030, as depicted in Table 2-2. The unemployment rate reached 12% in mid-2016 up from a 9% unemployment rate prior to 2011, the total population lived below the national poverty line is 28% in 2015, with an even higher rate of 60% recorded in Upper Egypt [22, 47].

Table 2-2: Development indicators of Egypt's Vision 2030 [47]

Targeted development indicators	2016	2020	2030
GDP real growth (%)	4.2	10	12
GDP per capita (USD)	3436	4000	10000
Inflation rate (CPI, annual %)	11.8	8	5.3
Industrial development rate (%)	5	8	10
Industry share of GDP (%)	12.5	15	18
Energy sector share of GDP (%)	13.1	20	25
Renewables' share in primary energy (%)	1	8	12
Renewables in electricity production (%)	1	21	32.5
Women in workforce (%)	22.8	25	35
Unemployment rate (%)	12.8	10	5
Poverty rate (%)	26.3	23	15
Acute poverty (%)	4.4	2.5	0

GDP: Gross Domestic Product; USD: United States Dollar; CPI = Consumer Price Index.

2.3.2 Energy Resources

Egypt is the Africa's 5th-oil-producing with a daily production of 588 000 barrels. The Egyptian resource endowments of fossil fuel energy including oil, natural gas and negligible amounts of low-quality coal are limited. As of end-2014 stood at about 3.4 billion bbl were in the form of crude oil and about 11.4 billion as natural gas [9].

Due to its location, topography and climate, Egypt has vast potential of renewable energy resources such as wind, solar and biomass [16, 17].

The solar atlas of Egypt indicates that, Global Horizontal Irradiance (GHI) has a maximal value in summer around 350 W/m^2 and in winter months around 180 W/m^{2}and Direct Normal Irradiance (DNI) between 250 to 380 W/m^2 with an average annual rate for solar radiation between 2,000 to 3,200 kWh/m^2/year [17].

According to the wind atlas of Egypt, the average wind speeds in the Gulf of Suez region override 10.5 m/s at a height of 50 m which could host up to 20000 MW installed wind farm capacity. In the east and west of the Nile region has an average wind speed around 7.5 m/s at a height of 80 m [16, 48].

The total energy generated from hydro-power plant has been estimated in 2018, at 12.7 TWh, accounting for 6.5% from the total production [18].

The Egyptian wastes has been estimated in 2016, at 90.76 million tonnes/year with an increase rate of 3.7% compared to the year 2015. About 80% of these wastes has been disposed in public and random landfill. The municipal solid waste per capita in Egypt has been estimated at 0.6 kg/person/day [19]. Egypt has vast potential of biomass resources. The quantity has been estimated at 40 million tonnes/year [4]. The Egyptian agricultural residues contributed an estimated 31 million tonnes/year. About 5 million tonnes/year of agricultural residues is available for bioenergy production [49].

The renewable energy targets according to the Egyptian government strategy to achieve 20% renewable energy (wind 12%, hydro 6% and solar 2%) by 2020 and 42% (solar 25%, wind 14% and hydro 2%) by 2035.

The renewable energy (wind and solar) in Egypt has grown at an average annual rate of 30.4% (750-965 MW) from 2017 to 2018. The total national hydro capacity has been estimated in 2018, at 2.83 GW, with an increasing 1.1% compared to year 2017. Based on this REmap analysis, Egypt has the potential to supply 53% of its electricity mix from renewables (wind, solar and hydro) by 2030. the Egyptian government policies of energy mobilizes action towards achieving producing 20% renewable energy (wind 12%, hydro 6% and solar 2%) by 2020 and 42% (solar 25%, wind 14% and hydro 2%) by 2035, up from just 5% overall in 2014 from renewable resources particularly from solar and wind power with current funding 2,5 billion/year to prospective funding 6.5 billion/year, with a reduction in total energy costs of USD 900 million annually in 2030 [22, 23].

The Egyptian government strategy to access their policies:

- On the private level, the governmental directives encourage the Build, Own and Operate system and the reverse auctions and offered very competitive prices for the electricity generated from wind and solar. the New and Renewable Energy Authority (NREA) promote the local, national and international discuses to development renewable energy projects [22, 23]
- On the governmental level, the New and Renewable Energy Authority (NREA) fulfilled some projects for wind farms and PV and plans to fulfil anthers projects with respective measurement, current installed capacities +1000 and +300 MW, 370 and +2000 MW under construction, 700 and 770 MW under development and 1270 and 500 MW planned. Establishment laboratory for the testing not only PV testing but also testing the household appliances [22, 23].
- In 2015, plans to build a 2 400 MW pumped storage hydroelectric plant in Attaqa were initiated, due for completion in 2022 [22, 23].

2.3.3 Energy consumption

Egypt is the largest oil and gas consumer in Africa continent. The Egyptian total primary energy supply according to utilization natural gas, oil, oil products and hydro, along with wind and solar, in 2016 with total production of 86.2 million tonnes of oil equivalent (Mtoe) and 44.8 Mtoe from natural gas 52% , 24.3 Mtoe oil ((including crude, liquefied natural gas [LNG] and feedstocks) accounted for 28% of TPES and with13.6 Mtoe accounted for 16% of TPES oil products, composed of liquefied petroleum gas (LPG) and kerosene for heating and cooking, diesel oil and gasoline for transport. Figure 2-3 shows the total primary energy supply in Egypt from the period 1990 to 2016 [10, 11]

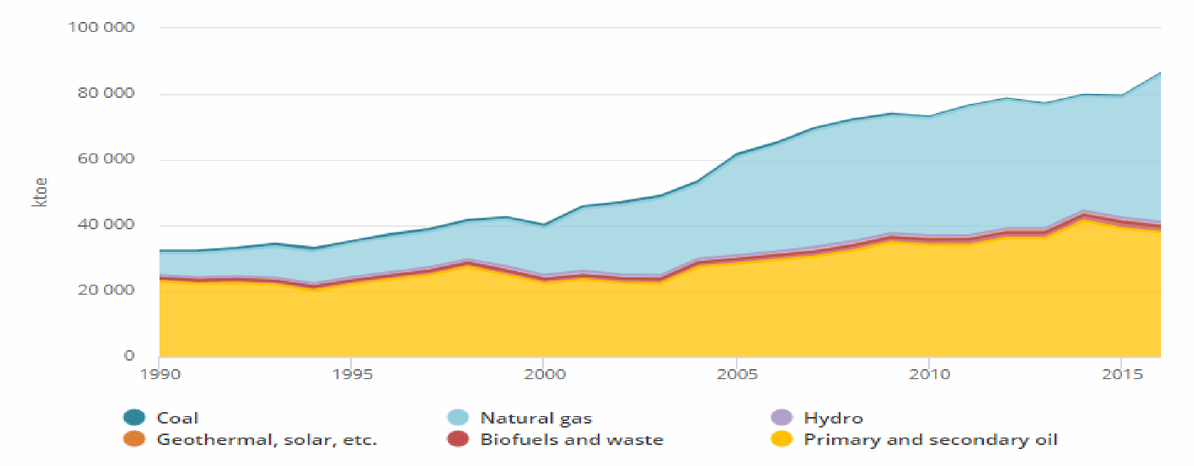

Figure 2-3: Total Primary Energy Supply by source Egypt (1990 – 2016)[11]

In 2015, with respective contributions of 92%, 7,5% and 1% accounted for natural gas and dual-fuel plants to electricity production, therefore, to recompense for increased local demand and insufficient production of crude oil and oil products, total petroleum imports have been rising, reaching 90.44 million bbl with a value of USD 11 billion in 2012/13, and USD 13.2 billion in 2014 [22].

The total electrical installed capacity in the year 2018 amounted to 55.2 GW with an increase rate 22.4% compared to the year 2017 amounted to 45.1 GW, include hydro (2.8 GW), thermal affiliated companies and Siemens (49.2 GW), new and renewables (1.2 GW) and private sector BOOT's (Thermal) (2.05 GW). Peak load was recorded at 30.8 GW in 2018, as depicted in Figure 2-4 and Table 2-3 [11, 18]. The total electrical energy production and consumption amounted to 183.5 and 159.7 TWh, while imports and exports of electrical energy amounted to 0.54 and 1.16 TWh [12].

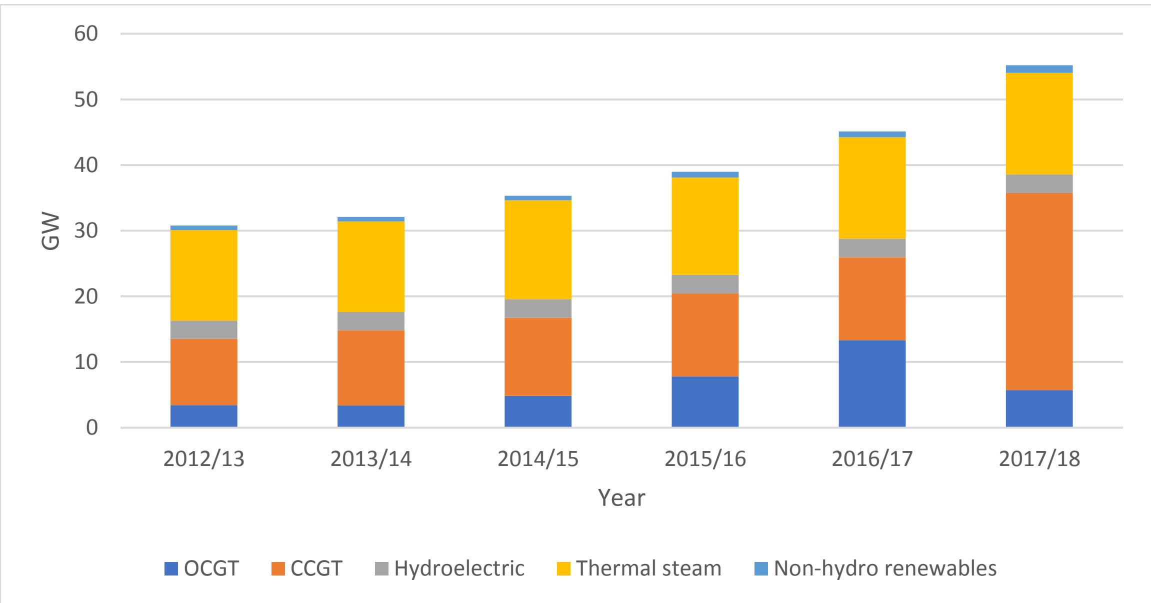

Figure 2-4: Capacity of electrical power plants MW [48]

Table 2-3: Installed capacity of electrical power plants by plant type [18]

Type	Capacity of power plants MW					
	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18
OCGT	3428	3415	4874	7845	13345	5745
CCGT	10080	11433	11880	12630	12630	30030
Hydroelectric	2800	2800	2800	2800	2800	2832
Thermal steam	13808	13783	15082	14798	15449	15449
Non-hydro renewables	687	687	687	887	887	1157
Total	30803	32118	35323	38960	45111	55213

MW: Mega Watt; OCGT: Open-Cycle Gas Turbine; CCGT: Combined-Cycle Gas Turbine.

The cylinders filled with Liquefied Petroleum Gas (LPG) is the most common method for cooking for more than 75% of Egyptian households. Although the LPG price has a governmental subsidization of 95 percent, but this is still a costly basic household item.

2.3.4 Biomass potential:

The Egyptian wastes has been estimated in 2016, at 90.76 million tonnes/year, with an average rate of increase 3% from the period 2004 to 2016, as depicted in Table 2-4, include Agricultural residues, Waterway cleaning waste, Municipal solid waste, Construction and demolition waste, Industrial waste, sewage sludge and hazardous wastes, with respective contributions of 34%, 28%, 23%, 6%, 5%, 2% and 2%, as depicted in Figure 2-5 [19].

Table 2-4: Residues Type and Quantity (2004-2016)[19]

Residues Type	Quantity million tonnes				Average Rate of Increase %
	2004	2014	2015	2016	
Municipal solid waste	14.5	20	20.17	21	4%
Agricultural residues	23	25.2	30	31	3%
Construction and demolition	3.5	3.9	4	5.8	6%
Industrial waste	4.25	5.5	6	4.9	5%
Hazardous wastes	0.12	0.528	0.53	1.06	65%
Sewage sludge	1.5	1.6	2	2	3%
Waterway cleaning waste	20	21	25	25	2%
Total	66.87	77.8	87.7	90.76	3%

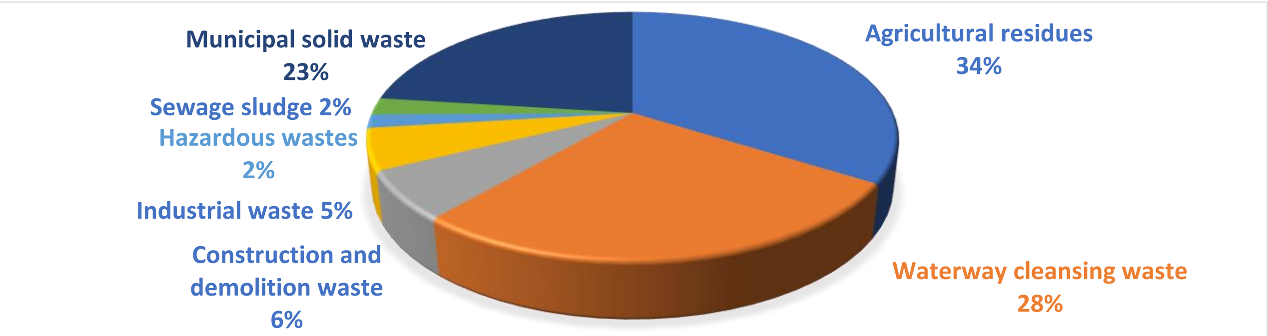

Figure 2-5: Residues Type in Egypt 2016 [18]

3 Wastes and agricultural residues as sustainable renewable biomass resources for Egypt

The main aim of the natural resources evaluation within this study is to estimate the potential of municipal solid waste, the potential of agricultural residues and the potential of livestock manure to calculate the biomass potential for energy production at governorate level.

3.1 Data collection process

Data for the estimation of bioenergy potential from municipal solid waste were obtained from the Egyptian ministry of environment "Egypt State of the Environment Report 2016", for estimate the bioenergy potential from agricultural residues were obtained from the Egyptian ministry of agriculture, land reclamation: economic affairs sector 2017 and FAO report 2017: BEFS Assessment for Egypt and for estimate the bioenergy potential from livestock manure was obtained from Egyptian ministry of agriculture, land reclamation: economic affairs sector number and kind of livestock at governorates level 2017. Table 3-1 below shows the data collection process that needed to estimate biomass potential.

Table 3-1: Data collection process for estimation of biomass potential

Municipal solid wastes	The list of Municipal solid wastes
	Organic matter percentage
	The dry weight factor
	The availability factor
Agricultural residues	The list of agricultural residue types
	The list of plant types
	Residue–to–product ratio (RPR)
	The list of dry weight factor
	The list of availability factor
Livestock	Livestock number
	Livestock manure production per head
	The list of dry weight factor
	The list of availability factor

The main aim of the biomass evaluation was to estimate the potential of municipal solid waste, the potential of agricultural residues and the potential of livestock manure for energy production, as well as their geographical allocation in Egypt. The agricultural residues were considered two main types: Primary residues produced in the field at the time of harvest and secondary residues produced during processing. The livestock manure was considered: cattle, chicken, sheep, goats, camels, horses, donkeys and mules. The waterway cleaning waste, industrial waste and sewage sludge were ignored, because there is not enough information about them, and some is too small cannot change the results.

3.2 Background

3.2.1 Municipal solid wastes (MSW)

The municipal solid waste per capita in Egypt has been estimated at 0.6 kg /person/day and 22 million tonnes in 2016, as depicted in Table 3-2, Cairo, Giza, Dakahlia and Alexandria have ranking at the top, with 48% of nation production. About 80% of these wastes disposed in public and random landfill. About 56% the largest part of the municipal solid waste was organic matter, other part was plastic, paper, glass and metals, as depicted in Figure 3-1 [19].

In this study, the focus was on estimating the potential biomass from the organic matter of the municipal solid waste at governorate level.

Table 3-2: Municipal solid wastes [19]

Region	Governorate	Daily quantity (100 tonnes)	Annual quantity (million tonnes)
Middle Delta	Gharbia	3.80	1.39
	Kafr-El Sheikh	2.75	1
	Dakahlia	4.80	1.75
	Damietta	0.95	0.35
	Menoufia	2.65	0.97
	Qalyoubia	3.80	1.39
Eastern Delta	Sharkia	2.35	0.86
	Ismailia	0.62	0.23
	Port Said	0.67	0.24
	Suez	0.41	0.15
	North Sinai	0.57	0.21
	South Sinai	0.25	0.09
Western Delta	Alexandria	4.30	1.57
	Behera	3.70	1.35
	Matruh	0.31	0.11
Middle Egypt	Cairo	15.00	5,48
	Giza	4.80	1.75
	Beni Suef	0.82	0.3
	Fayoum	0.74	0.27
	Menia	1.44	0.53
	Assuit	0.72	0.26
Upper Egypt	Suhag	1.13	0.41
	Qena	1.34	0.49
	Luxor	0.33	0.12
	Aswan	0.92	0.34
	New Valley	0.14	0.05
	Red Sea	0.47	0.17
	Total	59.77	21.83

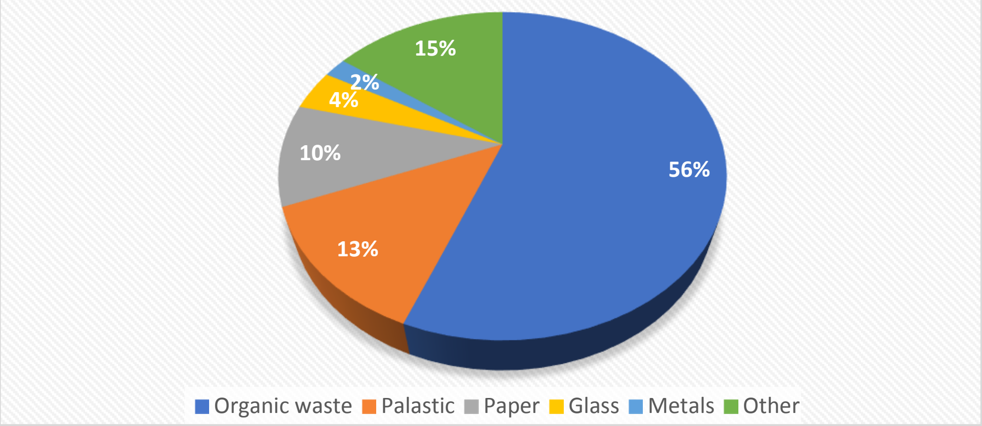

Figure 3-1: Type of municipal solid waste [18]

3.2.2 Agricultural residues

Agricultural residues are the organic matter those left in the field or accumulated as by–products during harvesting and processing of agricultural plants. As depicted in Figure 3-2 they are further classified as primary and secondary [50].

- Primary residues produced in the field at the time of harvest. They accumulated in the field, like in cereal straw, or be spread in the field, like in cotton and maize stalks [49].
- Secondary residues produced during processing, as in the case of sugar beet bagasse, maize cob, coconut shell, coconut husk, etc. [49].

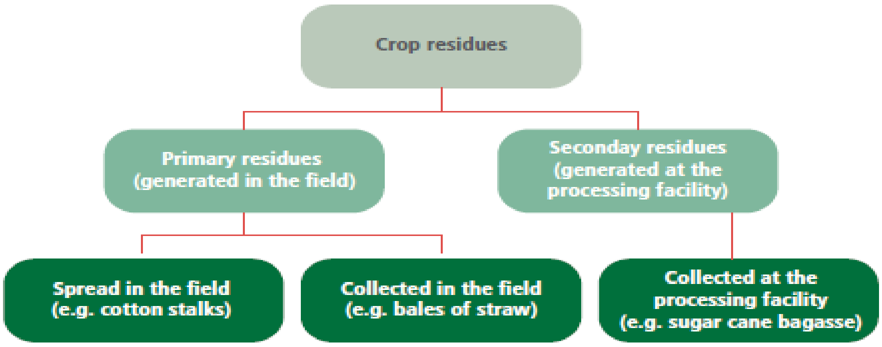

Figure 3-2: Crop residues [47]

The Table 3-3 below lists the residue types and which plant are they generated from. The main residues were straw, stalks, pruning, haulms, bagasse and mixed residues.

Table 3-3: Residues type [49]

Residue Type	Plant from which the residue is generated
Straw	Wheat, rice, broad beans, barley, flax
Stalks	Maize, cotton, sorghum, sesame, sunflower, pepper
Pruning	Citrus/orange, palm dates, grapes, olives
Haulms	Sugar beet, peanuts, soybeans, green pea, green beans, potato, courgette, tomato, onion, cucumber, strawberry, artichoke, garlic, carrot
Bagasse	Sugar cane
Mixed residues	Dry beans, cabbage, cauliflower, eggplant

The current using of agricultural residues were estimated, Left in the field (for soil protection), feed and bedding, energy production and Other use, which allowed for the calculation of the unused amount [49]. Table 3-4 shows the dry weight factor and availability factor of agricultural residues as percentage from the total weight and production.

Table 3-4: Dry weight factor and availability factor of agricultural residues

Agricultural residues	Dry weight factor % [51]	Availability factor % [49, 50]
Wheat straw	90	0
Maize stalk	67	36
Tomato haulm	48	98
Sugar cane bagasse	91	23
Rice straw	87	34
Sugar beet haulm	10.8	20
Citrus & Orange pruning	70	20
Sorghum stalk	89	0
Onion haulm	18 [50]	95
Potato haulm	88.4	90
Grapes pruning	70	25
Olive pruning	75	30
Palm dates pruning	90.89	15
Eggplant residue	20 [52]	80
Cotton stalk	44.04	80
Cabbage residue	20 [52]	80
Peanuts haulm	88.5	0
Broad beans straw	90	0
Green pea haulm	20 [53]	80
Artichoke haulm	20 [52]	80
Strawberry haulm	20 [53]	80
Soybeans haulm	88	0
Garlic haulm	20 [53]	80
Green Beans haulm	20 [53]	80
Carrot haulm	20 [53]	80
Pepper stalk	29.6 [54]	80
Courgette haulm	20 [53]	80
Barley straw	90	0
Sesame stalk	89	50
Cucumber haulm	20 [53]	80
Dry beans residue	40 [50]	80
Cauliflower residue	20 [53]	80
Flax straw	88.33	10
Sunflower stalk	90	50

3.2.3 Livestock manure

The type of livestock residues is displayed in the following Figure 3-3. The livestock residues assessed in this study are cattle, chicken, sheep, goats, horses, donkeys, mules and camels. In regard to cattle, the division was made between cows and buffalos and in regard to chicken between layers and broilers, due to primarily different management practices. The older the animal is the more the excretion, wherefore based on cattle the division was made according to age into three subgroups: less than 1 year, from 1 to 2 year and more than 2 year [49, 55].

