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School of Industrial and Information Engineering

Master of Science in Energy Engineering

Anaerobic Digestion of Animal Manure in Egypt: Providing Rural Households with Access to Alternative Fuel Sources Through Business Innovation

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Abstract

Egypt has 57.6% of its population residing in rural areas, 30% of the population are already engaging in agricultural activities. Additionally, agriculture is the third largest economic sector in Egypt generating approximately 57 Mtonnes of cattle manure every year. Hence, producing biogas through anaerobic digestion can be a highly beneficial solution in managing the growing rates of unutilized cattle waste within the rural context.

This study explores the ability of rural cooperatives to recover the value within the locally generated biowaste to provide rural households clean and easy access to biogas. Biogas from anaerobic digestion should supply the households with their daily cooking and water heating demands. On the other hand, the digestate produced from the anaerobic digestion can be used as biofertilizer, which is argued to increase the profitability of biogas production due to the savings on chemical fertilizers.

The results show that having a business model that involves more than six households sharing an anaerobic digestor through a cooperative framework would be economically feasible given the proper policy frameworks adopted by the relevant authorities. On the other hand, it was shown that the benefits extend beyond the economic aspects as the social and environment benefits can increase the attractiveness of the business model for rural households.

Keywords: Anaerobic Digestion – Egypt – Manure – Biogas – Rural development – Business models – Circular Economy – Product Service Systems – Local context

SOMMARIO