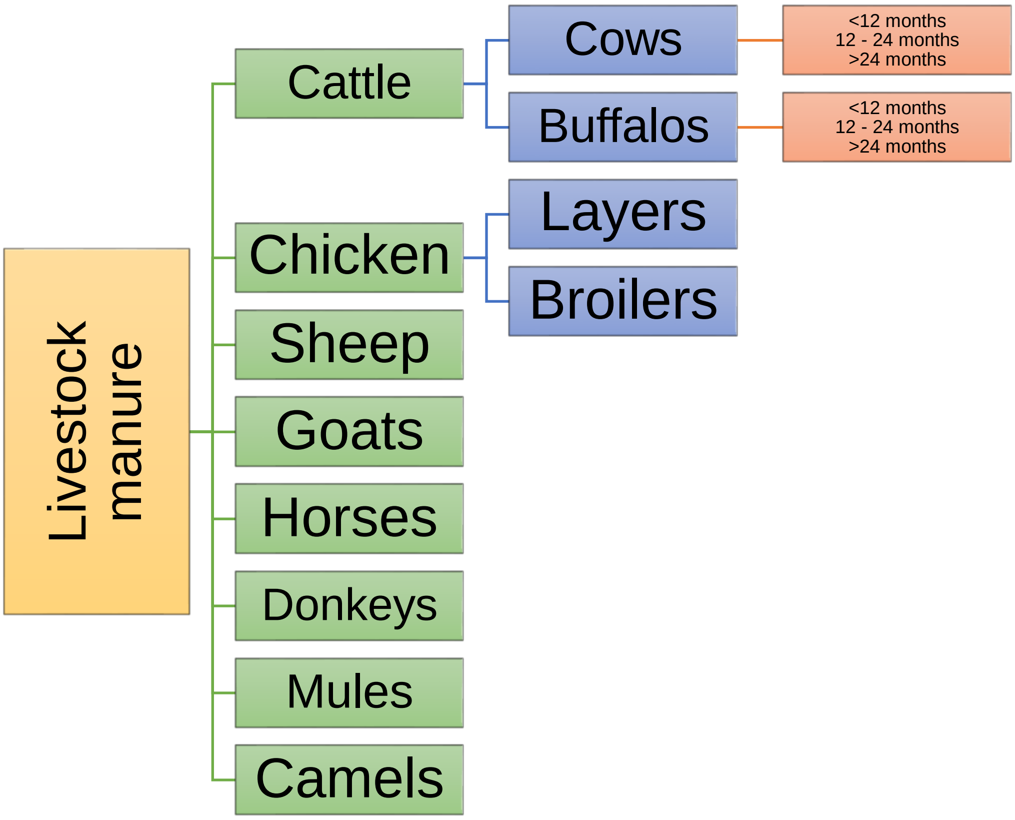

Figure 3-3: livestock manure by type [47]

In the case of livestock manure, in order to follow a systematic approach, which purposes to not overrate the potential, a moderate position has been applied here. This includes taking an average body weight and minimum compost secretion for each body weight of 6 percent [51].

In the case of chickens, this is largely dependent on breeding practices, which can be distinguished between layers and broiler chickens, given their aim (layers for eggs and broilers for meat) [51].

Table 3-5 below present the daily manure production per head and animal type. Manure production is depending on animal type, population density and body weight, which linked to the age of animal type [51].

Table 3-5: Daily manure production per heat [49, 51]

Livestock		Manure production kg/head/day
Cattle	Less than 1 year	3.15
	From 1 to 2 years	12.10
	Older than 2 years	35.60
Chicken	Layers	0.026
	Broilers	0.028
Sheep		5.00
Goats		5.00
Horses		10.00
Donkeys		10.00
Mules		10.00
Camels		10.00

The current using of livestock manure were estimated, composting, direct fertilizer, home energy and other use, which allowed for the calculation of the unused amount. The following Table 3-6 shows the dry weight factor and the availability factor of livestock manure as percentage from total weight [49].

Table 3-6: Dry weight rate and availability rate of livestock manure

Manure	Dry weight factor % [51]	Availability factor % [4, 49, 53]
Cows	13	50
Buffalos	12	50
Sheep	36	12.5
Goats	32	12.5
Chicken	85	60
Donkeys	24	12.5
Camels	34	12.5
Horses	24	12.5
Mules	24	12.5

3.3 Materials and methodology

The materials and the methodology used to perform the present chapter and it will focus on evaluation of potential biomass from production and availability of residues for each residues type (municipal solid waste, agricultural residues and livestock manure): estimation of the total quantity of residues generated as a result of type production at governorate level and displayed the results in a geographic map by ArcGIS Desktop 10.6.1 Software.

3.3.1 Total production of biomass potential

The total fresh matter (quantity) for each residues type was calculated according to Equation 3-1, per governorate and year. The organic matter and the Moisture were taken as percentage from total weight from the literatures.

Equation 3-1: Dry biomass [46]

$$DB = FM * OM_{rate} * W_f \ (\%)$$

Where:
DB (million tonnes/year) = dry biomass
FM (million tonnes/year) = fresh matter
OM_{rate} (%) = organic matter rate as percentage from total weight
W_f (%) = The dry weight factor

3.3.1.1 Production of municipal solid wastes

The total amount of wet biomass from municipal solid was collected according to Equation 3-2 per governorate and year. Total amount of municipal waste was obtained from the Egyptian ministry of environment "Egypt State of the Environment Report 2016" and the organic matter rate was taken as percentage from total weight from the literatures.

Equation 3-2 :Biomass from municipal solid wastes [56]

$$MSW_{tot(i)} = MSW_{prod(i)} * OM_{rate}$$

Where:
$MSW_{tot(i)}$ (million tonnes/year) = Total amount of wet biomass from municipal solid wastes per governorate (i) and year
$MSW_{prod(i)}$ (million tonnes/year) = Total amount of municipal solid wastes per governorate (i) and year
OM_{rate} (%) = Organic matter rate

3.3.1.2 Production of agricultural residues

The total agricultural residue production was collected according to Equation 3-3 per governorate and year. Total plant production was obtained from the Egyptian ministry of agriculture, land reclamation: economic affairs sector 2017 and FAO report 2017: BEFS Assessment for Egypt. Residue to product ratio was taken either as percentage from total weight from the literatures or was collected according to Equation 3-3 per type if their agricultural residue production was given.

Equation 3-3: Total agricultural residue production per year [49]

$$AR_{tot(i)} = RPr_{(i)} \times P_{(prod(i)}$$

Where:
$AR_{tot(i)}$ (tonnes/year) = Total agricultural residue production per governorate (i)/year
$RPr_{(i)}$ (%) = Residue to product ratio
$P_{prod(i)}$ (tonnes/year) = Total plant production per year

3.3.1.3 Production of livestock manure

The livestock manure production of each livestock category was collected according to Equation 3-4 per governorate and year. The number of livestock was obtained from the Egyptian ministry of agriculture, land reclamation: economic affairs sector: number and kind of livestock at governorates level 2017.

Equation 3-4: livestock manure production [49]

$$LVM_{tot(i)} = LV_{prod\ (i)} * M_{head}$$

Where:
$LVM_{tot(i)}$ [tonnes/year] = Total amount of livestock manure production per governorate (i)/year
$LV_{prod\ (i)}$ [head/year] = Number of livestock per governorate (i) and year
M_{head} [t/head] = Manure production per head of each livestock category per year

3.3.2 Total availability of dry biomass potential

The quantity of the total amount of biomass produced, with no other competitive uses can be considered as available for bioenergy production.

3.3.2.1 Availability of municipal solid wastes

Total available amount of dry biomass from municipal solid has been calculated according to Equation 3-5. Total amount of biomass from municipal solid wastes has been calculated according to Equation 3-2 and has been listed in Table 3-8. The dry weight and availability factor have taken as percentage from total production; W_f has been considered as 50% of the total weight [57], and A_f 80% of tot production [58].

Equation 3-5: dry available biomass from municipal solid wastes [31]

$$MSW_{av(i)} = MWS_{tot(i)} * W_f * A_f$$

Where:
$MSW_{av(i)}$ (million tonnes/year) = Total available amount of dry biomass from municipal solid per governorate (i) and year
$MWS_{tot(i)}$ (million tonnes/year) = Total amount of biomass from municipal solid wastes per governorate (i) and year
wastes per governorate (i) and year
W_f (%) = The dry weight factor
A_f (%) = The availability factor

3.3.2.2 Availability of agricultural residues

The total available amount of dry agricultural residue production collected according to Equation 3-6. The total agricultural residue production was collected according to Equation 3-3 per governorate and year. The dry weight factor and the availability factor were taken as percentage from the total weight and production for each residue and listed in Table 3-4.

Equation 3-6: Dry available biomass from agricultural residues

$$AR_{av(i)} = AR_{tot(i)} * W_f * A_f$$

Where:

$AR_{av(i)}$ (tonnes/year) = Total available amount of dry agricultural residue production per governorate (i) and year

$AR_{tot(i)}$ (tonnes/year) = Total agricultural residue production per governorate (i) and year

W_f (%) = The dry weight factor

A_f (%) = The availability factor

3.3.2.3 Availability of livestock manure

The availability of dry livestock manure production of each livestock category collected according to Equation 3-7 per governorate and year. Total amount of livestock manure production was collected according to Equation 3-4. The dry weight factor and the availability factor were taken as percentage from total weight und listed in Table 3-6.

Equation 3-7: Availability of dry livestock manure production [49]

$$LVM_{av(i)} = LVM_{tot(i)} * W_f * A_f$$

Where:

$LVM_{av(i)}$ (tonnes/year) = Total available amount of dry livestock manure production per governorate (i) and year

$LVM_{tot(i)}$ (tonnes/year) = Total amount of livestock manure production per governorate (i) and year

W_f (%) = The dry weight factor

A_f (%) = The availability factor

3.4 Results and discussion

3.4.1 Total production of biomass potential

The results show that the total production of biomass potential in Egypt in 2017 per residues type estimated at 135 and 38 million tonnes wet and dry biomass production, derives from agricultural residues, municipal solid wastes and livestock manure Table 3-7.

Table 3-7: Total production of biomass potential per residues type

Residues Type	Quantity million tonnes/year	Dry biomass million tonnes/year
Municipal solid wastes	12.2	8.00
Agricultural residues	36	16.22
Cows manure	31.9	3.20
Buffalos manure	25.2	2.40
Sheep manure	9.7	1.30
Goat manure	7.3	1.75
Chicken manure	6.4	3.70
Donkey manure	5.1	1.00
Camel manure	0.6	0.15
Horse manure	0.3	0.06
Mule manure	0.1	0.02
Total manure	86.5	13.58
Total	135	38

The analysis of total production of biomass potential at regions level, five regions recognized, with middle Egypt and middle delta have ranking at the top, accounting for 36 (27%) and 35 (26%) million tonnes/year. Western delta ranked at the third place with 23 million tonnes/year, contributing 17% of production. Upper Egypt and eastern delta have the smallest share to the national production with contributing 21 (16%) and 20 (14%) million tonnes/year.

The analysis of total production biomass potential at governorate level reveals that some governorates are visibly more productive than others. The geographic map below (Figure 3-4) also displays the total production biomass potential and the residue type at governorate level in Egypt. Graduated and different colors are used for each group or governorate with the identical production group as given in the previous figure, while the pie charts show the structure of the residues. The classification statistics depend on the natural breaks (Jenks) algorithm, which recognizes break points by choosing the class breaks that best assemble analogous values and maximize the differences between classes. The geographic map can be represented by three levels high, medium and low, the darker brown color is, the more productive.

Five groups can be recognized, that include governorates with a substantial homogeneity and similarity in waste structure and/or quantity of production. The first group includes the governorates more than 8.9 million tonnes. Behera and Sharkia are the highest biomass production governorate, with 18.5 (14%) and 15.6 (12%) million tonnes/year.

The second group includes the governorates between 6.4 and 8.9 million tonnes. The most productive governorates are Menia, Dakahlia, Suhag, Gharbia, Menoufia, Fayoum and

Assuit with more than 52 million tonnes of biomass each, contributing 39% of national production.

The third group includes Kafr-El Sheikh, Qena, Giza, Qalyoubia and Ben Suef with total production 28.2 million tonnes/year, contributing 21% of nation production.

The fourth group includes 4 governorates with more than 11 million tonnes/year, contributing 9% of national production.

The last group includes the remaining governorates (9) with biomass production reaches 9 million tonnes/year (7%). biomass in this group vary from 1.74 to 1.98 million tonnes/year.

It should also be mentioned that along the Nile basin, the production is increasing.

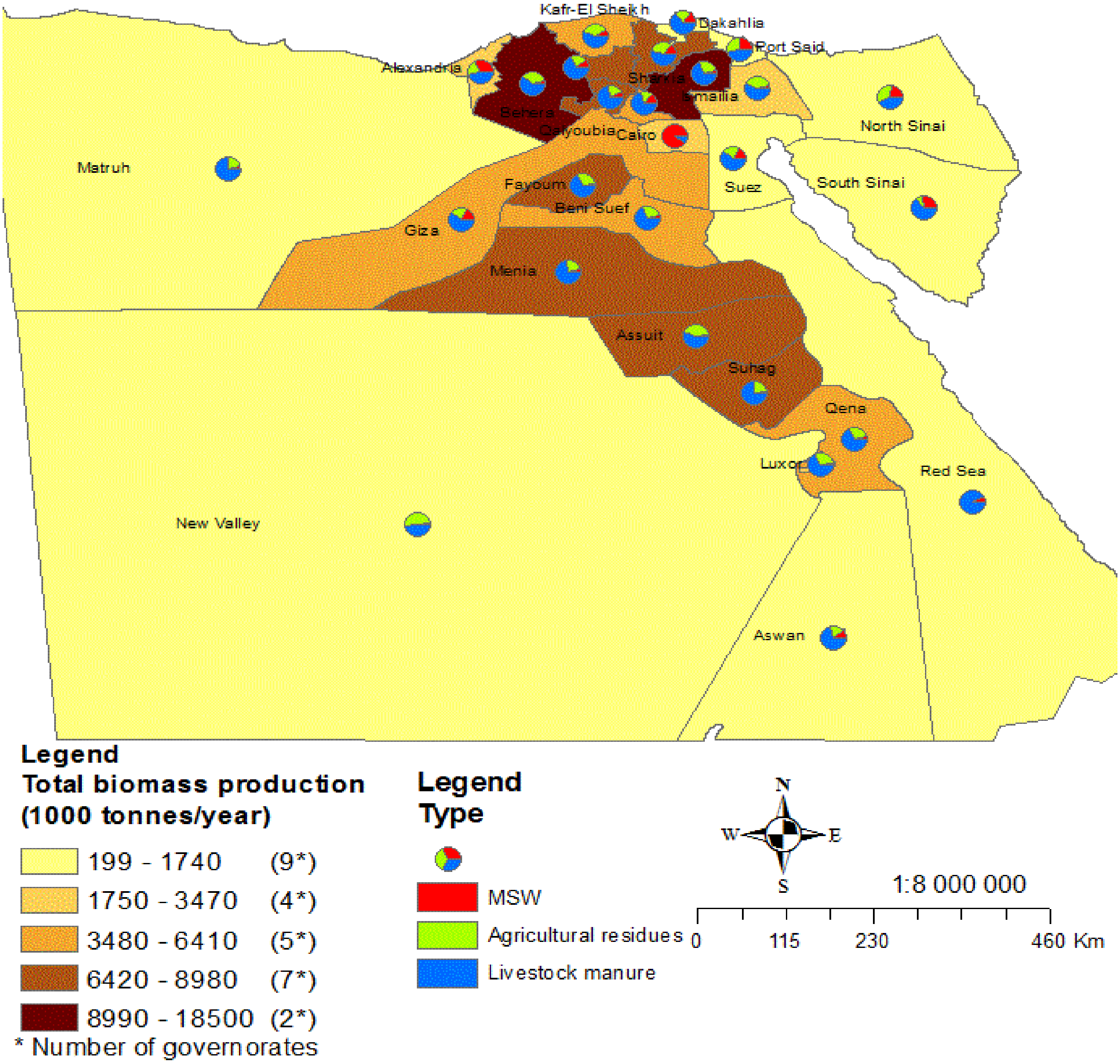

Figure 3-4: ArcGis map of total production of biomass potential in Egypt

3.4.1.1 Production of municipal solid wastes:

The analysis of biomass potential from municipal solid waste production at governorate level reveals that some governorates are visibly more productive than others. The analysis at regions level (Table 3-8), five regions can be recognized, with middle Egypt and middle delta have ranking at the top, with 39% and 31%. The third region includes western delta with 1.7 million tonnes/year, contributing 14% of nation production. Eastern delta and upper Egypt have the smallest share to the national production with contributing 0.99 (8%) and 0.89 (7%) million tonnes.

Table 3-8: Total biomass potential from MSW by governorate and region

Region	Governorate	Wet biomass quantity from MSW million tonnes/year
Middle Delta	Gharbia	0.78
	Kafr-El Sheikh	0.56
	Dakahlia	0.98
	Damietta	0.20
	Menoufia	0.54
	Qalyoubia	0.78
		3.84
Eastern Delta	Sharkia	0.48
	Ismailia	0.13
	Port Said	0.13
	Suez	0.08
	North Sinai	0.12
	South Sinai	0.05
		0.99
Western Delta	Alexandria	0.88
	Behera	0.76
	Matruh	0.06
		1.7
Middle Egypt	Cairo	3.07
	Giza	0.98
	Beni Suef	0.17
	Fayoum	0,15
	Menia	0.30
	Assuit	0.15
		4.82
Upper Egypt	Suhag	0.23
	Qena	0.27
	Luxor	0.07
	Aswan	0.19
	New Valley	0.03
	Red Sea	0.10
		0.89
	Total	**12.22**

Figure 3-5 and Figure 3-6 show the geographic map five groups that include governorates with a substantial homogeneity and similarity in waste structure and/or quantity of production. The geographic map displayed graduated and different colors to appear each group or governorate.

The first group includes the governorates more than 0.98 million tonnes. Cairo is the highest waste production governorate, with 3.07 million tonnes (25%).

The second group includes the governorates between 0.56 and 0.98 million tonnes. The most productive governorates are Giza, Dakahlia, Alexandria, Gharbia, Qalyoubia and Behera with more than 5 million tonnes of wastes each, contributing 42% of national production with 0.98, 0.98, 0,88, 0.78, 0.78, 0.76 million tonnes per year respectively.

The third group includes Kafr-El Sheikh, Menoufia and Sharkia with 0.56, 0.54, 0.48 million tonnes/year respectively, contributing 13% of nation production.

The fourth group includes 6 governorates with more than 1.30 million tonnes/year of wastes each, contributing 11% of national production.

The last group includes the remaining governorates with waste production reaches 1.05 million tonnes/year (9%). Wastes in this group vary from 0.03 to 0.17 million tonnes/year.

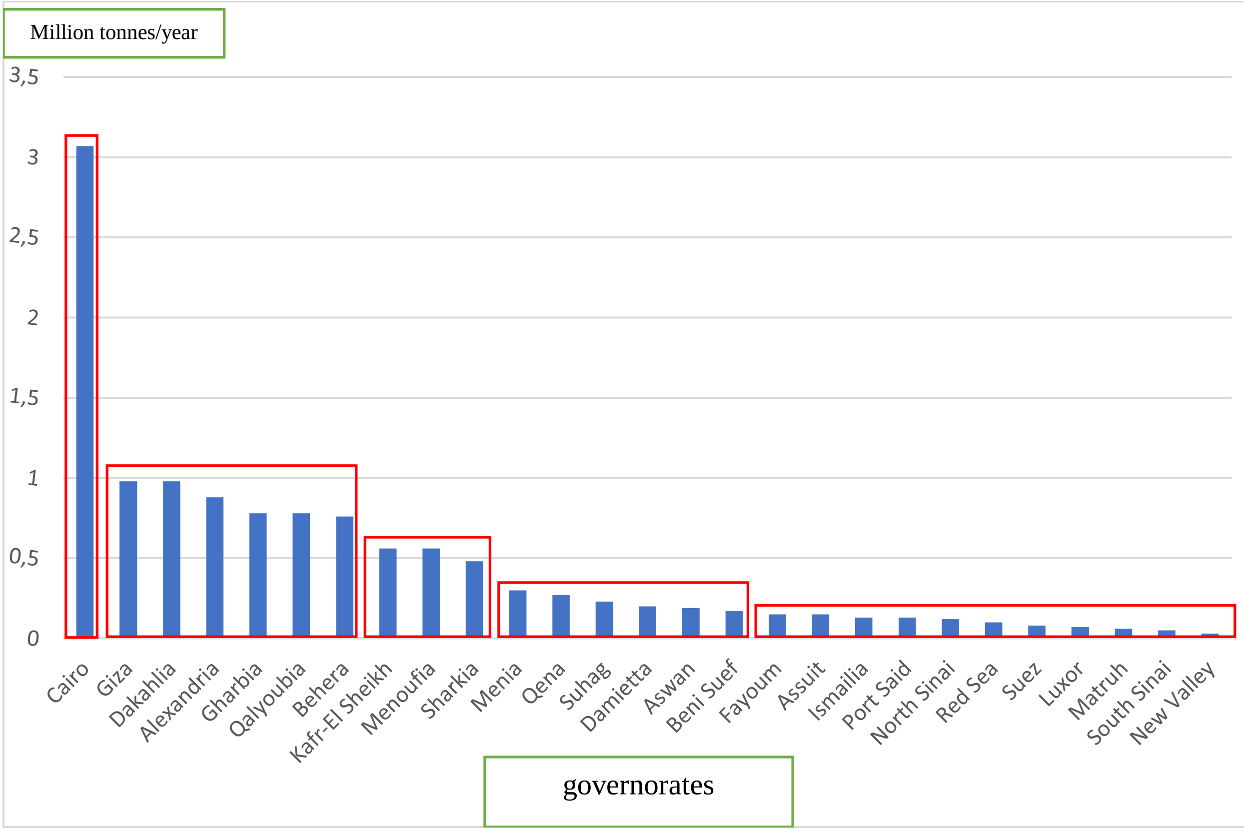

Figure 3-5: Biomass from municipal solid wastes per governorate

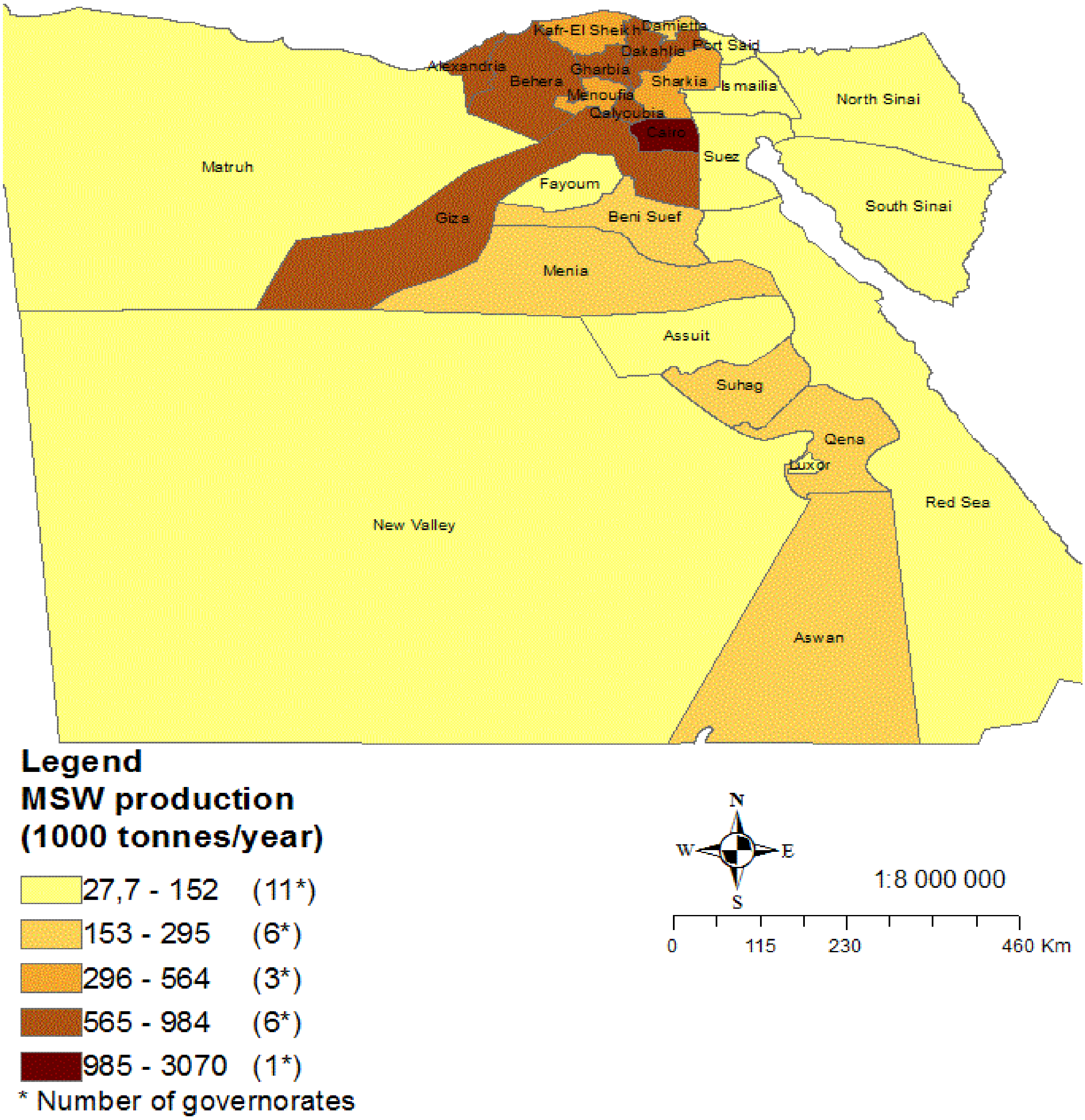

Figure 3-6: ArcGis map of biomass from municipal solid wastes in Egypt

3.4.1.2 Production of agricultural residues:

Table 3-9 presents the list of selected agricultural residues and corresponding residues to product ratios as percentage from total production. Residue to product ratio was taken either as percentage from total weight from the literatures or calculated if their agricultural residue production was given.

Table 3-9: Residue to product ratio (RPR)

Agricultural Residues		Residue to product ratio (RPR)	Reference
Crops	Wheat straw	90%	Calculated
	Maize stalk	100%	Calculated
	Sugar cane bagasse	200%	Calculated
	Rice straw	50%	Calculated
	Sugar beet haulm	20%	Calculated
	Sorghum stalk	120%	Calculated
	Cotton stalk	150%	Calculated
	Peanuts haulm	150%	Calculated
	Broad beans straw	180%	Calculated
	Soybeans haulm	320%	Calculated
	Barley straw	90%	Calculated
	Sesame stalk	180%	Calculated
	Flax straw	400%	Calculated
	Sunflower stalk	160%	Calculated
Fruits	Citrus & orange	50%	[59]
	Palm pruning	50%	[59]
	Grapes pruning	50%	Calculated
	Olive pruning	100%	Calculated
Legumes	Green pea haulm	100%	[60]
	Dry beans residue	150%	[50]
	Green beans haulm	100%	[60]
Vegetables	Potato haulm	30%	[60]
	Cabbage residue	90%	[50]
	Cauliflower residue	50%	[53]
	Courgette haulm	50%	[53]
	Tomato haulm	100%	[50]
	Onion haulm	30%	[50]
	Cucumber haulm	50%	[53]
	Strawberry haulm	50%	[61]
	Eggplant residue	50%	[53]
	Artichoke haulm	50%	[61]
	Garlic haulm	50%	[61]
	Pepper stalk	50%	[53]
	Carrot haulm	50%	[61]

Table 3-10 and Figure 3-7 show that the total agricultural residues production of 36 million tonnes per year. The most residues share in the total production derive cereals (51%), in particular wheat, maize and rice. The largest residue production derives wheat straw with production of 7.83 million tonnes (21.7%) followed by maize stalk with 6.77 million tonnes (18.8%), rice straw with 2.81 million tonnes (7.8%), and sorghum stalk with 0.95 million tonnes (2.6%). Among the sugar crops with total contribution 15.3% from the total residues production, account for 3.37 (9.4%) and 2.12 (5.9%) million tonnes from sugar cane bagasse and sugar beet haulm respectively. Fruit tree pruning contribute 10% to the total residues production, a significant contribution comes from citrus and orange pruning account for 5.4% of total national residue production, while a much smaller one is made by grapes pruning, olive pruning and palm dates pruning, which accounts for 1.7%, 1.5% and 1.4% respectively. Vegetables category become the second rank of total national residue production with contribution 19% of residues, with tomato haulm playing the most important role within the category (51%) followed by onion haulm 2.4%, potato haulm 2.2%, eggplant residue 1.1% and cabbage residue 0.8%. Legumes residues contribute 1.059 million tonnes (3%) to the national residue production. A significant contribution from the fibre crops category comes from cotton, accounting for 1.08% of the total residue production. The remaining crops contribute to a very little share to the total national residue production.

Table 3-10: Average agricultural residues production 2017

Agricultural residues	Residue production million tonnes/year
Wheat straw	7.83
Maize stalk	6.77
Tomato haulm	3.50
Sugar cane bagasse	3.37
Rice straw	2.81
Sugar beet haulm	2.12
Citrus & Orange pruning	1.96
Sorghum stalk	0.95
Onion haulm	0.88
Potato haulm	0.79
Grapes pruning	0.62
Olive pruning	0.53
Palm dates pruning	0.52
Eggplant residue	0.40
Cotton stalk	0.39
Cabbage residue	0.31
Peanuts haulm	0.30
Broad beans straw	0.20
Green pea haulm	0.199
Artichoke haulm	0.17
Strawberry haulm	0.16
Soybeans haulm	0.15
Garlic haulm	0.14
Green beans haulm	0.14
Carrot haulm	0.12

Pepper stalk	0.12
Courgette haulm	0.11
Barley straw	0.10
Sesame stalk	0.08
Cucumber haulm	0.08
Dry beans residue	0.07
Cauliflower residue	0.05
Flax straw	0.05
Sunflower stalk	0.03
Total	36.00

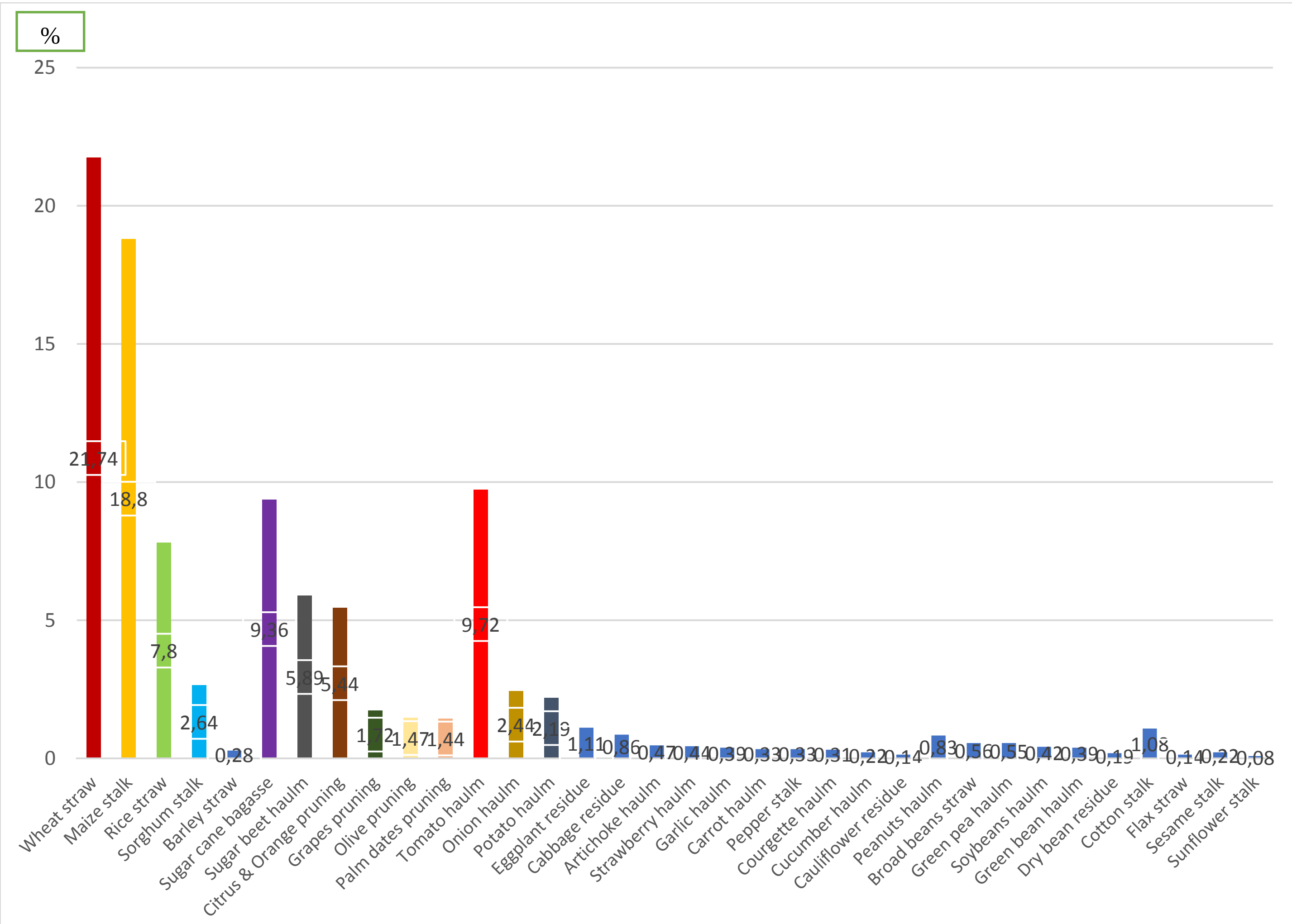

Figure 3-7: Shares of residue production by crop (%)

The analysis of biomass potential from Agricultural residues production at governorate level reveals that some governorates are visibly more productive than others. Table 3-11, five regions can be recognized. The regions contribute to the total national residues production similarity to municipal solid wastes where middle Egypt and middle delta have ranking at the top, with 26% and 24%. The third region includes western delta with 7.1 million tonnes/year, contributing 20% of nation production. Eastern delta and upper Egypt have the smallest share to the national production with contributing 5.7 (16%) and 5.2 (14%) million tonnes.

Table 3-11: Total production of agricultural residue by governorat and region

Region	Governorate	Total agricultural residue
	1000 Tonnes/year	
Middle Delta	Gharbia	1445.9
	Kafr-El Sheikh	2275.3
	Dakahlia	2586.0
	Damietta	293.8
	Menoufia	1294.7
	Qalyoubia	718.7
		8614.4
Eastern Delta	Sharkia	4334.7
	Ismailia	893.1
	Port Said	170.9
	Suez	113.9
	North Sinai	158.4
	South Sinai	18.6
		5689.6
Western Delta	Alexandria	550.3
	Behera	6196.0
	Matruh	338.9
		7085.2
Middle Egypt	Cairo	4.9
	Giza	1030.9
	Beni Suef	1428.1
	Fayoum	2050.4
	Menia	2132.7
	Assuit	2787.4
		9434.4
Upper Egypt	Suhag	1648.9
	Qena	1690.3
	Luxor	894.5
	Aswan	301.5
	New Valley	689.3
	Red Sea	0.4
		5224.9
	Total	**36048.6**

Figure 3-8 shows six groups where each group includes governorates with a substantial homogeneity and similarity in residue structure and/or quantity of production.

Behera is the highest residue production governorate in the country, with 6.196 million tonnes/year contributing 17.2% to the national production, in which maize stalk, wheat straw, citrus pruning and tomato haulm are the main resource of residues. Sharkia ranking at the second place, with 4.335 million tonnes/year, 12% of national production, most of residues within this governorate derive from wheat straw, tomato haulm, rice straw and maize stalk, accounting for 73% of total governorate production.

With more than 11.8 million tonnes of residues ranked Assuit, Dakahlia, Kafr-El Sheikh, Menia and Fayoum group the second place, contributing 32.8% of national production with 2.788, 2.586, 2.275, 2.133 and 2.050 million tonnes/year respectively. The agricultural residues composition in this group can be divided into two subgroup, first one includes middle delta governorates Dakahlia and Kafr-El Sheikh with resource of residues from rice straw, wheat straw sugar beet haulm and maize stalk, contributing more than 80% within this subgroup. The second subgroup includes middle Egypt governorates Assuit, Menia and Fayoum, the most of residues derive from wheat straw, maize stalk, sugar cane bagasse and sorghum stalk, contributing more than 80%.

Similar to the previous group is distributed among also five governorates: Qena, Suhag, Gharbia, Beni Suef and Menoufia 20.8% of the total national production, with 1.690, 1.649, 1.446, 1.428 and 1.295 million tonnes/year, with dividing into tow subgroup: Qena, Suhag and Beni Suef subgroup, with a prevalence of sugar cane bagasse, wheat straw, maize stalk, sorghum stalk and tomato haulm residues and Gharbia and Menoufi subgroup, with a prevalence of maize stalk, wheat straw, rice straw, citrus & orange pruning and sorghum stalk.

The fourth group includes Giza, Luxor, Ismailia, Qalyoubia, New Valley and Alexandria and provides 13.3% of the total national residue production, with 1.031, 0.895, 0.893, 0.719, 0.689 and 0.550, respectively. Most of the residues derive from wheat straw, maize stalk, tomato haulm, sugar cane bagasse, citrus & orange pruning, Palm dates pruning and potato haulm.

The fifth group contributes 1.264 million tonnes (3.5%) of the total national residue production and is distributed among also five governorates: Matruh, Aswan, Damietta, Port Said and North Sinai, with olive pruning, tomato haulm, wheat straw, rice straw and sugar beet haulm as the main resources.

The last group includes the remaining governorates: Suez, South Sinai, Cairo, and Red Sea, provides 0.4% of the total national residue production with 0.138 million tonnes/year. It should also be mentioned that Suez playing the most important role within this group with 0.114 million tonnes, accounting for 83% to the total production of this group, most of the residues derives from tomato haulm, maize stalk, citrus & orange pruning and wheat straw.

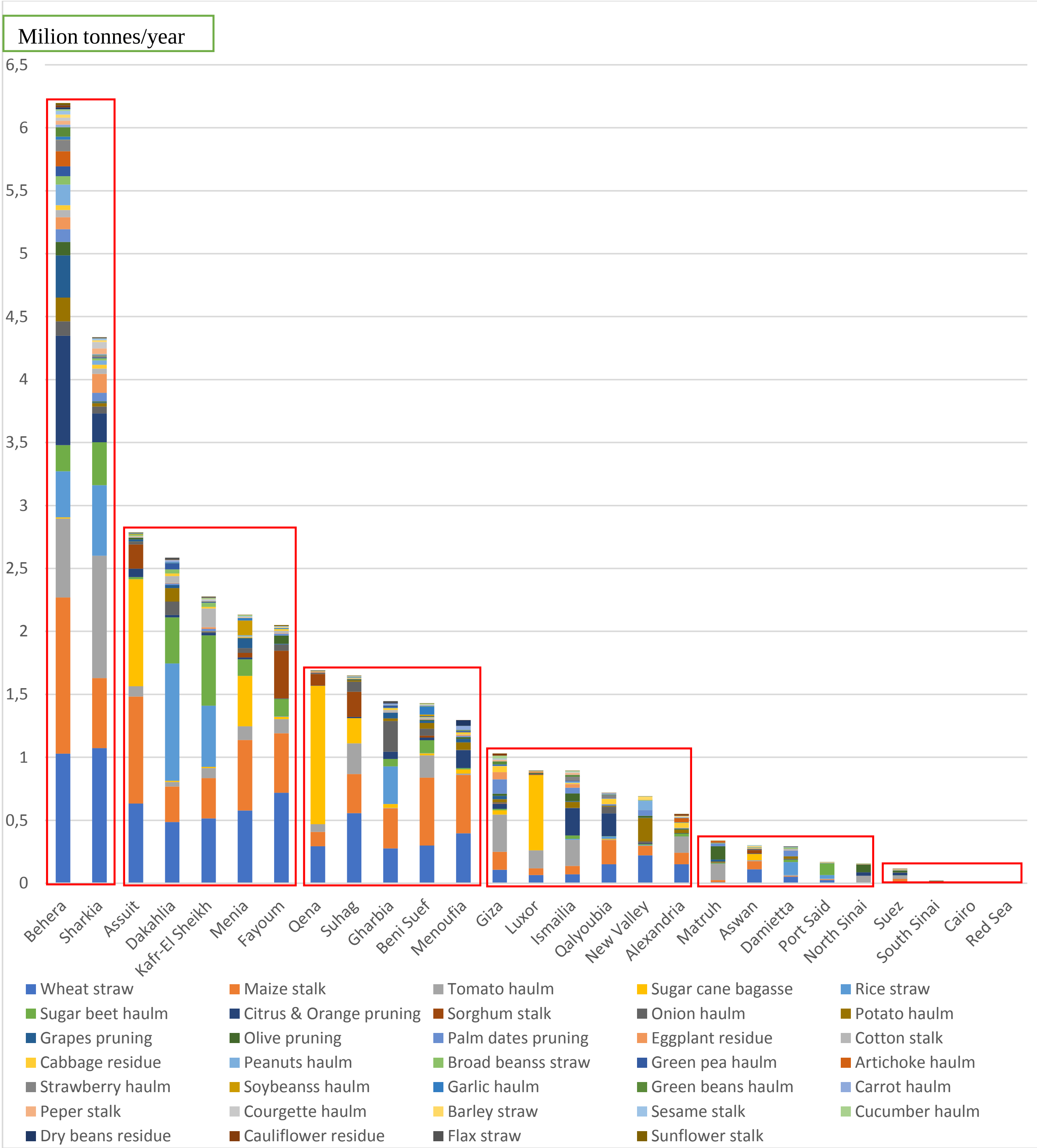

Figure 3-8: Total agricultural residues production by governate

The geographic map below (Figure 3-9) displays the total agricultural residue production and the residue type at governorate level in Egypt. The lighter colors on the map displays the lower production. It should also be mentioned that along the Nile basin, the production is increasing.

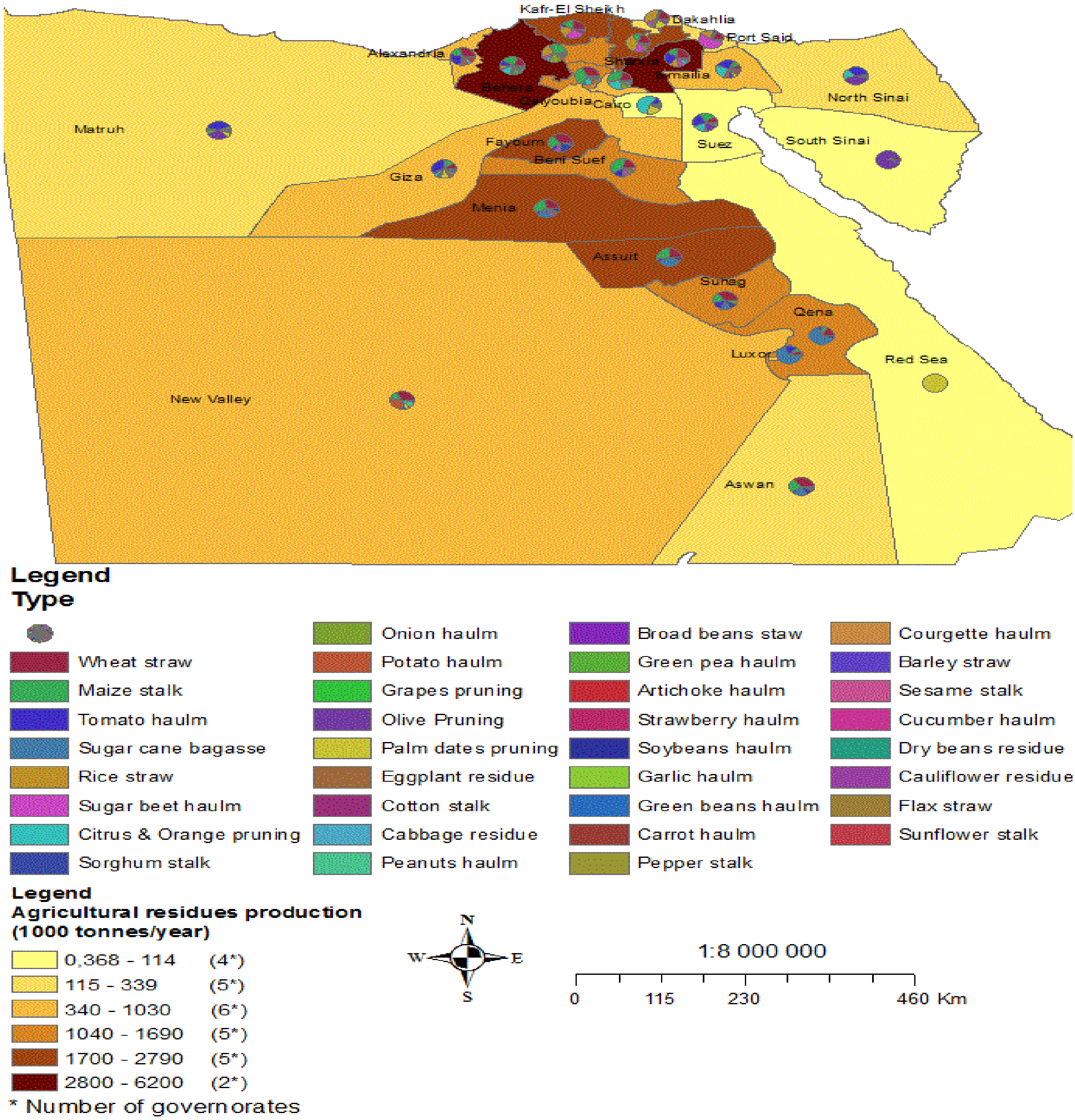

Figure 3-9: ArcGis map of total agricultural residue production in Egypt

3.4.1.3 Production of livestock manure:

Table 3-12 shows that of the total livestock manure production of 86.5 million tonnes/year. The most residues share in the total production derive cattle 57 million tonnes/year, contributing 66% of the total national residues production, in particular cows and buffalos, contributing 32 (37%) and 25 (29%) million tonnes/year respectively. The second place ranked by sheep with a contribution 11% of the total national residues production. Goats ranked the third place with a production accounting for more than 8% of the total residues. Chicken manure from layers and broilers contributes more than 6 million tonnes/year (7%). Donkeys manure accounts more than 5 million tonnes/year, contributing 5.9% of total residues. The remaining livestock contribute very little share to the total national production, accounting for 0.57, 0.28 and 0.09 million tonnes/year from camels, horses and mules respectively.

Table 3-12: Average livestock manure production 2017

Livestock	Manure production million tonnes/year
Cows	31.88
Buffalos	25.21
Sheep	9.71
Goats	7.27
Chicken	6.39
Donkeys	5.07
Camels	0.57
Horses	0.28
Mules	0.09
Total	86.47

The analysis of biomass potential from livestock manure production at governorate level reveals that some governorates are visibly more productive than others. Table 3-13, five regions can be recognized. The regions contribute to the total national residues production with various contributions to municipal solid wastes and agricultural residues where middle delta and middle Egypt have ranking at the top, with contributing 22.5 (26%) and 22 (25.4%) million tonnes/year. Upper Egypt region ranked at the third place with a production 14.9 million tonnes/year, contributing 17.3% of the total national production. western and eastern delta have the smallest share to the national production with contributing 14.1 (16.3%) and 13 (15%) million tonnes.

Table 3-13: Total production of livestock manure by governorate and region

Region	Governorate	Total livestock manure
	1000 Tonnes/year	
Middle Delta	Gharbia	5071.7
	Kafr-El Sheikh	3570.8
	Dakahlia	4276.5
	Damietta	889.6
	Menoufia	4977.3
	Qalyoubia	3689.3
		22475.3

Eastern Delta	Sharkia	10739.7
	Ismailia	1324.7
	Port Said	259.6
	Suez	302.2
	North Sinai	225.2
	South Sinai	129.1
		12980.7
Western Delta	Alexandria	1218.3
	Behera	11524.9
	Matruh	1338.2
		14081.5
Middle Egypt	Cairo	387.3
	Giza	3231.9
	Beni Suef	3489.0
	Fayoum	4586.2
	Menia	6555.4
	Assuit	3749.5
		21999.4
Upper Egypt	Suhag	5642.8
	Qena	4290.3
	Luxor	2048.6
	Aswan	1202.0
	New Valley	707.6
	Red Sea	1051.1
		14942.5
	Total	**86479.4**

Figure 3-10 shows five groups where each group includes governorates with a substantial homogeneity and similarity in residue structure and/or quantity of production.

Similar to the agricultural residues Behera and Sharkia are the highest residue production governorates in the country, with 11.5 and 10.7 million tonnes/year contributing more than quarter the total amount of residues production accounting for 13.3% and 12.4% to the national production.

More than quarter the total amount of residues produced 22.3 million tonnes (25.8%) is distributed among 4 governorates: Menia, Suhag, Gharbia and Menoufia, accounting for 6.6, 5.6, 5.1 and 5 million tonnes/year, respectively.

With a contribution more than 30 million tonnes of residues, accounting for 35.7% of the total national residues production ranked 8 governorates: Fayoum, Qena, Dakahlia, Assuit, Qalyoubia, Kafr-El Sheikh, Beni Suef and Giza the third group. In this group, residues vary from 3.2 to 4.6 million tonnes/year/governorate.

The fourth group includes 7 governorates: Luxor, Matruh, Ismailia, Alexandria, Aswan, Red Sea and Damietta provides 90.7 million tonnes/year, contributing 10.5% of the tot25al national residue production, with a varying from 0.89 to 2.05 million tonnes/year/governorate.

Luxor is playing the most important role within this group with a contribution 22.6% to the total production of this group.

The last group includes the remaining governorates: New Valley, Cairo, Suez, Port Said, North Sinai and South Sinai provides 2.3% of the total national residue production, accounting for more than 2 million tonnes/year. It should also be mentioned that New Valley playing the most important role within this group with 0.7 million tonnes, accounting for 35.2% to the total production of this group.

It should also be mentioned that the most productive governorates for cows, buffalos, goats, donkeys, horses and mules are Behera and Sharkia, contributing (13.2% and 14.5%), (14.8% and 11.1%), (12.8% and 9.1%), (12.4% and 11%), (13,1% and 13.4%) and (18.2% and 17.4%). Sharkia and Suhag ranked at the top with 8.8% and 7% of national production from sheep manure. With a contribution 34.8% of national chicken residues ranked Sharkia and Menia at the top with production of 18.2% and 16.6%. Almost half the total amount of camel residues produced (45.7%) is distributed between Red Sea and Matruh.

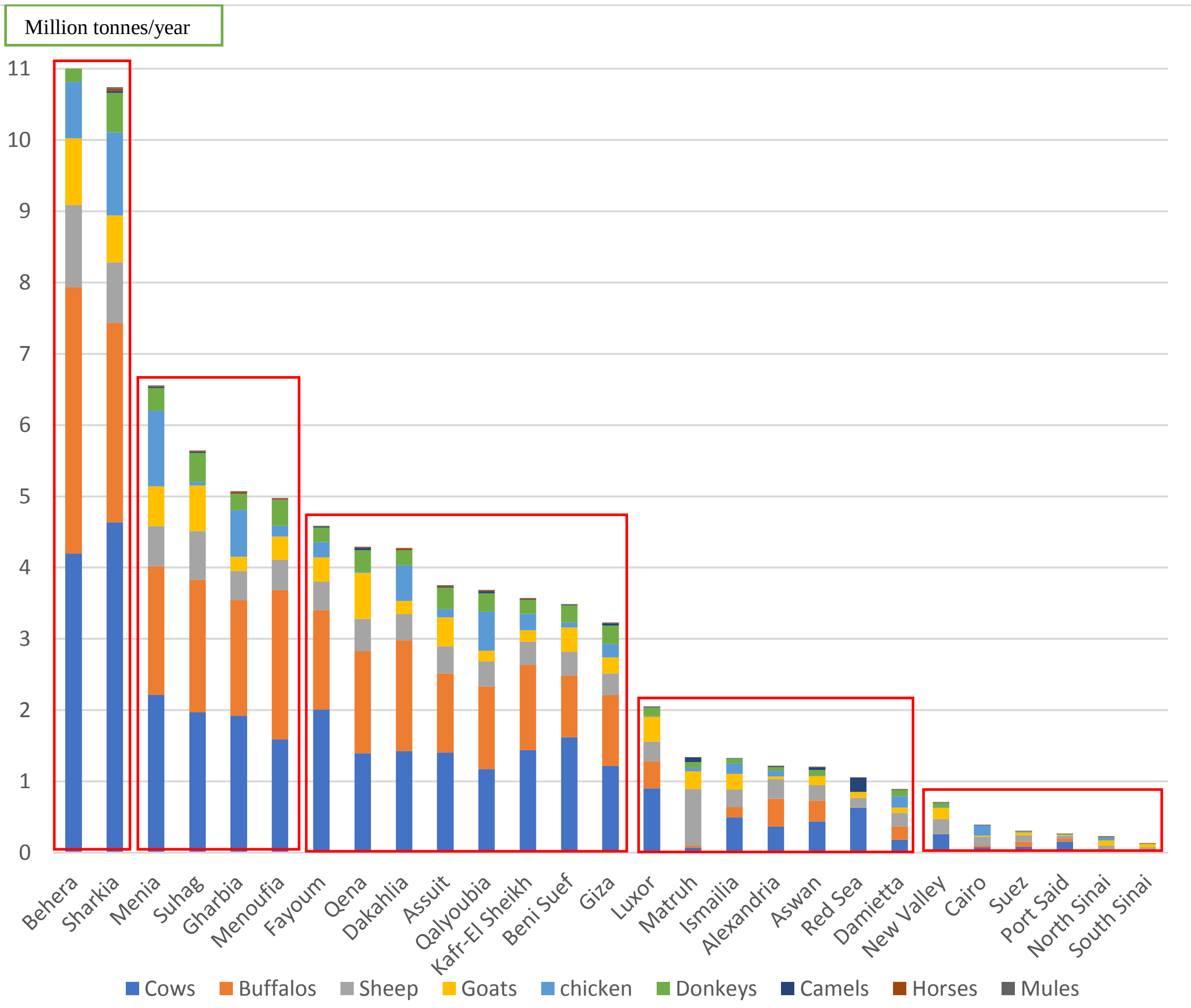

Figure 3-10: Total livestock manure production by governorate .

The geographic map below (Figure 3-11) displays the total manure production and the residue type at governorate level in Egypt. Graduated and different colors are appeared each group or governorate with the identical production group as given in the previous figure, while the pie charts show the structure of the manure type. The darker brown areas represent higher manure production, while the lighter represent lower manure production. The geographic map can be represented by three levels high, medium and low. The western and eastern delta show the high production (represented with darker brown on the map). Medium production is concentrated in the middle delta. It should also be mentioned that along the Nile basin, the production is increasing, excepting the camel's manure is concentrated in the desert areas.

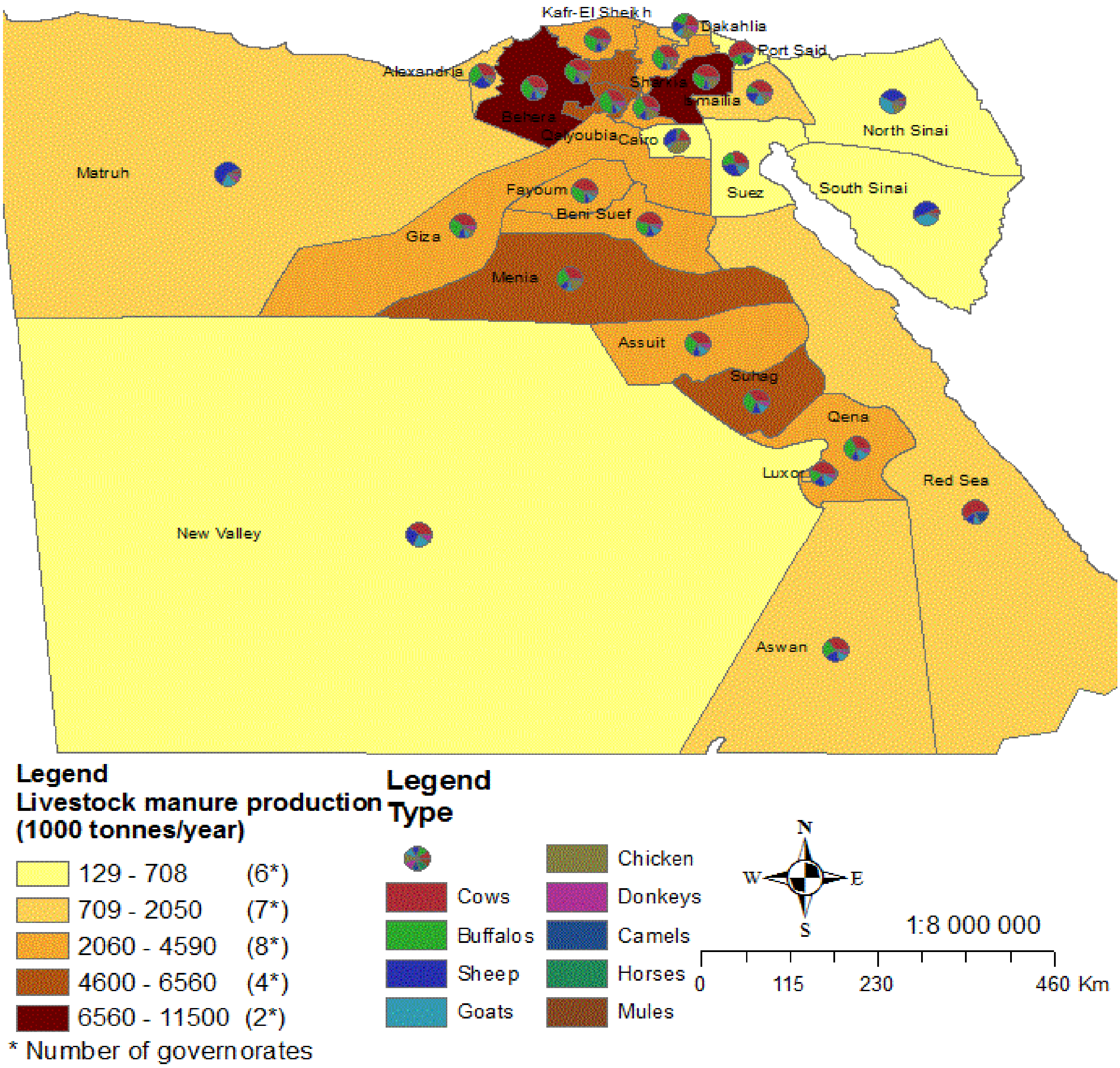

Figure 3-11: ArcGis map of total manure production in Egypt

3.4.2 Total availability of dry biomass potential:

The results show that the total availability of dry biomass potential in Egypt in 2017 per residues type estimated at 18 million tonnes, derives from agricultural residues, municipal solid wastes and livestock manure as in Table 3-14.

Table 3-14: Total availability of dry biomass potential per residues type

Residues Type	Availability of dry biomass million tonnes/year
Municipal solid wastes	5
Agricultural residues	5
Cows manure	2.1
Buffalos manure	1.5
Sheep manure	0.4
Goat manure	0.3
Chicken manure	3.3
Donkey manure	0.2
Camel manure	0.02
Horse manure	0.01
Mule manure	0.002
Total manure	7.8
Total	17.3

The analysis of total availability of dry biomass potential at regions level shows various contributions to total production of biomass potential, five regions can be recognized, middle delta, middle Egypt, western delta, eastern delta and upper Egypt contribute 5.2 (29.8%), 5.1 (29.6%), 2.8 (16.1%), 2.4 (13.6%) and 1.9 (10.9) million tonnes/year, respectively.

The analysis of total availability of dry biomass potential at governorate level reveals that some governorates are visibly more productive than others. The geographic map below (Figure 3-12) also displayed the total availability of dry biomass potential and the residue type at governorate level in Egypt.

Five groups can be recognized, that include governorates with a substantial homogeneity and similarity in waste structure and/or quantity of production.

Similar to total production, Behera and Sharkia are the highest availability of dry biomass potential, with 2.1 (12%) and 11.8 (10%) million tonnes/year. It should also be mentioned that along the Nile basin, the production is increasing.

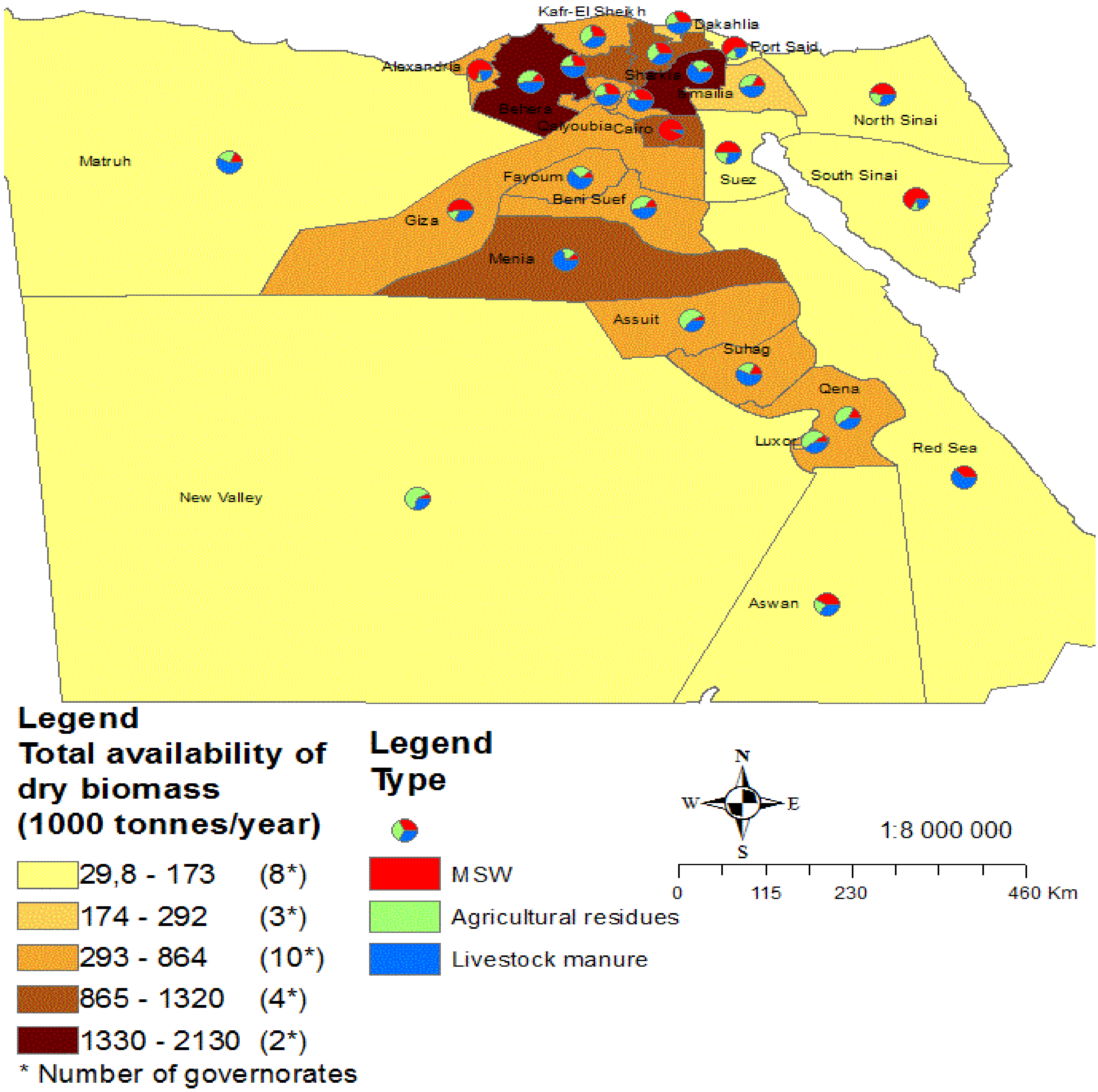

Figure 3-12: ArcGis map of availability of dry biomass potential in Egypt

3.4.2.1 Availability of municipal solid wastes:

The analysis of municipal solid wastes available for bioenergy at governorate and region level reveals the same spatial distribution noted for wastes production. Following Table 3-15 shows the potential availability of dry biomass from municipal solid wastes at governorate level and year, with total availability of 4.9 million tonnes. At region level, middle Egypt and middle delta have ranking at the top. And at governorate level, Cairo, Giza, Dakahlia and Alexandria have the higher availability of municipal solid wastes for bioenergy.

Table 3-15: Potential availability of dry biomass from municipal solid wastes

Region	Governorate	Availability of dry MSW 1000 tonnes/year
Middle Delta	Gharbia	311.5
	Kafr-El Sheikh	225.5
	Dakahlia	393.5
	Damietta	77.9
	Menoufia	217.3
	Qalyoubia	311.5
		1537.2
Eastern Delta	Sharkia	192.7
	Ismailia	50.8
	Port Said	54.9
	Suez	33.6
	North Sinai	46.7
	South Sinai	20.5
		399.3
Western Delta	Alexandria	352.5
	Behera	303.3
	Matruh	25.4
		681.3
Middle Egypt	Cairo	1229.8
	Giza	393.5
	Beni Suef	67.2
	Fayoum	60.7
	Menia	118.1
	Assuit	59.0
		1928.3
Upper Egypt	Suhag	92.6
	Qena	109.4
	Luxor	27.1
	Aswan	75.4
	New Valley	11.1
	Red Sea	38.1
		353.8
	Total	**4899.8**

3.4.2.2 Availability of agricultural residues:

From Table 3-4, it is clear that among the cereals, wheat straw, barley straw and sorghum stalk are already completely utilized, mostly for animal feed and bedding. The same is true for soybeans haulm, peanut haulm and broad beans straw, competition for current uses is very high.

Table 3-16 and Figure 3-13 show that the total amount of dry agricultural residues available for bioenergy estimated at 4.6 million tonnes/year, based on the total amount of production and on percentage of availability and dry weight of each plant. These residues are cereals residues, in particular maize stalk (35%) and rice straw (18%). Additionally, other high–ranking crops include sugar cane bagasse (15%) among the sugar crops. A significant contribution from the fibre crops category comes from cotton (3%). The fruit category also shows a consistent degree of availability of residues, with citrus and orange (6%) in the highest ranking. In the vegetable's category, potato haulm (4.5%), tomato haulm and onion haulm (3.6%) show higher degree of availability of residues. Among legumes residues, green pea haulm and green beans haulm show higher availability.

Table 3-16: Availability of dry agricultural residues production by type

Agricultural residues	Availability of dry residues production 1000 tonnes/year
Maize stalk	1631.9
Rice straw	830.7
Sugar cane bagasse	705.3
Citrus & Orange pruning	274.4
Potato haulm	209.5
Tomato haulm	166.1
Onion haulm	150.7
Cotton stalk	135.8
Olive pruning	119.3
Grapes pruning	108.3
Palm dates pruning	68.7
Sugar beet haulm	45.7
Sesame stalk	36.3
Green pea haulm	31.9
Garlic haulm	22.9
Green beans haulm	22.1
Dry been residue	14.1
Sunflower stalk	13.8
Eggplant residue	12.8
Pepper stalk	5.7
Cabbage residue	5.5
Artichoke haulm	5.4
Strawberry haulm	5.1
Carrot haulm	3.9
Courgette haulm	3.6

Cucumber haulm	2.4
Cauliflower residue	1.7
Flax straw	1.1
Wheat straw	0.0
Sorghum stalk	0.0
Peanuts haulm	0.0
Broad beans straw	0.0
Soybeans haulm	0.0
Barley straw	0.0
Total	4634.9

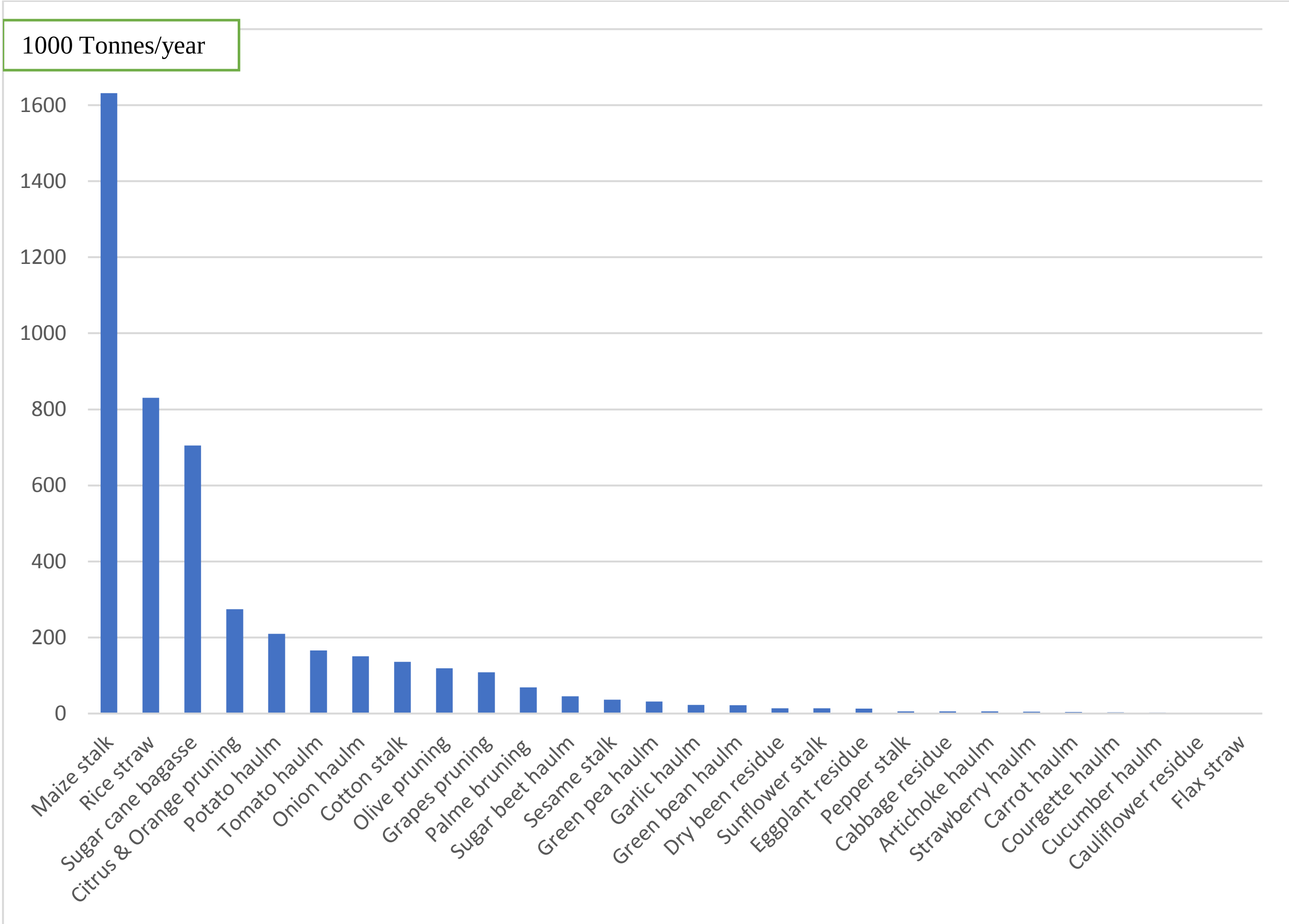

Figure 3-13: Availability of dry agricultural residues production by type

The analysis of residues available for bioenergy at region level reveals that middle delta and middle Egypt ranked at the top, accounting for 1.3 (28.4%) and 1.1 (24.5%) million tonnes. Western delta contributes 0.9 (19.5%) million tonnes/year of total availability. With 14.6% and 12.9% have upper Egypt and eastern delta the smallest share to the national availability.

The analysis at governorate level (Figure 3-14) reveals six groups where each group includes governorates with a substantial homogeneity and similarity in residue structure and/or quantity of production. Behera has the highest availability of dry agricultural residues with 0.8 million tonnes, accounting for 17.6% of total availability.

Second group includes Sharkia, Dakahlia and Assuit with contribution of 28% of national production, accounting for 0.45, 0.44 and 0.41 million tonnes/year, respectively.

Kafr-El Sheikh, Qena, Menia and Gharbia ranked third group with contribution of 1.1 million tonnes (23.1%).

With 0.84 million tonnes (18%) contribute Beni Suef, Menoufia, Fayoum, Suhag and Luxor, of the total available national residues.

Seven governorates ranked the fifth group with contribution of 0.5 million tonnes (11.3%). In this group the governorates show a range of 0.04 to 0.11 million tonnes.

The remaining governorates contribute with small production, accounting for 0.86 million tonnes/year (1.9%). The contribution in this group vary from 48.8 to 31,980 tonnes/year.

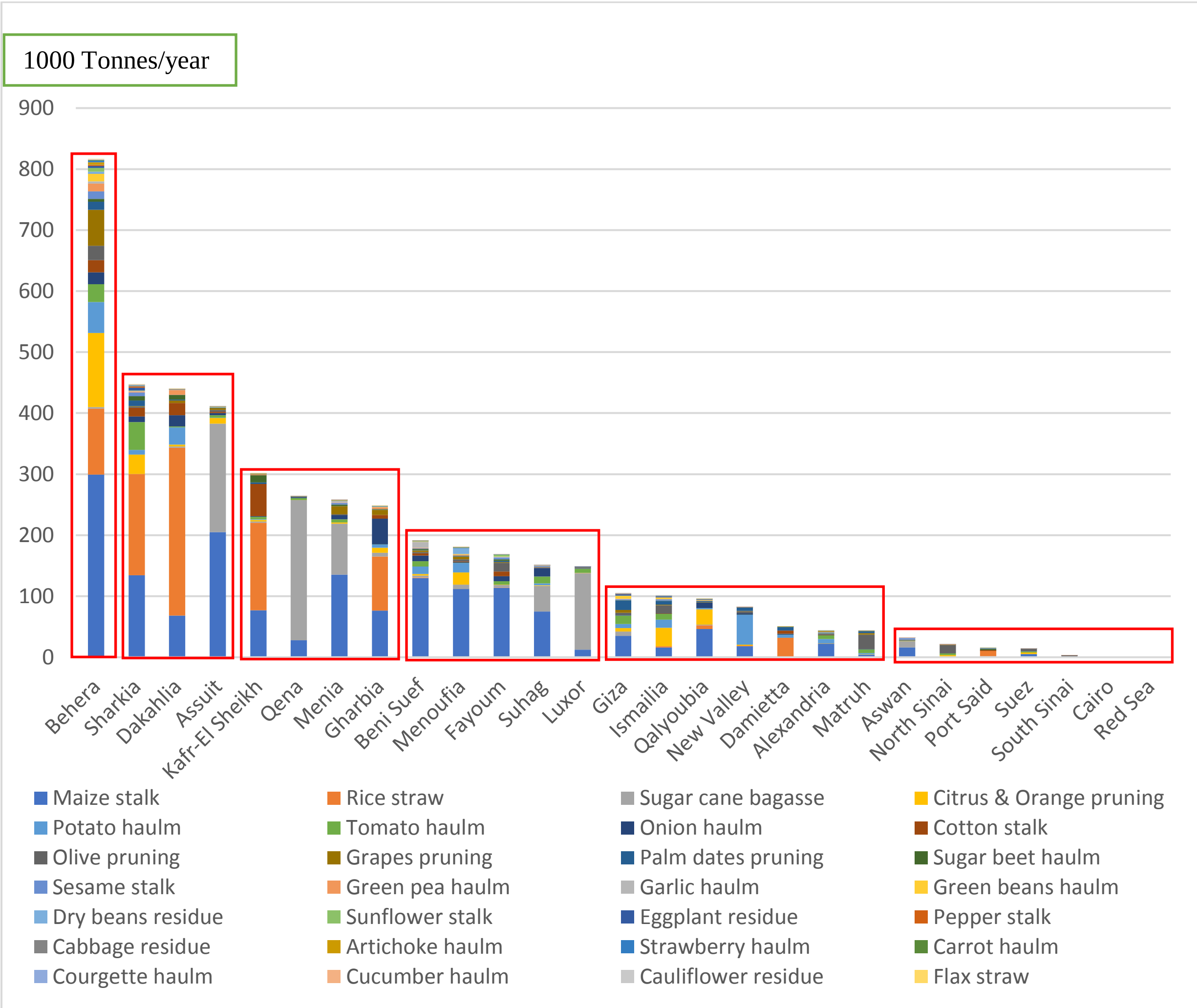

Figure 3-14: Availability of dry agricultural residues production per governorate

The geographical map (Figure 3-15) below shows the distribution of the availability of dry agricultural residues in Egypt and the distribution of residue types at governorate level. Similar to residue production, high rates of residue availability (the darker areas) is mainly concentrated in the middle delta region. Medium rates are located in Middle Egypt, along the Nile basin, while low rates are distributed among governorates further away from the Nile and along the coast.

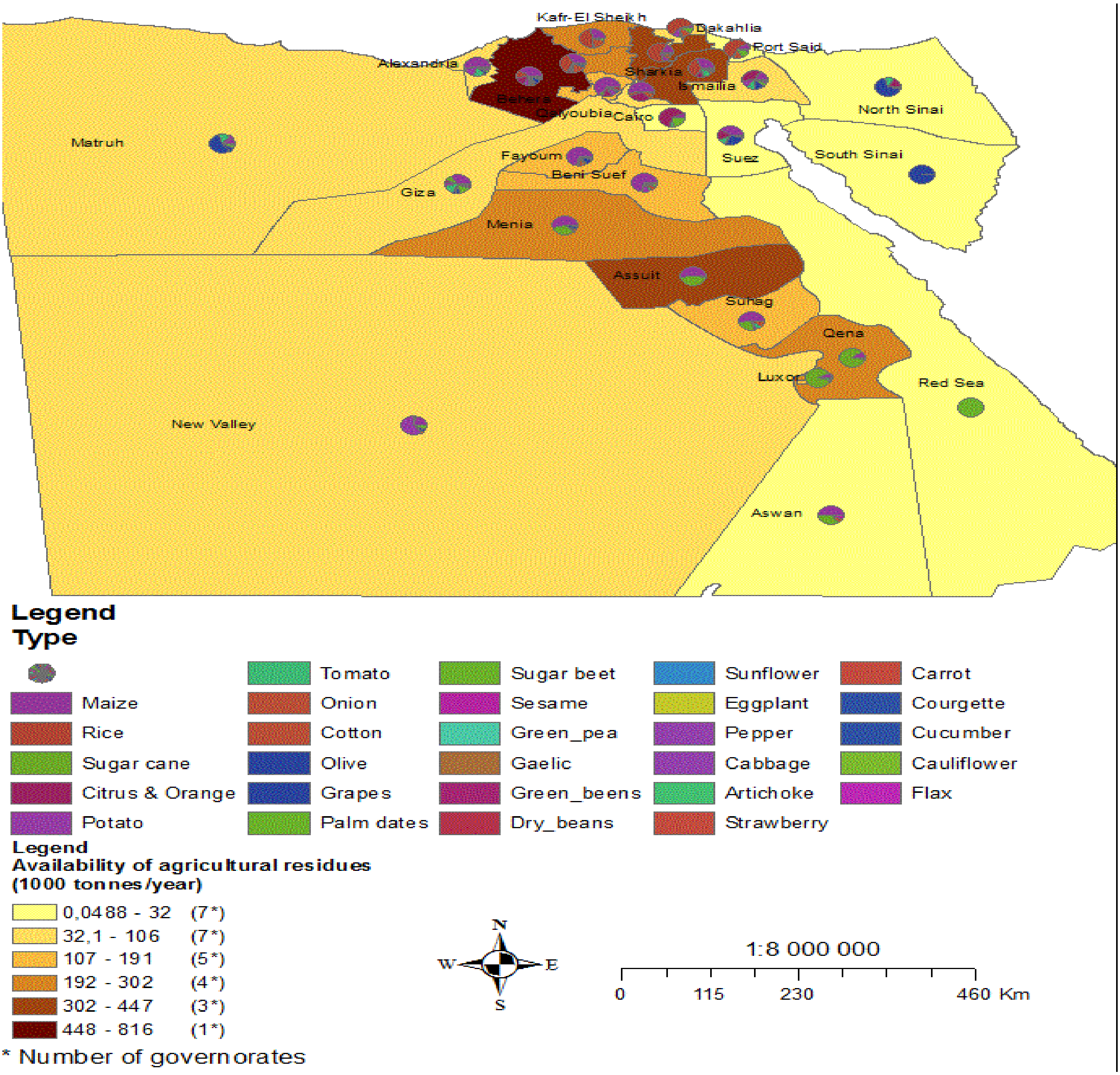

Figure 3-15: ArcGis map of availability of dry agricultural residue production in Egypt

3.4.2.3 Availability of livestock manure:

Table 3-17 shows that the total amount of dry livestock manure available for bioenergy estimated at 7.8 million tonnes/year, based on the total amount of production and on percentage of availability and dry weight factor of each livestock.

Almost half the total available quantity of manure produced (42%) derives from chicken manure. A significant contribution from cattle manure, accounting for 26.7% and 19.5% for cows and buffalos. Sheep and goats contribute 5.6% and 3.8% from the total availability of production. The rest of livestock contribute 2.4% to the total available.

Table 3-17: Availability of dry livestock manure by type

Livestock	Available manure production 1000 tonnes/year
Chicken	3261.1
Cows	2072.4
Buffalos	1512.9
Sheep	436.9
Goats	290.9
Donkeys	152.1
Camels	24.2
Horses	8.3
Mules	2.7
Total	7761.5

The analysis of manure available for bioenergy at region level reveals that middle delta and middle Egypt ranked at the top, accounting for 2.3 (29.6%) and 2.1 (26.5%) million tonnes. Eastern delta contributes 1.4 (17.4%) million tonnes/year of total availability. With 1.2 (15.5%) and 0.9 (11%) million tonnes have western delta and upper Egypt the smallest share to the national availability.

The analysis at governorate level (Figure 3-16) reveals five groups where each group includes governorates with a substantial homogeneity and similarity in residue structure and/or quantity of production. Sharkia have the highest availability of dry livestock manure with 1.1 million tonnes, accounting for 14.8% of total availability. Among the most productive governorates, Behera and Menia should also be mentioned, with a production 1 (13%) and 0.9 (11%) million tonnes of national production.

Second group includes Gharbia, Dakahlia and Qalyoubia with contribution of 19.6% of national production, accounting for 0.59, 0.47 and 0.46 million tonnes/year, respectively.

Eight governorates: Fayoum, Menoufia, Suhag, Kafr-El Sheikh, Giza, Assuit, Qena and Beni Suef ranked third group with contribution of 2.4 million tonnes (30.3%).

With 0.65 million tonnes (8.3%) contribute Ismailia, Damietta, Luxor, Alexandria, Cairo and Matruh of the total available national residues.

Seven governorates ranked the fifth group with contribution of 0.23 million tonnes (3%). In this group the governorates show a range of 5.8 to 65.7 thousand tonnes.

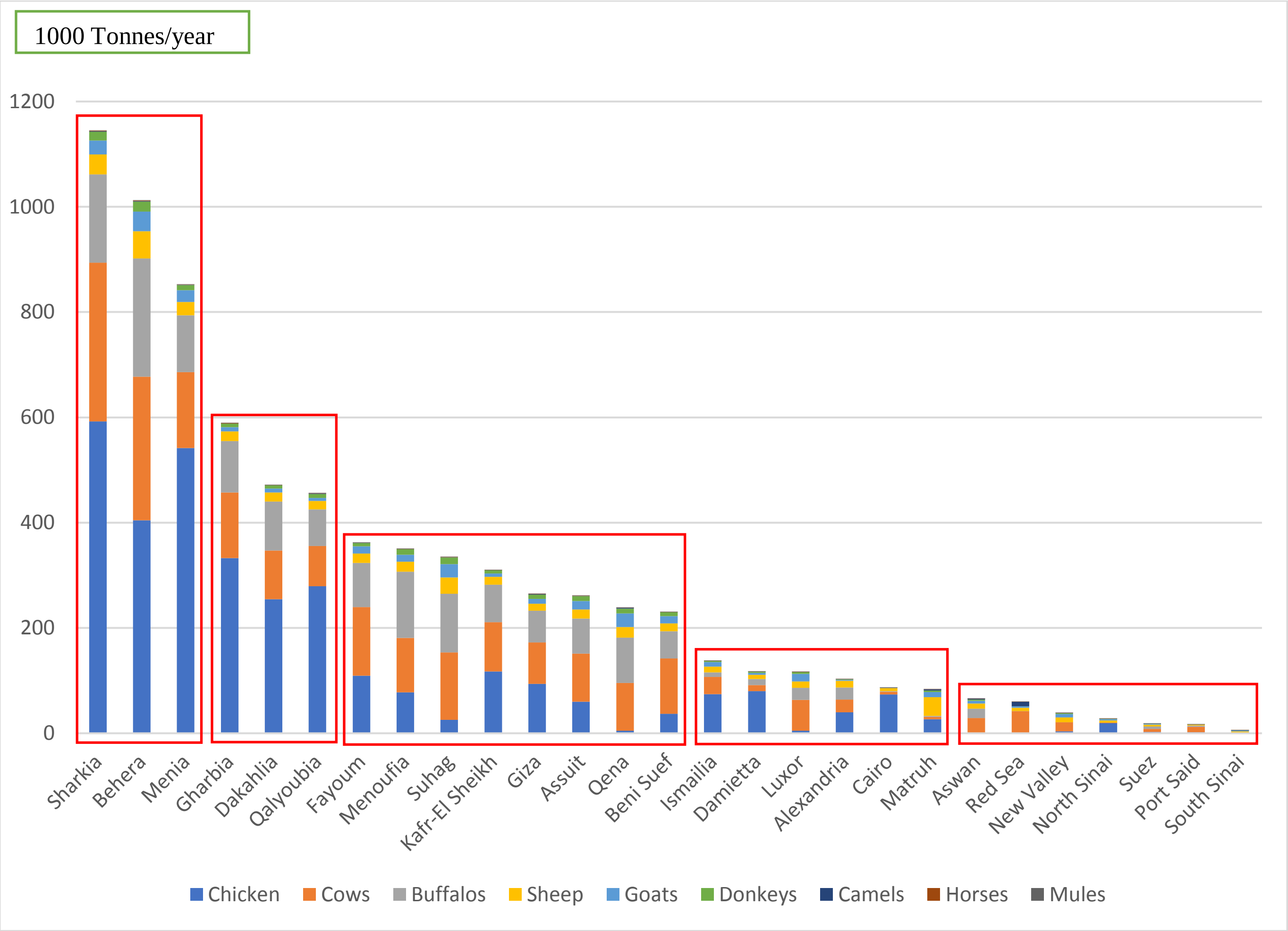

Figure 3-16: Total availability of dry livestock manure per governorate

The geographical map (Figure 3-17) below shows the distribution of the availability of dry livestock manure in Egypt and the distribution of residue types at governorate level. Similar to residue production, high rates of residue availability (the darker areas) is mainly concentrated in the middle delta region. Medium rates are located in Middle Egypt, along the Nile basin, while low rates are distributed among governorates further away from the Nile and along the coast.

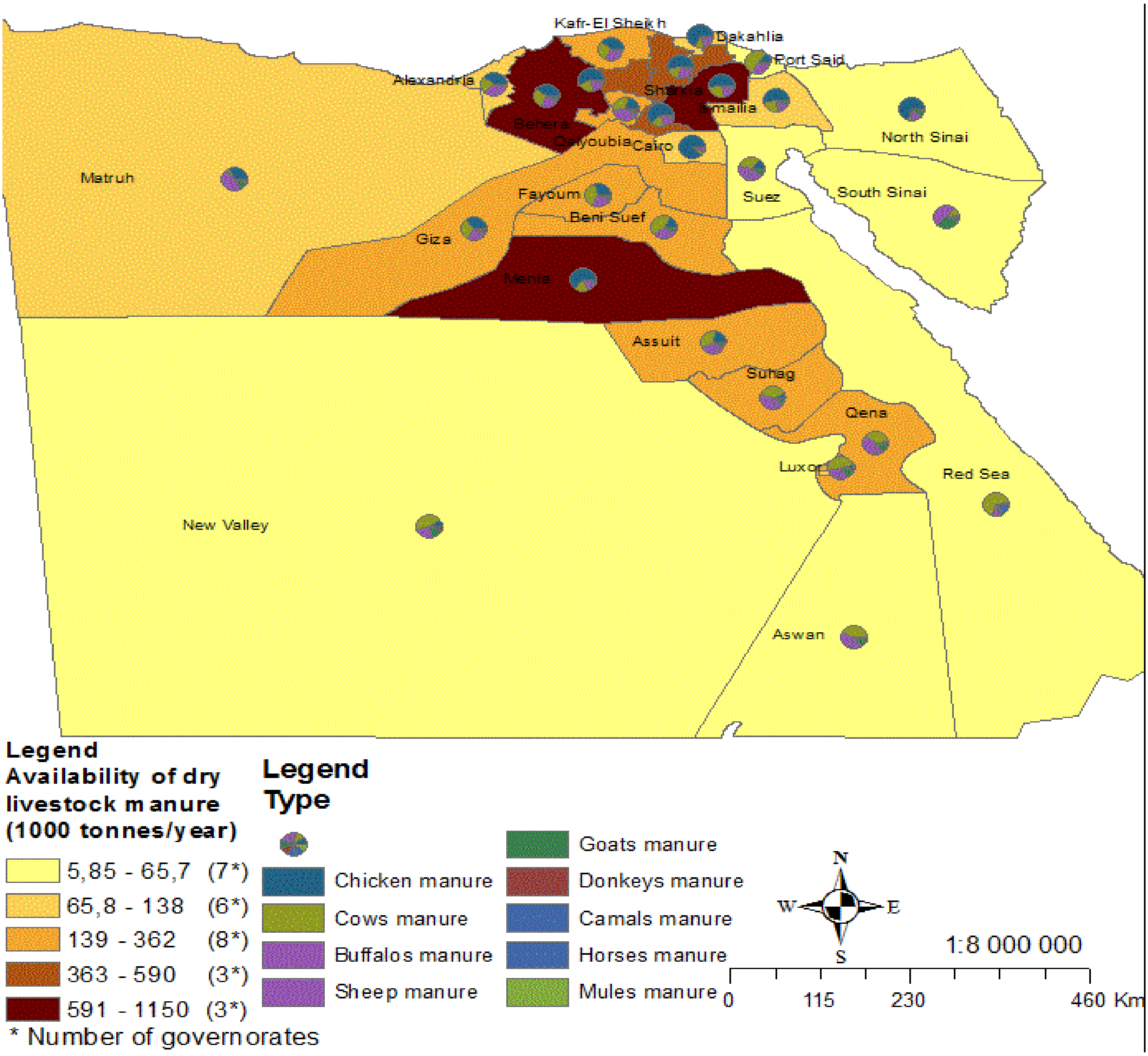

Figure 3-17: ArcGis map of availability of dry livestock manure production in Egypt

3.5 Summary

Based on the residue and waste types specified, the biomass potential evaluation analysis estimated the quantity of residues and wastes produced and potentially available for bioenergy production, as well as their geographical division within Egypt per governorate. Municipal solid wastes, agricultural residues and livestock manure were studied within the analysis. The evaluation covered production and availability and enumerates the issues that would need to be treated in terms of accessibility of residues. In general, the middle Egypt and middle delta regions show larger potential production and availability of biomass potential.

The total production of biomass as well as the total availability of dry biomass for bioenergy production were estimated to be around 135 and 18 million tonnes/year. In both cases, Behra and Sharkia are the governorates with the largest production in the country, accounting for 18.5 (14%) and 15.6 (12%) million tonnes/year of total production of biomass and for 2.1 (12%) and 11.8 (10%) million tonnes/year of total availability of dry biomass, respectively.

In the case of municipal solid wastes, the total production of biomass as well as the total availability of dry biomass for bioenergy production were estimated to be around 12 and 5 million tonnes/year. Cairo is the highest waste production governorate, accounting for 25% of total national production.

In the case of agricultural residues, the total production of biomass was estimated at 36 million tonnes per year. The most residues share in the total production derive cereals (51%), in particular wheat, maize and rice. In addition to cereals residues, sugar crops (15.3%), in particular sugar cane bagasse and sugar beet haulm, are promising feedstock for total production. Fruit tree pruning contribute 10% to the total residues production, a significant contribution comes from citrus and orange pruning (5.4%). Vegetables category become the second rank of total national residue production with contribution 19% of residues, with tomato haulm playing the most important role within the category (5%). Legumes residues contribute 1.059 million tonnes (3%) to the national residue production. A significant contribution from the fibre crops category comes from cotton (1%). The total availability of dry agricultural residues for bioenergy production was estimated to be around 5 million tonnes/year. maize stalk (35%), rice straw (18%), sugar cane bagasse (15%) and citrus and orange (6%) were the top four most available residues in the country. The analysis at governorate level reveals that Behera is the highest production and availability of dry agricultural residues.

In the case of livestock manure, the total amount of manure production was estimated to be around 86.5 million tonnes/year. Cattle (66%), sheep (11%), goats (8%) and chicken (7%) were the top four most manure production in the country. The total amount of manure available for bioenergy use was estimated to be around 7.8 million tonnes/year. The availability of cattle manure was found to be highest in the country, with 3.6 million tonnes/year, representing approximately half of the overall available amount in Egypt. Followed by chicken manure with 42% of the total available quantity of manure production in Egypt. At governorate level, Sharkia and Behra show the largest production and availability of manure.

4 Evaluation of bioenergy potential in Egypt

4.1 Background

The information presented in the previous chapter has shown that Egypt has vast potential of biomass resources, in particular municipal solid wastes, agricultural residues and animal manure. These biomass resources could be used to produce bioenergy.

There are many methods for the conversion of biomass into energy as depicted in Figure 4-1. Physico-chemical, biochemical and thermo-chemical conversion are the most common methods of biomass conversion [62, 63].

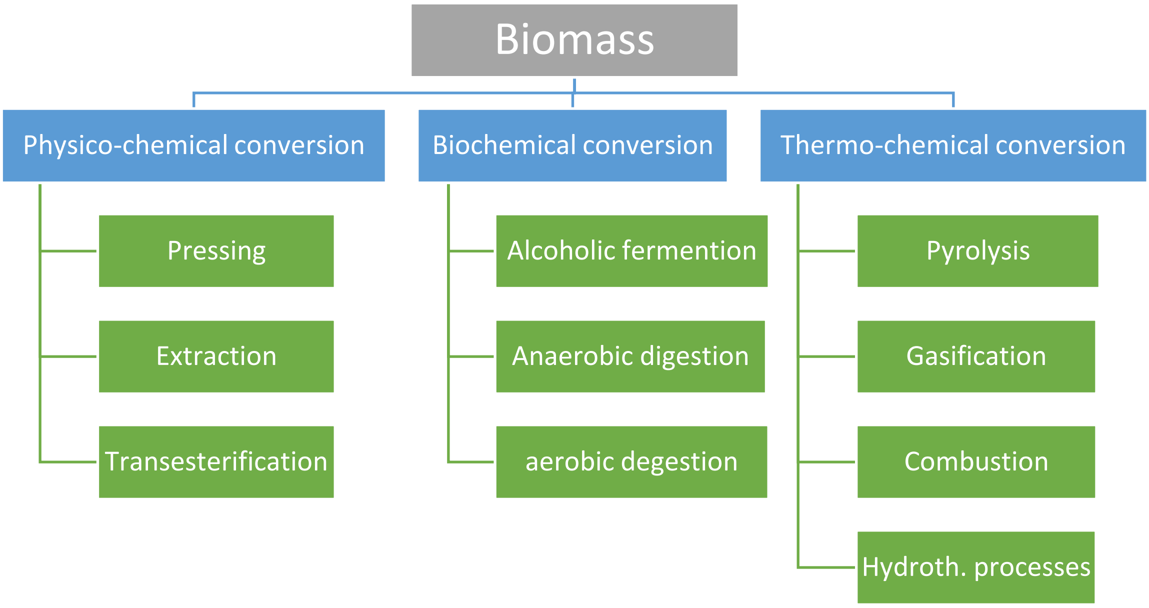

Figure 4-1: Biomass conversion methods [62]

In this study, two methods have been analysed: thermo chemical conversion by incineration and biochemical conversion by anaerobic digestion (biogas).

The anaerobic digestion conversion methods depend basically on the biodegradability of the organic fraction that can be contributed to produce bioenergy [64].

Incineration is a technology to utilize untreated or minimum treated wastes, where the wastes are combusted directly at high temperatures in the presence of air and produce ash, flue gas and heat. Besides the energetic benefits, it help to decrease the dump volumes [65]. In the thermo-chemical conversion, all of the organic matter, not only biodegradable, but also non-biodegradable, contributes to the energy output [64]. On the other hand, incineration of waste results in generation of chlorides of sodium and potassium which causes corrosion problems of the metallic parts of the boiler. Moreover, the produced ashes of incineration process, which might be hazardous and required to a special landfill. Emissions from boiler can include heavy metals, dioxins and furans, which may be present in the waste gases, water or ash. Waste incineration systems produce a wide variety of pollutants which are detrimental to human health. Incineration is a limitation of the recycling process and the costs of boiler can be enormous [66].

Therefore, in this study, anaerobic digestion used as the main method to convert biomass into energy and to compare the results, the potential bioenergy using incineration has been analysed. Table 4-1 below shows the data collection process that needed to estimate bioenergy potential.

Table 4-1: Data collection process for estimation of bioenergy potential

Municipal solid wastes	The list of total available amount of dry biomass from MSW
	LHV of MSW
	Volatile solid of MSW
	Methane yield of MSW
	Methane heating value
Agricultural residues	The list of total available amount of dry agricultural residue production
	The list of LHV
	The list of organic matter rate
	The list of volatile solid
	The list of methane yield
	Methane heating value
Livestock	The list of total available amount of dry livestock manure production
	The list of methane yield
	The list of methane yield
	Methane heating value

The following Table 4-2 shows the proximate analysis of agricultural residues as percentage from total dry weight.

Table 4-2: Proximate analysis of agricultural residues

Agricultural residues	Organic matter % [51]	Volatile solid % [53, 57, 67]	Methane yield m^3/kg of vs [53, 68, 69]	$LHV_{average}$ MJ/kg [49, 50, 57, 67, 70]
Maize stalk	91.22	73.19	0.34	17.95
Rice straw	82.76	66.62	0.47	14.92
Sugar cane bagasse	94.26	83.3	0.51	17.27
Citrus & Orange pruning	91.22	80.95	0.26	16.93
Potato haulm	83.62	71.76	0.47	13.5
Tomato haulm	89.01	73.15	0.26	12.42
Onion haulm	75.62	71.76	0.26	18.6
Cotton stalk	93.41	62.9	0.137[71]	17.09
Olive pruning	94.62	76.2	0.26	17.4
Grapes pruning	92.1	76.99	0.26	17.75
Palm dates pruning	94.4	77.71[72]	0.21	18.6
Sugar beet haulm	78.5	71.76	0.3	16.6
Sesame stalk	85.66	72.3	0.2	15.92
Green pea haulm	86.12	71.76	0.39	14.78

Garlic haulm	75.62	71.76	0.26	14.04
Green beans haulm	86.12	71.76	0.39	14.78
Dry beans residue	90 [50]	71.76	0.39	13.5
Sunflower stalk	87.5	71.76	0.31	17.19
Eggplant residue	87.2 [54]	71.76	0.26	17.07
Pepper stalk	92.28	80.61	0.26	12.68
Cabbage residue	78 [50]	71.76	0.26	14.9
Artichoke haulm	75.62	71.76	0.26	14.9
Strawberry haulm	75.62	71.76	0.26	14.9
Carrot haulm	75.62	71.76	0.26	14.9
Courgette haulm	75.62	71.76	0.26	14.9
Cucumber haulm	75.36	65.71	0.26	14.9
Cauliflower residue	75.62	71.76	0.26	14.9
Flax straw	98	78.8	0.2	18.71

The following Table 4-3 shows the proximate analysis of livestock manure as percentage from total weight.

Table 4-3:Proximate analysis of livestock manure

Manure type	Volatile solid % [57]	Methane yield m^3/kg of VS [53, 68, 69]
Cow	70.27	0.15
Buffall	70.27	0.16
Sheep	65.2	0.17
Goat	65.2	0.17
Chicken	69.13	0.33
Donkey	66.98	0.15
Camel	66.98	0.15
Horse	66.98	0.15
Mule	66.98	0.15

4.2 Materials and methodology

The materials and the methodology used to perform the present chapter and it will focus on evaluation of potential bioenergy from potential availability of dry biomass for all residue's types: estimation of the total bioenergy that could actually be accessed from potential biomass at governorate level and displayed the results in a geographic map by ArcGIS Desktop 10.6.1 Software.

4.2.1 Bioenergy potential from municipal solid wastes

The bioenergy potential from availability of dry municipal solid wastes in this study can be recovered from organic fraction of wastes, with an assumption that there is a recycling operation.

4.2.1.1 Biochemical conversion: Anaerobic digestion

Energy potential of municipal solid wastes via anaerobic digestion has been calculated according to Equation 4-1. Total available amount of dry biomass from municipal solid ($MSW_{av(i)}$) has been calculated according to Equation 3-5 and has been showed in Table 3-15. The volatile solid has been considered as percentage from organic matter (66%). The methane yield has been considered as volume from the volatile solid (0.23 m^3/kg of VS) [64]. The higher heating value of methane is according to literature 36 MJ/m^3 of methane yield [62].

Equation 4-1: Energy potential of municipal solid wastes via anaerobic digestion [52]

$$EP_{MSW(i)} = MSW_{av(i)} * VS * M_{yield} * HHV_{methane}$$

Where:

$EP_{MSW(i)}$ (PJ/year) = Energy potential of municipal solid wastes per governorate (i) and year

$MSW_{av(i)}$ (million tonnes/year) = Total available amount of dry biomass from municipal solid per governorate (i) and year

VS (%) = Volatile solid

M_{yield} (m^3/kg of VS) = Methane yield

$HHV_{methane}$ (MJ/m^3) = Higher heating value of methane

4.2.1.2 Thermo-chemical conversion: Incineration:

Energy potential of municipal solid wastes via incineration has been calculated according to Equation 4-2. The average of lower heating value ($LHV_{average}$) has been considered as 12.13 MJ/kg [57].

Equation 4-2: Energy potential of municipal solid wastes via incineration [56, 64]

$$EP_{MSW(i)} = MSW_{av(i)} * LHV_{average}$$

Where:

$EP_{MSW(i)}$ (PJ/year) = Energy potential of municipal solid wastes per governorate (i)/year

$MSW_{av(i)}$ (million tonnes/year) = Total available amount of dry biomass from municipal solid per governorate (i) and year

$LHV_{average}$ (MJ/kg) = The average of lower heating value

4.2.2 Bioenergy potential from agricultural residues

The bioenergy potential from agricultural residues in this study can be recovered from the available residues at the governorate level.

4.2.2.1 Biochemical conversion: Anaerobic digestion

The bioenergy potential from agricultural residues via anaerobic digestion can be calculated according to Equation 4-3.

Equation 4-3: Energy potential of agricultural residues via anaerobic digestion [56]

$$EP_{AR(i)} = AR_{av(i)} * VS * M_{yield(i)} * HHV_{methane}$$

Where:

$EP_{AR(i)}$ (PJ/year) = Energy potential of agricultural residues per governorate (i) and year

$AR_{av(i)}$ (million tonnes/year) = Total available amount of dry agricultural residue production per governorate (i) and year

VS (%) = Volatile solid per type

$M_{yield(i)}$ (m^3/kg of VS) = Methane yield per type

$HHV_{methane}$ (MJ/m^3) = Higher heating value of methane

The volatile solid has been considered as percentage from total dry weight and listed in Table 4-2. The methane yield has been considered as volume from the volatile solid and listed in Table 4-2. The higher heating value of methane is according to literature 36 MJ/m^3 of methane yield [62].

4.2.2.2 Thermo chemical conversion: Incineration

The bioenergy potential from agricultural residues via incineration can be calculated according to Equation 4-4.

Equation 4-4: Energy potential of agricultural residues via incineration [56, 64]

$$EP_{AR(i)} = AR_{av(i)} * OM * LHV_{average}$$

Where:

$EP_{AR(i)}$ (PJ/year) = Energy potential of agricultural residues per governorate (i) and year

$AR_{av(i)}$ (million tonnes/year) = Total available amount of dry agricultural residue production per governorate (i) and year

OM_{rate} (%) = Organic matter rate

$LHV_{average}$ (MJ/kg) = The average of lower heating value

Total available amount of dry agricultural residue production has been calculated according to Equation 3-6 and listed in Table 3-16. The organic matter is taken as percentage from total dry weight and listed in Table 4-2. The average of lower heating value of the residues is as approximate value from the literature depended on the dry weight of the residues.

4.2.3 Bioenergy potential from animal manure

The bioenergy potential from livestock manure in this study can be recovered from the available manure at the governorate level. Because of the higher moisture content of manure, wherefore in this study, biochemical conversion by anaerobic digestion (biogas) is used to produce bioenergy from livestock manure.

4.2.3.1 Biochemical conversion; Anaerobic digestion

The bioenergy potential from livestock manure via anaerobic digestion can be calculated according to Equation 4-5.

Equation 4-5: Energy potential of livestock manure via anaerobic digestion [56]

$$EP_{LV(i)} = LVM_{av(i)} * VS * M_{yield} * HHV_{methane}$$

Where:

$EP_{LV(i)}$ (PJ/year) = Energy potential of livestock manure per governorate (i) and year

$LVM_{av(i)}$ (million tonnes/year) = Total available amount of dry livestock manure production per governorate (i) and year

VS (%) = Volatile solid per type

M_{yield} (m^3/kg of VS) = Methane yield per type

$HHV_{methane}$ (MJ/m^3) = Higher heating value of methane

Total amount of available livestock manure production has been calculated according to Equation 3-7 and listed in Table 3-17. The volatile solid has been considered as percentage from total dry weight and listed in Table 4-3. The methane yield has been considered as volume from the volatile solid and listed in Table 4-3. The higher heating value of methane is according to literature 36 MJ/m^3 of methane yield [62].

4.3 Results and discussion

4.3.1 Biochemical conversion: Anaerobic digestion

The results show that the total bioenergy potential produced using anaerobic digestion in Egypt estimated at 103 PJ/year, in particular 27 (26%), 44 (43%) and 32 (31%) PJ/year produced from municipal solid wastes, agricultural residues and livestock manure respectively.

The analysis of bioenergy potential using anaerobic digestion at governorate level reveals that some governorates are visibly more productive than others. In Table 4-4, the analysis at regions level, five regions can be recognized, with middle delta and middle Egypt have ranking at the top, with similar accounting for 30.26 and 30.19 PJ/year contributing for 29.4% and 29.3% of total bioenergy. Western delta ranked at the third place with 15.66 PJ/year, contributing 15.2% of nation production. Upper Egypt and eastern delta have the smallest share to the national production with contributing 14.02 (13.6%) and 12.82 (12.5%) PJ/year.

Table 4-4: Bioenergy potential using anaerobic digestion

Region	Governorate	MSW	Agricultural residues	Livestock manure	Total
PJ/year					
Middle Delta	Gharbia	1.70	2.27	2.44	6.41
	Kafr-El Sheikh	1.23	2.69	1.28	5.2
	Dakahlia	2.15	4.47	1.96	8.58
	Damietta	0.43	0.48	0.50	1.41
	Menoufia	1.19	1.61	1.45	4.25
	Qalyoubia	1.70	0.82	1.91	4.43
		8.40	**12.33**	**9.53**	**30.26**
Eastern Delta	Sharkia	1.05	4.06	4.73	9.84
	Ismailia	0.28	0.73	0.57	1.58
	Port Said	0.30	0.14	0.07	0.51
	Suez	0.18	0.09	0.08	0.35
	North Sinai	0.26	0.05	0.12	0.43
	South Sinai	0.11	0.0005	0.02	0.1305
		2.18	**5.06**	**5.58**	**12.82**
Western Delta	Alexandria	1.93	0.37	0.42	2.72
	Behera	1.66	6.49	4.17	12.32
	Matruh	0.14	0.14	0.35	0.63
		3.72	**7.00**	**4.94**	**15.66**
Middle Egypt	Cairo	6.72	0.004	0.36	7.084
	Giza	2.15	0.84	1.10	4.09
	Beni Suef	0.37	1.64	0.94	2.95
	Fayoum	0.33	1.30	1.47	3.1
	Menia	0.65	2.66	3.55	6.86
	Assuit	0.32	4.71	1.08	6.11
		10.54	**11.15**	**8.50**	**30.19**

Upper Egypt	Suhag	0.51	1.54	1.37	3.42
	Qena	0.60	3.81	0.98	5.39
	Luxor	0.15	2.09	0.47	2.71
	Aswan	0.41	0.33	0.27	1.01
	New Valley	0.06	0.84	0.16	1.06
	Red Sea	0.21	0.0003	0.23	0.4403
		1.93	**8.61**	**3.48**	**14.02**
	Total	**26.78**	**44.16**	**32.03**	**102.97**

At the governorates level, Figure 4-2 shows five groups where each group includes governorates with a substantial homogeneity and similarity in residue structure and/or quantity of production. Behera is the governorate with the highest bioenergy potential production in the country, with 12.32 PJ/year contributing 12% to the national production. Among the most productive governorates, Sharkia and Dakahlia should also be mentioned, with 9.84 (9.6%) and 8.58 (8.3%) PJ of national production.

With more than 37.05 PJ ranked Cairo, Menia, Gharbia, Assuit, Qena and Kafr-El Sheikh group the second place, contributing 36% of national production. The bioenergy potential composition in this group is diverse, most of production derive from municipal solid wastes (95.3%) in Cario, from livestock manure (63.7%) in Menia and from agricultural residues in Assuit (77%), Qena (70.7%) and Kafr-El Sheikh (51.8%).

More than 27.67 PJ (26.9%) of bioenergy produced is distributed among eight governorates: Qalyoubia, Menoufia, Giza, Suhag, Fayoum, Beni Suef, Alexandria and Luxor. In this group, production vary from 2.7 to 4.4 PJ/year/governorate.

The fourth group includes Ismailia, Damietta, New Valley and Aswan provides 5.06 PJ (4.9%) of the total national production, with 1.58, 1.41, 1.06 and 1.01 PJ/year respectively.

The last group includes the remaining governorates: Matruh, Port Said, Red Sea, North Sinai, Suez and South Sinai provides 2.4% of the total national production with 2.49 PJ/year. In this group, production vary from 0.13 to 0.63 PJ/year/governorate.

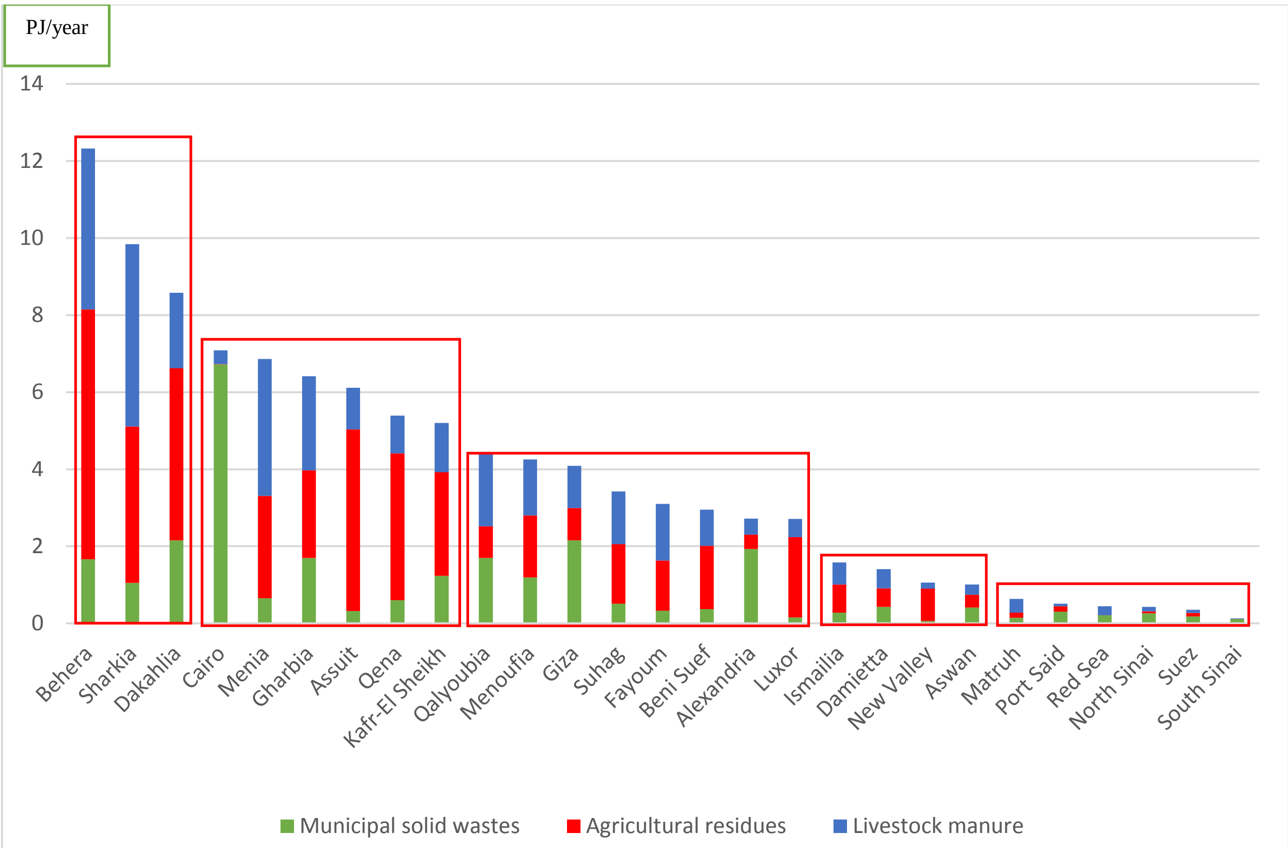

Figure 4-2: Bioenergy potential by governorate and type

In order to calculate the electric energy, it was assumed that combined and heat power (CHP9 was used to produce electrical and thermal energy. The electrical and thermal conversion efficiency assumed as 38% and 47% [56]. The results show that for 103 PJ/year total energy production, the annual electrical and thermal energy were 39.14 PJ (10.9 TWh) and 48.41 PJ (13.4 TWh). This could cover 7% of the total electricity consumption, as well as the thermic energy that can be used for external needs.

The geographic map below (Figure 4-3) displays also the total bioenergy potential production and the residue type at governorate level in Egypt. The darker brown the color, the more productive is the region. The lighter colors on the map displays the lower production. It should also be mentioned that the more along the Nile basin is, the more productive.

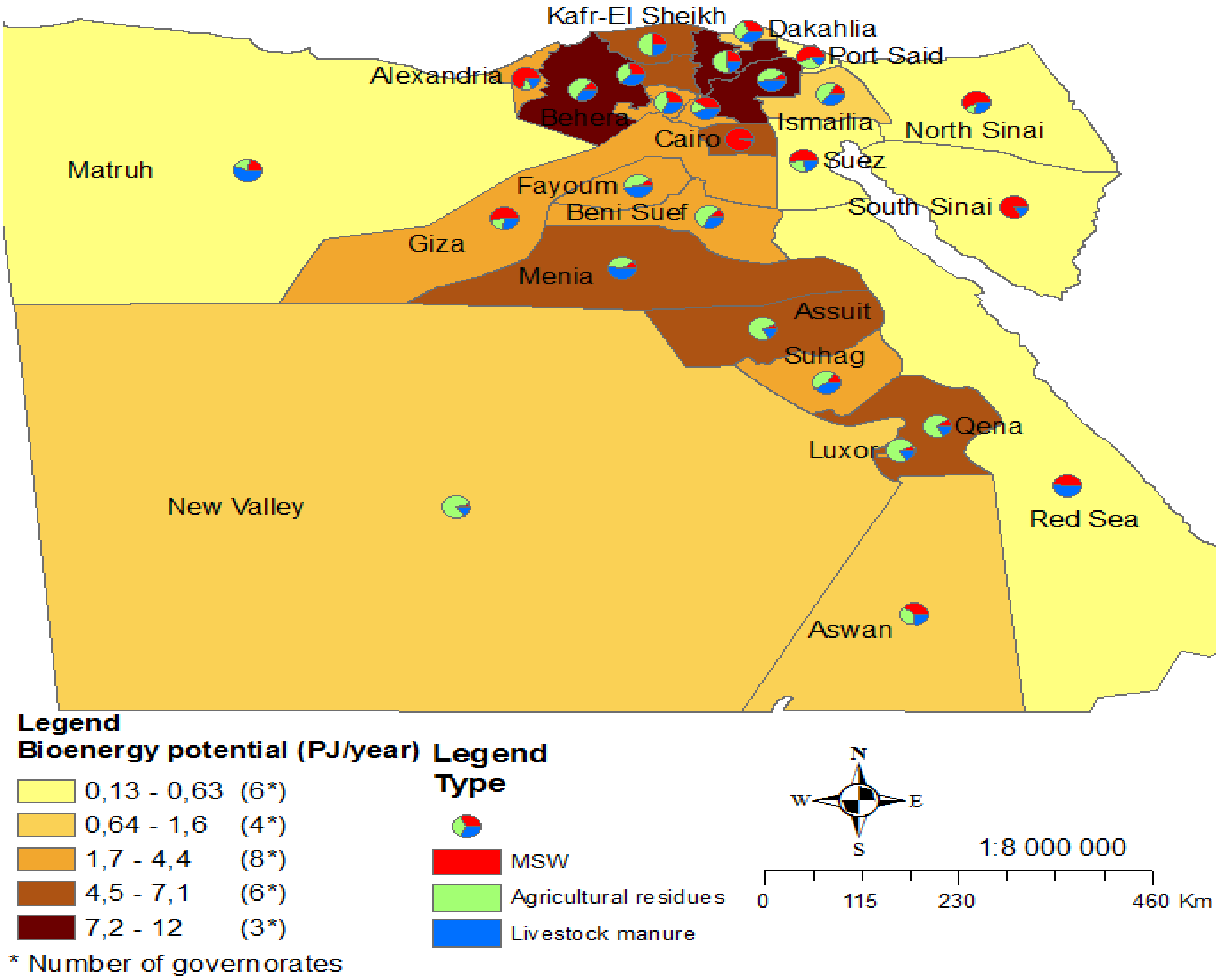

Figure 4-3: ArcGis map of bioenergy potential in Egypt

4.3.2 Thermo chemical conversion: Incineration

The results show that the total bioenergy potential produced using incineration in the country estimated at 59.4 and 69.1 PJ/year from municipal solid wastes and agricultural residues.

The analysis of bioenergy potential using incineration at governorate level reveals that some governorates are visibly more productive than others. Table 4-5 shows the results using thermo-chemical conversion via incineration from municipal solid wastes and agricultural residues, five regions can be recognized. Most of bioenergy potential from municipal solid wastes derive middle Egypt and middle delta, accounting for 23.4 and 18.6 PJ/year, contributing for 39.4% and 31.3% of total bioenergy. Western delta, Eastern delta and upper Egypt contribute 8.3, 4.8 and 4.3 PJ/year, accounting for 14%, 8.1% and 7.2% respectively. Cairo is the largest bioenergy production governorate from municipal solid wastes, accounting for 25%.

More than 50% of bioenergy potential from agricultural residues produced is distributed middle delta and middle Egypt, accounting for 18.6 and 18 PJ/year. Western delta, upper Egypt and Eastern delta contribute 13.6, 10.6 and 8.5 PJ/year, accounting for 19.7%, 15.3% and 12.3% respectively. Behera is the highest bioenergy production governorate from agricultural residues, accounting for 17.5%. The bioenergy potential value obtained from municipal solid wastes and agricultural residues using incineration is greater than that obtained using anaerobic digestion. This is because, in the incineration, all of organic matter, not only biodegradable like in anaerobic digestion, but also non- biodegradable, contributes to the bioenergy output.

Table 4-5: Bioenergy potential using incineration

Region	Governorate	Municipal solid wastes	Agricultural residues
PJ/year			
Middle Delta	Gharbia	3.78	3.55
	Kafr-El Sheikh	2.73	4.26
	Dakahlia	4.77	5.83
	Damietta	0.94	0.67
	Menoufia	2.64	2.79
	Qalyoubia	3.78	1.47
		18.65	**18.58**
Eastern Delta	Sharkia	2.34	6.24
	Ismailia	0.62	1.48
	Port Said	0.67	0.20
	Suez	0.41	0.23
	North Sinai	0.57	0.33
	South Sinai	0.25	0.06
		4.84	**8.52**
Western Delta	Alexandria	4.28	0.63
	Behera	3.68	12.12
	Matruh	0.31	0.67
		8.26	**13.42**
Middle Egypt	Cairo	14.92	0.01
	Giza	4.77	1.59
	Beni Suef	0.82	2.92
	Fayoum	0.74	2.68
	Menia	1.43	4.13
	Assuit	0.72	6.66
		23.39	**17.99**
Upper Egypt	Suhag	1.12	2.35
	Qena	1.33	4.28
	Luxor	0.33	2.38
	Aswan	0.91	0.51
	New Valley	0.13	1.09
	Red Sea	0.46	0.001
		4.29	**10.60**
	Total	**59.43**	**69.12**

4.4 Summary

An evaluation was carried out to assess the viability of selected bioenergy technologies anaerobic digestion and direct incineration. Anaerobic digestion used as the main method to convert biomass into energy and to compare the results, the potential bioenergy using incineration has been analysed. The aim was to identify the total bioenergy potential, based on the identified biomass amounts available, as well as their geographical division within Egypt per governorate.

In the case of anaerobic digestion, the total bioenergy potential produced using anaerobic digestion in the country estimated at 103 PJ/year, in particular 27 (26%), 44 (43%) and 32 (31%) PJ/year for bioenergy produced from municipal solid wastes, agricultural residues and livestock manure respectively. Middle delta and middle Egypt have ranking at the top, with similar contributing for 29.4% and 29.3%, respectively. The governorates of Behera, Sharkia and Dakahlia are the most promising areas, contributing 12%, 9.6% and 8.3%, of national production, respectively. Using CHP shows that the electrical and thermal energy were 39.14 (10.9 TWh) and 48.41 PJ/year (13.4 TWh). This could cover 7% of the total electricity consumption, as well as the thermic energy that can be used for external needs.

Because of the higher moisture content of manure, wherefore in this study, biochemical conversion by anaerobic digestion (biogas) is used to produce bioenergy from livestock manure.

In the case of incineration, the total bioenergy potential produced using incineration in the country estimated at 59.4 and 69.1 PJ/year from municipal solid wastes and agricultural residues.

The bioenergy potential value obtained from municipal solid wastes and agricultural residues using incineration is greater than that obtained using anaerobic digestion. This is because, in the incineration, all of organic matter, not only biodegradable like in anaerobic digestion, but also non- biodegradable, contributes to the bioenergy output.

5 Techno-Economic evaluation of biogas plant in one governorate in Egypt

The aim of this chapter is to simulate, dimension and perform the economic analysis of the case study of a biogas plant for treatment of biomass from one governorate in Egypt by EcoGas (Version 07-E1) Software.

The information presented in the previous chapter has shown that Behera is the governorate with the highest bioenergy potential production in the country, using biochemical conversion via anaerobic digestion. Therefore, the biogas plant has been considered in a small area of this governorate.

5.1 Background

5.1.1 Anaerobic Digestion Parameters

AD has several stages and those carried out by diverse microorganisms that depends on several parameters with different conditions. The main parameters are related to reactor operating conditions and influencing characteristics. These parameters and their effects are discussed in the following paragraphs [42].

5.1.1.1 The type of biomass

The composition of the substrates determines the theoretical biogas yield (Table 5-1) [73]. The stability of the AD process is reflected by the concentration of intermediate products like the volatile fatty acids (VFA), where instability lead to accumulation of VFA, which can lead furthermore to a drop of pH value. The drop of pH value of the medium below 6.2 will lead to a toxic effect on the methanogenic bacteria [62].

Table 5-1: Theoretical biogas yields

Substrate	Biogas Nm^3/kg TS	CH_4 (%)	CO_2 (%)
Raw protein	700	67-68	32-33
Raw fat	1200-1250	70-71	29-30
Carbohydrates	790-800	50	50
Lignin	00	0	0

5.1.1.2 Temperature

Temperature is a very important physical characteristic for the microbial growth and thus for AD and it is important to keep a constant temperature during the digestion process. Low temperatures lead to higher viscosity; therefore, the start-up period may take longer, and the removal efficiency decreases. Higher temperatures lead to faster rates of reaction, therefore, producing more efficient operation and results in smaller tank sizes as well as in higher metabolic rates, consequently higher specific growth rates. Table 5-2 shows temperature requirements in the different stages of anaerobic digestion [42, 62].

Table 5-2: Temperature requirements in the different stages of anaerobic digestion

Influencing variable	Acidogenesis	Methanogenesis	
Temperature (°C)	25-35	Mesophilic	32-42
		Thermophilic	50-58

5.1.1.3 pH-values

The different microorganisms involved in anaerobic digestion have variable optimal pH-values, therefore, the pH-value is important for each stage. The pH-value decreases, as mentioned above, by accumulation of VFA. The pH-value can be increased by ammonia production or adding alkali metals. The optimum pH ranges between 5.2 and 6.3 for acidogenesis stage and between 6.7 and 7.5 for methanogenesis stage [62].

5.1.1.4 Hydraulic retention time (HRT)

HRT is a measure of the average time that a soluble compound remains in a constructed bioreactor. HRT is the volume of the aeration tank divided by the influent flow rate. It is an important factor to establish the bioreactor size as it relates the digester volume with the influent flow rate. HRT decreases when the influent flow rate increases. The methane production is related to HRT, the longest time in the reactor leading to biodegradation of most organic matter and more biogas production, otherwise, the longest time reduces the plant economy [42, 62].

5.1.1.5 Organic loading rate (OLR)

OLR is the organic substrate fed per time unit divided by the volume of the aeration tank. Increasing of OLR lead to an increase of the treatment efficiency of complex wastewaters in high rate anaerobic reactors up to a certain limit. Otherwise increase in OLR will lead to operational problems like sludge bed flotation, as well as accumulation of undigested ingredients. The OLR can be varied by changing the influent concentration and by changing the flow rate. Thus, implies changing the HRT and by changing the flow rate [42].

5.1.1.6 Sludge retention time (SRT)

SRT is the key parameter affecting biochemical and physical properties of sludge. It is the mass of solids in tank divided by solids removal rate. It determines the ultimate amount of hydrolysis and methanogenesis in a upflow anaerobic sludge blanket (UASB). It should be long enough to provide sufficient methanogenic activity at the prevailing conditions [42].

5.1.2 Anaerobic digestion technology

The construction methods of the biogas plants can differ due to the different arrangement of the components and a different process technology. However, the basic scheme of a biogas plant is very similar. The kind and quantities of substrate are the most important variables that affects the biogas plant design, where the type of substrate determine the technology used while the amount if substrate determine the digester size, storage capacity and CHP unit [26].

The process stages and biogas plant components shown in Figure 5-1[26]:

- Storage stage includes the storage tank for manure (2), the collection bins (3), the sanitation tank (4), the drive-in storage tanks (5) and the solid feedstock feeding system (6).
- Biogas production stage includes the biogas reactor (digester) (7)
- Biogas storage and utilisation stage includes gas storage tank (8) and the CHP-unit (9).
- Fertiliser storage stage includes the storage tank for digestate (10) and the utilisation of digestate as fertiliser on the fields (11).

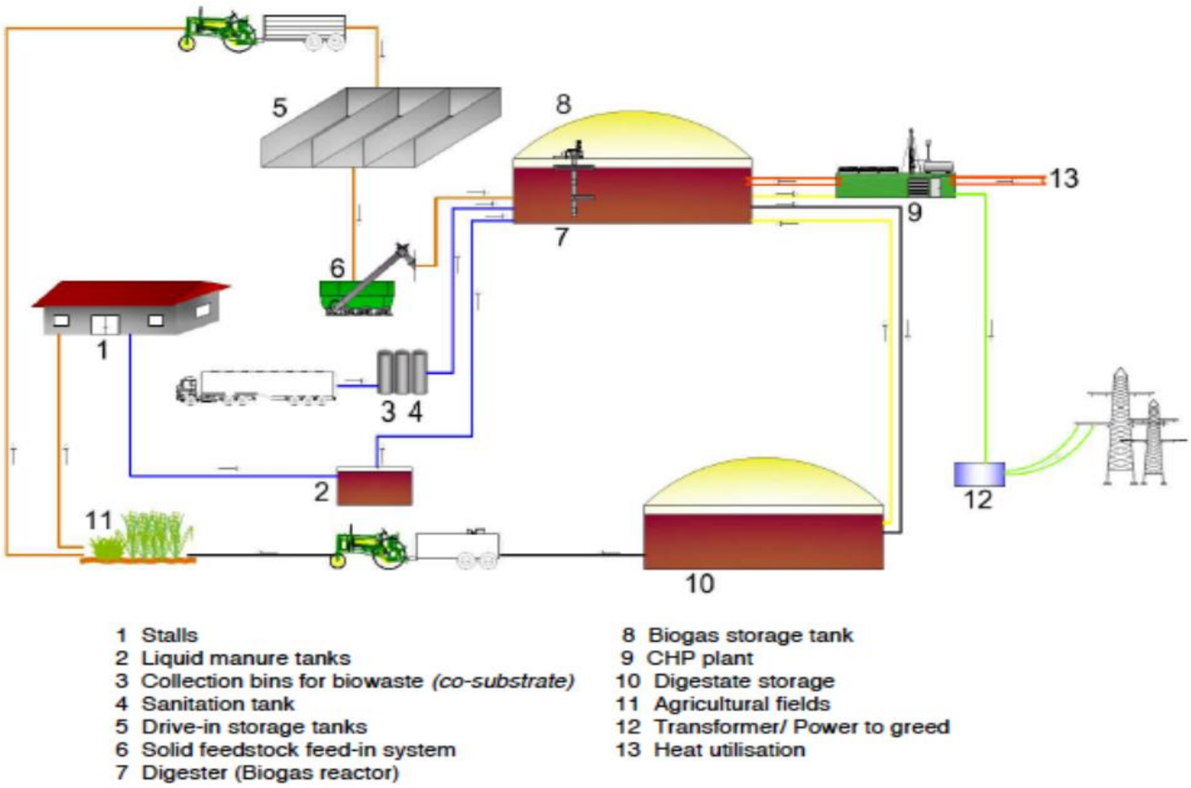

Figure 5-1: Typical biogas plant [25]

5.1.2.1 Feedstock storage and conditioning

The substrates, such as liquid manure, solid manure, renewable raw materials, ... or co-substrates must be stored. Storage can take place in storage tanks, flat storage, etc. The legal and structural regulations have to be followed. The storage capacity must be coordinated with the biomass required for biogas plant [74].

In order to create a favourable starting situation for the biogas process, the substrate is prepared before being introduced. There are several possibilities for conditioning the substrates[26]:

- Feedstock sorting and separation.
- Sanitation.
- Crushing.
- Mashing and homogenising.

5.1.2.2 Feeding system

Feeding system is input and output system for fed the substrates into the digester. The feeding technique depends on the feedstock type. There are two types of feeding system depending on pumpability of substrates: pumps for transport of pumpable feedstock (animal manure and liquid organic wastes, and transport of stackable feedstock (non-pumpable substrates such as fibrous materials, grass and silage). Other classification of feeding system depends on feeding mode, continuous feeding, where the substrates are constantly fed into the digester, and batch feeding, where the substrates are loaded with a portion which is allowed to digest and then is completely removed [26].

5.1.2.3 Digester (biogas reactor):

Digesters are air proof reactor tanks, where the anaerobic digestion of substrates takes place, and where biogas is produced. There are common characteristics of all digesters such as air proof, feeding system and output system for biogas and digestate. Digesters can be vertical, horizontal or multiple tank systems. Other classification of digesters depends on dry matter content, where there are two types, dry digestion, dry matter content is 20-40% DM, it does not need stirring, and wet digestion, dry matter content is about < 15% DM, needs stirring. Because the stirring of biomass inside digesters taking place by passive stirring is not adequate for optimal operation an active stirring must be implemented, using mechanical, hydraulic or pneumatic equipment [26, 41].

5.1.2.4 Biogas storage and cleaning

The resulting biogas is initially stored in a biogas storage. Biogas storage systems differ significantly in their operating pressure and construction [26]:

- Low pressure tank: overpressure in the tanks between 0.05 – 0.5 mbar.
- Medium and high-pressure tanks: pressure in the tanks between 5 – 250 bar.
- Biogas flares: back-up solutions for extraordinary high gas production rates. However, this is not efficient and should only be used for emergency situations.

Biogas cleaning takes place to remove water H_2S and other undesired trace contaminants. Biogas upgrading takes place to remove CO_2. The biogas cleaning stages are gas conditioning, desulphurization and drying [26].

5.1.2.5 The control unit

Aiming to guarantee successful operation and avoid failures, centrally controlling and monitoring with computer is an essential part of plant operation. Following parameters should be monitored, as a minimum [26]:

- Type and quantity of inserted feedstock (daily).
- Process temperature (daily).
- pH value (daily).
- Gas quantity and composition (daily).
- Short-chain fatty acids content.
- Filling level.

5.1.2.6 Combined heat and power (CHP) plant

CHP (Combined Heat and Power) or co-generation is coupled generation of heat and electrical and/or mechanical power from biogas, where biogas is burned in a block power plant or in an internal combustion engine that drives a generator to generate electricity. More efficiency and benefits are derived from CHP. The electricity can be used in the AD process or sold to the grid. The heat can be used in the AD to heat up the digester and approximately 2/3 of all produced energy can be used for external needs such as industry processes, agricultural activities, households and space heating or for power-heat-cooling-coupling systems [41].

5.2 Materials and methodology

The materials and the methodology used to perform the present chapter and it will focus on simulation, dimensioning and performance the economic analysis of the case study biogas plant for treatment of biomass from one governorate in Egypt (Behera) by EcoGas Software.

5.2.1 Raw materials

The biomass substrates were selected from the total available production of Behera the governorate with the highest bioenergy potential production in the country. The selection was based on either the substrates with the highest production in this governorate or/and the substrates with the highest methane yield.

In order to use the EcoGas Software previously the following information were needed:

- Fresh matter (tonnes)
- Mixture ratio (%)
- W_f – The dry weight factor (%)
- VS –Volatile solids (%)
- Bulk density (tonnes/m^3)
- Methane yield (m^3/kg of vs)
- Operation time (days)
- Average methane concentration (%)
- HRT–Hydraulic retention time (days)
- Digester: number of digesters and digester internal temperature

Table 5-3: Fresh matter and bulk density for each substrate

Substrate	Fresh matter Tonnes	Bulk density tonnes/m^3 [75-78]
Maize stalk	4500	0.2
Citrus & Orange pruning	1700	0.2
Rice straw	1200	0.4
Onion haulm	1000	0.2
Grapes pruning	800	0.2
Green pea haulm	600	0.2
Tomato haulm	600	0.2
Green beans haulm	600	0.2
Potato haulm	500	0.2
Cotton stalk	400	0.2
Sugar beet haulm	400	0.2
Olive pruning	200	0.2
Sunflower stalk	75	0.2
Sugar cane bagasse	20	0.7
MSW	5	0.5
Cows manure	850	1
Buffalos manure	700	1
Chicken manure	1600	1

Table 5-3 shows the total amount of fresh matter as well as the bulk density. The bulk density is an important factor to calculate the digester volume and was collected from the literatures.

The mixture ratio is an important factor to achieve the desired pH for a good anaerobic digestion performance: In order to achieve that the mixture ratio will be assumed as 80% for agricultural residues and MSW and 20% for manure [41, 71]. In order to calculate the electric and thermal power, the biogas plant was assumed to operate 8100 h per year. To achieve the maximum methane production as well as acclimate microorganisms the hydraulic retention time was assumed as 40 days and the hydraulic retention time post digester was assumed as 52 days [38, 71]. Average methane concentration was assumed as 60% [26]. The biogas plant is size with 4 reactors. The best temperature for a good anaerobic performance will be 37ºC [62].

The dry weight factor, volatile solids and methane yield were mentioned in the previous chapters.

5.2.2 EcoGas software

EcoGas (Version 07E1) Software, which has been developed at BOKU- Vienna- is part of a comprehensive and inclusive toolkit comprising technological, economical, social, environmental and cultural dimensions of development. This software uses powerful search algorithms to identify potential trade-offs among factors such as cost, performance and reliability. EcoGas will be used in this work for the simulation, dimensioning and to perform the economic analysis of the case study biogas plant for treatment of by-product from biomass in Egypt.

With this software the following factors can be defined and calculated:

- Technical aspects of the bioreactor
- Investment costs
- Energy partitioning and consumption
- Energy balance (kWh)
- Annual revenue and investment costs
- Reduction of emission

5.3 Results and discussion

5.3.1 Characteristics of the biogas plant

5.3.1.1 Digester design

Table 5-4 below shows that the total amount of fresh matter that needs to be treated was about 173 m^3/day and the total dry matter content 24.6 tonnes/day accounting for 57% from total fresh matter.

Table 5-4: Total fresh matter and dry matter content

		Agricultural residues +MSW	Manure	Total
FM/year	Tonnes	12,600	3150	15,750
FM/day	m^3	164	9	173
Proportion	%	80	20	100
DM/year	Tonnes	7,431	1555	8,986
DM/day	Tonnes	20.4	4.3	24.6
DM	%	59	49	57

The results show that the volume of the digester will be 7,014 m^3 and each reactor is designed with a diameter of 13 m, a height of 13 m and surface area 805 m^2. Based on the amount of substrate, wet digestion and completely stirred digesters are considered.

5.3.1.2 Biogas and methane production

Table 5-5 below shows the total volatile solid, biogas and methane production. The results show that the annual VS is 6,535 tonnes and 17.9 tonnes daily. The annual methane and biogas yield were 3.6 and 2.2 million Nm^3 with daily production 5,907 and 9,846 Nm^3 daily.

Table 5-5: Biogas and methane production

		Agricultural residues +MSW	Manure	Total
VS/year	Tonnes	5,458	1,077	6,535
VS/day	Tonnes	14.95	2.95	17.9
Methane yield	Nm^3/year	1,824,887	331,347	2,156,234
	Nm^3/day	5,000	907	5,907
Biogas yield	m^3/year	3,041,479	552,245	3,593,724
	m^3/day	8,334	1,512	9,846

5.3.1.3 Biogas storage tank

The recommended volume of the biogas storage tank should be about one or two days of the production capacity and a minimum of one fourth of the daily production capacity [41]. In order to simplify the construction process and minimize the cost for the construction as well as for back-up solutions for extraordinary high gas production rates, the biogas storage tank is sized as one day production for each reactor 2,462 m^3 with total volume 9,848 m^3.

5.3.2 Energy balance

The electrical and thermal conversion efficiency assumed as 38% and 47% [56]. The results show that for 2.2 million Nm^3/year methane production, the annual electrical and thermal energy were 8.2 and 10.1 GWh and the daily production were 22.38 and 27.68 MWh. The electric capacity of CHP for 8100 hours/year of operation, was 1009 kW_{el} as shows in Table 5-6.

Table 5-6: EcoGas software energy production of the CHP

Energy partitioning and consumption				
Power heat coupling		without CHP		
Losses	15%	resp.	3 224 648 kWh/year	
Useable Energy			18 273 006 kWh/year	
Thermic energy	47,0%	resp.	10 103 898 kWh/year	
Electric energy	38,0%	resp.	8 169 109 kWh/year	22,38 MWh/d
Electric energy	22 381 kWh/day			
Hours of operation per year (day)	8 100 h	22,5 h/day		
kW_{el} CHP	1 009 kW			

5.3.3 Economic analysis

5.3.3.1 Investment costs

The investment costs of the biogas plant refer to different costs of the plant settling and will take into account the cost of the biogas plant and the CHP costs. The investment costs depend on the resulting electrical energy. In this study, the investment cost per kW_{el} for the biogas plant and for CHP assumed as 3000 and 900 €/kW_{el} [69]. For 1009 KW_{el} the costs of the biogas plant and the CHP cost are 3.3 million € and 700 thousand €, so the total investment in this plant will be of about 4 million €.

5.3.3.2 Annual revenue and running costs

Table 5-7 below shows that the total annual revenue is 784 thousand €, in particular electrical energy 719 thousand € with tariff 0.088 €/kWh in summer and winter months and heat energy 65 thousand € with tariff 0.011 €/kWh.

Table 5-7: EcoGas software annual revenue

Revenue		kWh/year	Tariff	Revenue in €	
Electric energy		8 169 109			
Own consumption					
Process energy	6,1 %	494 449	0,0880 €	43 511 €	
Input to network	93,9 %	7 674 660	0,0880 €		
Summer months	183 days				
High tariff	100%	3 839 050	0,0880 €	337 836 €	
Low tariff					
Winter months	182 days				
High tariff	100%	3 835 610	0,0880 €	337 534 €	
Low tariff					
Revenue from electric energy					718 882 €
Heat energy					
Own consumption					
Heat sold		6 000 000	0,011 €	64 620 €	
Potential		2 476 710	242%		
Revenue from heat energy					64 620 €
Annual revenue					783 502 €

Table 5-8 below shows that the annual running costs 135 thousand €. The balance between the revenue and the costs is 648 thousand €/year. That means the biogas plant is economically feasible.

Table 5-8: EcoGas software running costs

Running costs	Quantity	Unit	€ per unit	Total in €
Operational costs				132 111 €
Operation management		h	25,00 €	
Maintenance	1,50%	of	4 000 000 €	60 000 €
Insurance	0,19%	of	4 000 000 €	7 600 €
Process energy	494 449	kWh	0,0880 €	43 511 €
Accountancy, tax consultancy			2 000 €	2 000 €
Rental of property			3 000 €	3 000 €
Saleries and wages			12 000 €	12 000 €
Engine oil				
Administrative expense			4 000 €	4 000 €
Costs of logistic				5 000 €
Variable costs of vehicles		h		
Variable costs of machinery		h		
Fuel for machinery			5 000 €	5 000 €
Lorries + vehicles				
Other costs				3 200 €
Fermenter residues supply	16 000	t	0,20 €	3 200 €
Costs of silage purchase				
Costs of liquid manure	700,00	t		
Glycerol	5,00	t		
Annual costs				135 311 €

Figure 5-2 shows the equity capital is assumed as 550 thousand € in the beginning. External financing is needed to cover the total investment (4 million €). This divided into a grant of 1 million € and a loan of 2.45 million € with a rate of interest 5.5% for 15 years, the equity will be after 20 year 1.2 million € and the actual balance will be 15.2 million €. The biogas plant shows positive actual balance after 4 years and profit after 5 years.

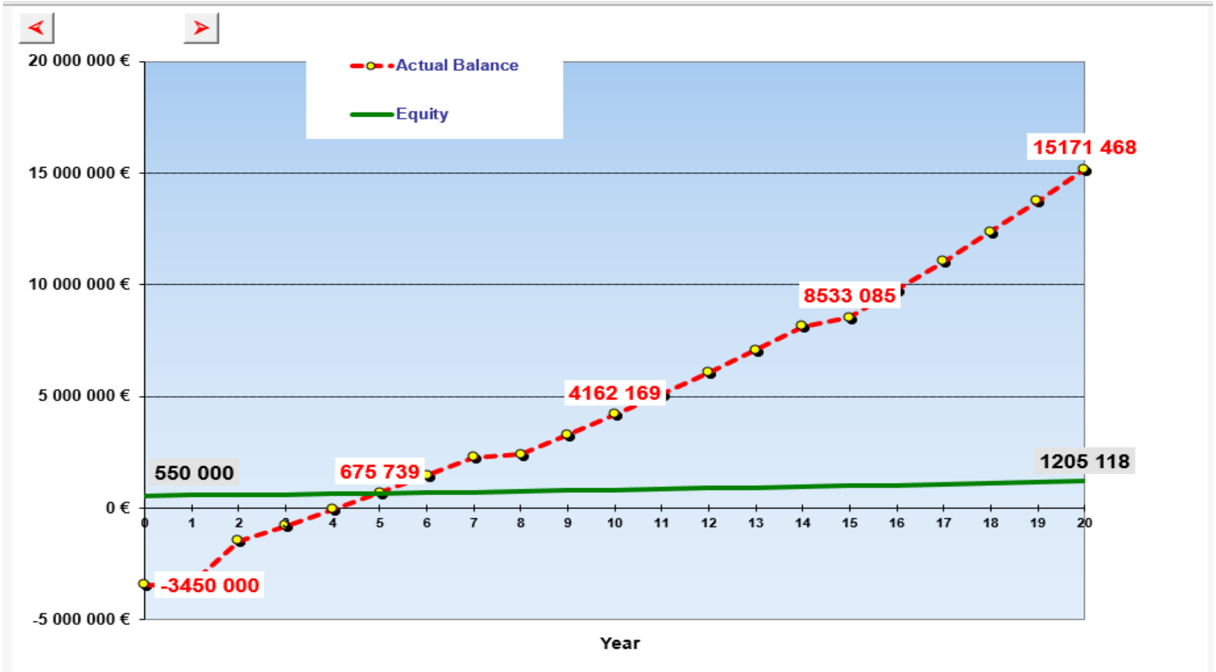

Figure 5-2: EcoGas return on equity actual balance

Table 5-9 shows the performance figures for the biogas plant. The loading rate is 2.55 kg of VS/m^3 digester volume and day, and the methane productivity is 0.84 Nm^3 CH_4/m^3 digester volume. The investment costs, the running expenses and thereof substrate costs per kW$_{el}$ are 3699, 134 and 3 € respectively. The total costs per kWh$_{el}$ is 0.08 €, in particular, average costs of capital and running expenses 0.06 and 0.02 € respectively. The total costs per Nm³ CH_4 is 0.29 €, in particular, average cost of capital and running expenses 0.22 and 0.07 € respectively. The proportion of revenue divided into 92% from electric energy and 8% from heat energy.

performance figures		
produced electric energy	MWh/d	22,38
CH4 [Nm³]	Nm³/d	5 907
CH4 in [%]	Vol. %	60,00
biogas [m³]	m³/d	9 846
total fM in t	t fm / d	43,2
total fM in m³	m³ fm / d	172,8
dry matter total	t dm	24,62
VS total	t/d	17,90
specific methane yield	m³/kg VS	0,33
hydraulic retention time	d	40,6
VS in fresh matter	%	41,5
loading rate	kg VS/m3 digester volume and day	2,55
methane productivity	Nm³ CH4/m³ digester volume	0,84
investment costs per kW$_{el}$	€ / kW$_{el}$	3 966
running expenses per kW$_{el}$	€ / kW$_{el}$	134
thereof substrate costs per kW$_{el}$	€ / kW$_{el}$	3
average cost of capital per year per kWh$_{el}$	€ / kWh$_{el}$	0,06
running expenses per kWh$_{el}$	€ / kWh$_{el}$	0,02
thereof substrate costs per kWh$_{el}$	€ / kWh$_{el}$	0,0004
total costs per kWh$_{el}$		0,08
average cost of capital per year per Nm³ Methan	€ / kWh$_{el}$	0,22
running expenses per Nm³ Methan	€ / kWh$_{el}$	0,06
thereof substrate costs per Nm³ Methan	€ / kWh$_{el}$	0,0015
total costs per Nm³ Methan		0,29
proportion of revenue		
electric energy	%	92
heat energy	%	8
waste processing	%	0

Table 5-9: EcoGas performance figures of biogas plant

5.3.4 Balance of emission

Table 5-10 shows the balance of emission, where the positive values stand for a reduction in emission and negative values for an increase in emission. The biogas plant shows a reduction in CO_2 and CO emission calculated as 3,758 and 31 tonnes/year, respectively.

Table 5-10: EcoGas balance of emission

Pollutant source	CO_2 in t / year	NO_x in kg / year	SO_2 in kg / year	CO in kg / year
CHP	0,0	-15 048,4	-7 524,2	-15 048,4
Electricity	2 060,7	1 970,4	2 264,5	1 970,4
Heat	1 697,8	1 166,4	4 222,8	43 718,4
Liquid manure, solide dung storage	0,0			
Total	3 758,4	-11 911,6	-1 036,9	30 640,4

5.4 Summary

The aim of this chapter is to simulate, dimension and perform the economic analysis of the governorate Behara one case study with a model biogas plant using the EcoGas Software (Version 07-E1). The total amount of fresh matter that needs to be treated is about 173 m^3/day, with a mixture ratio 80% for agricultural residues and MSW and 20% for manure, where the total dry matter content accounting for 57% from total fresh matter.

The volume of the digester was 7014 m^3, where the biogas plant is size with 4 reactors and the biogas storage tank as one day production was 9848 m^3. The annual VS is 6,535 tonnes. The annual methane and biogas yield were 3.6 and 2.2 million Nm^3.

The annual electrical and thermal energy produced is calculated to 8.2 (38%) and 10.1(47%) GWh, respectively. The calculation electric capacity is 1009 kW_{el} of CHP for 8100 hours/year of operation.

The total investment in this plant would be about 4 million €, where the investment cost per kW_{el} for the biogas plant and for CHP assumed as 3000 and 900 €/kW_{el}. The biogas plant has an economic feasibility, where the balance between the revenue and the costs is 648 thousand €/year, where the total annual revenue is 784 thousand € and the annual running costs 135 thousand €. The biogas plant will show profit after 5 years with an equity capital 550 thousand € in the beginning, a grant of 1 million € and a loan of 2.45 million € with a rate of interest 5.5% for 15 years. The loading rate is 2.55 kg of VS/m^3 digester volume and day, and the methane productivity is 0.84 Nm^3 CH_4/m^3 digester volume. The total costs per kWh_{el} and per Nm^3 CH_4 are 0.08 € and 0.29 €, respectively.

The biogas plant shows a reduction in CO_2 and CO emission calculated as 3,758 and 31 tonnes/year, respectively.

6 Conclusions and recommendation

The evaluation of the bioenergy potential and the application of EcoGas tool have proven to be useful as a first step for assessing the contribution of individual biogas plants to greenhouse gas (GHG) mitigation and primary energy savings in Egypt.

This study has shown that Egypt has vast potential of biomass resources with total production in 2017 of 135 million tonnes of dry biomass. The main resources of biomass that discussed in this study are divided into three resources: (i) municipal solid wastes (12 million tonnes), (ii) agricultural residues (36 million tonnes) and (iii) livestock manure (87 million tonnes). The total potential availability of dry biomass estimated at 18 million tonnes/year.

The analysis of agricultural residues at type level reveals that the most residues share in the total production derive cereals (51%), wheat, maize and rice. Maize stalk and rice straw are the most residues share in total availability of dry agricultural residues (53%). In the case of livestock manure, the most residues share in the total production derive cattle manure 66%. Almost half the total available quantity of manure produced derives from cattle manure (46%) and chicken manure (42%).

The total bioenergy potential in Egypt produced from available dry biomass using anaerobic digestion estimated at 103 PJ in 2017. Using CHP shows that the electrical and thermal energy were 39.14 (10.9 TWh) and 48.41 PJ/year (13.4 TWh). This could cover 7% of the total electricity consumption, as well as the thermic energy that can be used for external needs.

The analysis of biomass and bioenergy potential at governorate level reveals that Behera is the governorate with the highest bioenergy potential production in the country, with 12.32 PJ/year contributing 12% to the national production.

The result of bioenergy potential produced using incineration is greater than that obtained using anaerobic digestion, because, in the incineration, all of organic matter contributes to the bioenergy output. On the other hand, Incineration of waste can cause corrosion problems of the metallic part of the boiler and environmental problems such as release of the parts of the produced ashes as well as gaseous emissions. Incineration reduces the possibility to recycle valuable components out of the waste and the costs of boilers can be enormous. Where anaerobic digestion technology has various benefits such as environmental benefits by reducing the emission and economic benefits where biogas plant has a relatively inexpensive and simple reactor designs and operating procedures. Biogas sludge can be used as fertilizer on arable land or for recovery of degraded lands, or for the reclamation of polluted soil, which could be useful in Egypt for desert reclamation. This recycling of nutrients is regular with development of a circular economy and sustaining soil organic carbon concentrations.

For the governorate Behara one case study with a model biogas plant has been selected and investigated using the EcoGas Software (Version 07-E1). The total amount of fresh matter that needs to be treated is about 173 m^3/day. The annual methane was 2.2 million Nm^3. The volume of the digester was 7014 m^3 and the biogas storage tank as one day production was 9848 m^3.

The annual electrical and thermal energy produced is calculated to 8.2 and 10.1 GWh, respectively. The calculation electric capacity is 1009 kW_{el}. The electricity can be used in the AD process or sold to the grid. The heat can be used in the AD to heat up the digester and approximately 2/3 of all produced energy can be used for external needs such as (i) industry processes, (ii) agricultural activities such as drying crops, separation and further treatment of digestate (iii) households such as space heating and water heating or for (iiii) power-heat-cooling-coupling systems. This process, known from refrigerators, is used e.g. for cooling food storage or for air conditioning.

The total investment in this plant would be about 4 million €. The biogas plant has an economic feasibility, where the balance between the revenue and the costs is 648 thousand €/year. The biogas plant will show profit after 5 years with an equity capital 550 thousand € in the beginning, a grant of 1 million € and a loan of 2.45 million € with a rate of interest 5.5% for 15 years. The total costs per kWh_{el} and per Nm^3 CH_4 are 0.08 € and 0.29 €, respectively. These numbers are based on the actual data with the sustainable development strategy: ‘‘Egypt Vision 2030’’ was declared from the ministry of planning. The real growth of the gross domestic product (GDP) was 332,484 million USD by 2016 and will be reached at 12% by 2030. The energy sector was shared of GDP at 13% by 2016 and expect to reach at 25% by 2030. The renewable was shared in primary energy and electricity production at 1% for both and expect to reach at 12% and 32.5% by 2030. The annual inflation rate (CPI) exceeded 11.8% by 2016 and will be reached at 5.3% by 2030.

The biogas plant shows a reduction in CO_2 and CO emission calculated as 3,758 and 31 tonnes/year, respectively.

- **Recommendations for future work**

The actual work provides a good basis for future investigations on utilization of organic residues for the production of electricity for local communities. The following steps are needed to provide important data for decision makers before a commercial application could be launched.

- Techno-Economic feasibility of scaling up for biogas plants in Egypt
- Techno-Economic feasibility study for using another conversion method such as pyrolysis, where the bioenergy potential is higher than anaerobic digestion and reduces the treatment process for lignocellulose residue.
- Impacts of biogas sludge on land reclamation in Egypt and its effect on the soil

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8 Appendix

Table 8-1: Residue production average by governorate – part 1

Governorate	Wheat straw	Maize stalk	Tomato haulm	Sugar cane bagasse	Rice straw	Sugar beet haulm	Citrus & Orange pruning	Sorghum stalk	Onion haulm
1000 Tonnes/year									
Gharbia	276.9	317.6	4.5	30.0	299.0	58.8	57.8	0.0	243.6
Kafr-El Sheikh	515.6	318.8	80.7	10.0	484.4	558.3	21.2	0.0	8.4
Dakahlia	486.5	282.6	35.3	10.0	931.0	365.9	19.5	0.0	105.6
Damietta	52.1	5.4	7.7	0.0	102.6	19.5	0.2	0.0	7.2
Menoufia	395.7	463.3	11.7	35.0	0.1	8.3	141.0	0.0	4.8
Qalyoubia	150.7	192.1	4.5	5.0	19.7	1.4	181.3	0.0	52.7
Sharkia	1072.7	556.9	971.9	0.0	560.4	339.8	229.3	0.0	54.6
Ismailia	70.9	66.7	207.7	0.0	7.2	27.8	216.4	0.0	1.4
Port Said	25.1	6.5	4.2	0.0	29.6	92.7	0.0	0.0	0.0
Suez	12.3	22.0	27.8	0.0	0.0	0.7	19.4	0.0	2.9
North Sinai	2.4	0.2	56.5	0.0	0.0	0.0	26.3	0.0	0.0
South Sinai	1.3	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Alexandria	151.3	91.5	128.2	0.0	0.8	23.2	3.3	0.0	0.1
Behera	1028.7	1241.3	626.2	10.0	366.0	206.6	869.9	0.0	113.3
Matruh	7.7	18.1	128.4	0.0	0.0	5.8	2.2	0.0	1.3
Cairo	0.0	0.2	0.5	0.0	0.0	0.0	2.7	0.0	0.0
Giza	106.4	144.2	294.7	35.0	0.0	10.1	39.7	5.6	7.0
Beni Suef	299.8	538.5	178.3	15.0	2.2	102.4	20.7	16.0	54.6
Fayoum	718.1	472.1	113.2	20.0	2.1	138.7	3.8	378.8	49.4
Menia	577.0	560.5	108.9	400.0	0.0	131.1	15.3	36.0	38.6
Assuit	632.3	849.7	82.8	850.0	0.0	17.6	66.2	193.0	21.0
Suhag	557.6	310.2	242.6	200.0	0.0	0.0	9.6	200.2	80.8
Qena	294.5	114.1	60.1	1100.0	0.0	0.0	1.2	90.9	10.4
Luxor	65.4	52.1	142.9	600.0	0.0	0.0	1.5	3.6	3.1
Aswan	110.1	65.6	7.8	50.0	0.0	0.0	2.6	26.6	8.1
New Valley	221.0	75.6	2.6	0.0	3.1	8.1	8.9	0.5	12.2
Red Sea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	7831.9	6765.8	3530.9	3370.0	2808.2	2116.6	1960.1	951.2	881.2

Table 8-2: Residue production average by governorate – part 2

Governorate	Potato haulm	Grapes pruning	Olive pruning	Palm dates pruning	Eggplant residue	Cotton stalk	Cabbage residue	Peanuts haulm	Broad beans straw
1000 Tonnes/year									
Gharbia	20.9	45.5	0.0	2.6	0.7	18.6	13.1	0.0	3.0
Kafr-El Sheikh	3.4	0.0	0.0	19.7	12.2	148.7	13.9	0.0	32.7
Dakahlia	106.9	25.0	0.0	11.4	3.4	56.8	19.7	0.0	33.2
Damietta	19.5	0.0	0.0	45.2	0.1	14.2	1.1	0.0	10.1
Menoufia	59.1	26.5	16.0	8.3	8.9	3.3	16.0	0.5	0.6
Qalyoubia	7.5	2.5	0.0	10.2	1.3	0.0	42.4	1.1	0.0
Sharkia	27.8	5.5	7.0	68.4	151.2	41.2	31.5	34.5	16.0
Ismailia	48.6	5.5	60.0	45.7	30.0	1.3	7.7	10.3	0.4
Port Said	0.1	0.0	0.0	0.4	0.0	4.3	0.0	0.0	0.6
Suez	0.0	0.0	17.0	1.6	1.5	0.0	2.4	0.0	1.0
North Sinai	0.4	2.5	60.0	0.0	1.9	0.0	0.1	0.0	0.0
South Sinai	0.0	0.0	15.0	0.0	0.1	0.0	0.0	0.0	0.0
Alexandria	27.1	2.0	7.0	3.1	0.7	1.7	37.8	0.0	4.9
Behera	190.0	335.0	105.5	101.0	95.5	57.1	38.1	163.8	67.0
Matruh	8.7	16.5	105.0	23.1	0.0	0.0	0.0	0.0	4.2
Cairo	0.0	0.0	0.0	1.0	0.1	0.0	0.1	0.0	0.0
Giza	25.0	26.5	16.5	115.1	57.7	0.0	47.5	2.9	0.2
Beni Suef	46.2	16.5	8.0	2.0	3.2	10.6	4.3	1.2	0.6
Fayoum	0.0	5.5	65.0	14.2	3.9	20.6	11.6	0.0	2.0
Menia	0.0	76.5	5.0	0.0	4.5	0.5	4.4	8.2	1.7
Assuit	1.8	15.5	15.0	1.5	2.1	5.9	3.8	1.6	11.6
Suhag	10.8	3.5	6.0	0.0	3.1	0.8	4.9	2.7	2.9
Qena	0.0	2.5	0.0	0.0	6.5	0.0	3.8	0.0	0.8
Luxor	0.0	2.0	6.5	0.2	9.4	0.0	3.3	0.1	0.6
Aswan	0.0	2.0	0.0	0.0	2.8	0.0	3.8	0.8	3.6
New Valley	186.4	2.0	15.5	42.8	0.1	0.0	0.6	76.7	3.2
Red Sea	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Total	790.1	619.0	530.0	518.0	400.9	385.5	311.9	304.3	201.0

Table 8-3: Residue production average by governorate – part 3

Governorate	Green pea haulm	Artichoke Haulm	Strawberry haulm	Soybeans haulm	Garlic haulm	Green beans Haulm	Carrot haulm	Pepper stalk	Courgette haulm
1000 Tonnes/year									
Gharbia	18.5	0.0	0.2	0.0	1.0	1.6	13.8	0.0	0.1
Kafr-El Sheikh	7.9	0.2	0.0	0.5	0.0	0.0	6.3	0.8	9.6
Dakahlia	46.6	0.0	0.3	1.1	6.2	0.2	17.3	1.7	1.5
Damietta	0.0	0.0	0.0	0.0	0.4	0.0	4.3	0.0	0.3
Menoufia	10.1	0.0	1.8	0.1	0.4	6.0	31.9	0.0	0.1
Qalyoubia	5.0	0.0	22.4	0.7	1.7	3.6	9.3	0.1	0.8
Sharkia	8.6	0.0	11.5	1.4	3.3	3.2	6.8	43.1	51.5
Ismailia	5.4	0.0	33.3	0.1	0.1	14.0	0.3	14.0	5.1
Port Said	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Suez	0.5	0.0	0.0	0.0	0.5	0.0	0.0	2.3	0.1
North Sinai	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.7
South Sinai	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alexandria	1.1	33.5	0.0	0.0	1.9	1.1	4.6	0.2	3.5
Behera	77.8	119.9	89.8	2.6	25.0	74.7	19.3	30.8	25.5
Matruh	0.9	15.1	0.0	0.0	0.1	0.0	0.0	0.0	1.7
Cairo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Giza	4.8	0.0	0.1	0.0	3.6	25.7	0.4	9.8	7.9
Beni Suef	5.3	0.0	0.0	14.1	62.8	3.1	7.5	3.7	0.0
Fayoum	0.0	0.0	0.0	0.6	6.9	1.0	0.0	0.5	2.4
Menia	3.2	0.0	0.0	115.9	18.0	1.8	1.1	4.2	0.4
Assuit	0.0	0.0	0.0	5.9	4.5	0.0	0.0	1.2	0.0
Suhag	1.0	0.0	0.0	0.8	2.6	0.9	0.0	2.5	0.4
Qena	0.0	0.0	0.0	0.0	1.7	0.1	0.0	1.9	0.0
Luxor	0.0	0.0	0.0	0.1	0.9	0.0	0.0	0.6	0.1
Aswan	0.0	0.0	0.0	0.0	1.4	0.4	0.0	1.7	0.4
New Valley	0.2	0.0	0.0	1.7	0.0	0.8	0.0	0.1	0.0
Red Sea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	199.1	168.7	159.5	145.6	143.2	138.3	123.2	119.8	113.3

Table 8-4: Residue production average by governorate – part 4

Governorate	Barley straw	Sesame stalk	Cucumber haulm	Dry beans residue	Cauliflower residue	Flax straw	Sunflower stalk	Total
1000 Tonnes/year								
Gharbia	0.0	0.0	0.3	4.6	0.2	12.9	0.0	1445.9
Kafr-El Sheikh	2.9	0.2	8.6	0.0	2.2	8.0	0.0	2275.3
Dakahlia	0.1	0.0	0.8	0.0	0.2	17.0	0.0	2586.0
Damietta	0.0	0.0	0.0	0.0	0.0	3.6	0.0	293.8
Menoufia	0.0	0.0	0.0	44.6	0.1	0.6	0.0	1294.7
Qalyoubia	0.0	0.0	0.2	0.0	0.9	0.4	1.3	718.7
								8614.4
Sharkia	13.7	13.8	2.1	0.7	0.5	5.0	0.7	4334.7
Ismailia	3.4	3.9	5.9	0.0	0.0	0.0	0.0	893.1
Port Said	5.6	1.6	0.0	0.0	0.0	0.0	0.0	170.9
Suez	1.0	0.6	0.1	0.0	0.2	0.0	0.0	113.9
North Sinai	0.1	0.0	3.3	0.0	0.0	0.0	0.0	158.4
South Sinai	1.1	0.0	0.1	0.0	0.0	0.0	0.0	18.6
								5689.6
Alexandria	5.4	2.2	0.0	0.0	13.3	0.0	1.1	550.3
Behera	25.4	28.4	11.9	16.1	15.7	3.4	14.7	6196.0
Matruh	0.1	0.0	0.0	0.0	0.0	0.0	0.0	338.9
								7085.2
Cairo	0.0	0.0	0.0	0.0	0.1	0.0	0.0	4.9
Giza	1.0	3.7	22.3	0.0	15.8	0.0	1.9	1030.9
Beni Suef	0.1	2.4	7.4	0.0	0.1	0.0	1.3	1428.1
Fayoum	5.4	6.5	0.3	0.0	0.9	0.0	7.0	2050.4
Menia	2.4	5.8	10.3	0.0	0.1	0.0	1.8	2132.7
Assuit	0.6	1.3	0.4	0.0	1.2	0.0	1.1	2787.4
								9434.4
Suhag	0.4	3.1	0.2	0.0	1.0	0.0	0.2	1648.9
Qena	0.4	0.9	0.4	0.0	0.0	0.0	0.0	1690.3
Luxor	0.4	1.3	0.3	0.0	0.1	0.0	0.0	894.5
Aswan	7.6	6.0	0.2	0.0	0.0	0.0	0.0	301.5
New Valley	26.6	0.1	0.2	0.0	0.0	0.0	0.1	689.3
Red Sea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
								5224.9
Total	103.8	81.6	75.3	66.0	52.5	51.0	31.2	**36048.6**

Table 8-5: Livestock manure poduction by governorate – part 1

Governorate	Cows	Buffalos	Sheep	Goats	Chicken
1000 Tonnes/year					
Gharbia	1919.3	1627.6	407.4	198.9	652.7
Kafr-El Sheikh	1439.3	1194.9	328.2	157.9	229.9
Dakahlia	1423.9	1553.5	370.7	186.3	499.4
Damietta	181.9	186.8	186.9	78.1	156.6
Menoufia	1587.7	2098.7	422.0	325.5	152.7
Qalyoubia	1173.7	156.7	354.0	149.1	548.0
Sharkia	4635.6	2795.8	850.1	662.2	1161.5
Ismailia	495.2	146.0	242.3	223.3	146.3
Port Said	153.3	46.2	32.6	16.3	4.1
Suez	85.3	70.5	87.0	40.9	5.6
North Sinai	12.4	1.8	85.8	70.4	37.9
South Sinai	10.8	0.5	61.4	48.6	0.2
Alexandria	365.4	389.2	274.3	40.7	78.5
Behera	4197.3	3740.8	1150.1	933.5	793.6
Matruh	70.3	31.4	791.7	246.7	52.3
Cairo	74.3	24.7	121.2	17.3	144.9
Giza	1214.9	997.6	302.0	226.6	184.0
Beni Suef	1618.0	867.2	333.6	339.8	72.1
Fayoum	2008.0	1396.6	399.9	340.0	214.1
Menia	2214.0	1805.8	563.9	556.3	1062.3
Assuit	1405.1	1108.6	380.6	406.6	117.7
Suhag	1968.1	1861.4	679.5	641.8	50.3
Qena	1394.0	1432.6	451.7	649.5	9.8
Luxor	903.1	381.2	275.3	348.7	9.3
Aswan	438.8	292.1	217.5	126.5	1.0
New Valley	260.5	4.6	205.2	159.6	7.3
Red Sea	633.2	2.0	133.8	80.9	2.0
Total	31883.3	25 214.7	9708.8	7271.9	6394.3

Table 8-6: Livestock manure production by governorate – part 2

Governorate	Donkeys	Camels	Horses	Mules	Total
1000 Tonnes/year					
Gharbia	230.9	1.7	25.3	7.9	5071.7
Kafr-El Sheikh	200.7	0.5	15.0	4.4	3570.8
Dakahlia	212.0	0.6	26.3	3.7	4276.5
Damietta	89.5	0.2	8.9	0.7	889.6
Menoufia	360.8	5.4	16.6	7.9	4977.3
Qalyoubia	256.1	27.6	19.5	4.5	3689.3
					22475.3
Sharkia	555.4	26.4	37.1	15.7	10739.7
Ismailia	63.4	6.1	1.9	0.3	1324.7
Port Said	5.9	1.0	0.3	0.0	259.6
Suez	10.2	1.9	0.8	0.1	302.2
North Sinai	6.9	9.9	0.1	0.1	225.2
South Sinai	2.2	4.7	0.5	0.0	129.1
					12980.7
Alexandria	52.3	10.9	5.7	1.4	1218.3
Behera	630.2	26.9	36.2	16.4	11524.9
Matruh	78.0	64.1	1.4	2.2	1338.2
					14081.5
Cairo	2.1	0.5	2.0	0.2	387.3
Giza	262.4	30.3	10.9	3.2	3231.9
Beni Suef	240.8	8.8	4.3	4.6	3489.0
Fayoum	205.6	13.9	4.0	3.9	4586.2
Menia	319.3	19.1	8.0	6.8	6555.4
Assuit	300.0	11.2	17.7	1.9	3749.5
					21999.4
Suhag	408.7	18.5	11.8	2.7	5642.8
Qena	308.6	32.0	11.4	0.7	4290.3
Luxor	120.2	6.3	4.2	0.3	2048.6
Aswan	84.1	38.6	3.2	0.2	1202.0
New Valley	60.9	6.3	2.7	0.5	707.6
Red Sea	2.5	196.6	0.1	0.0	1051.1
					14942.5
Total	5070.0	569.9	276.1	90.3	**86479.4**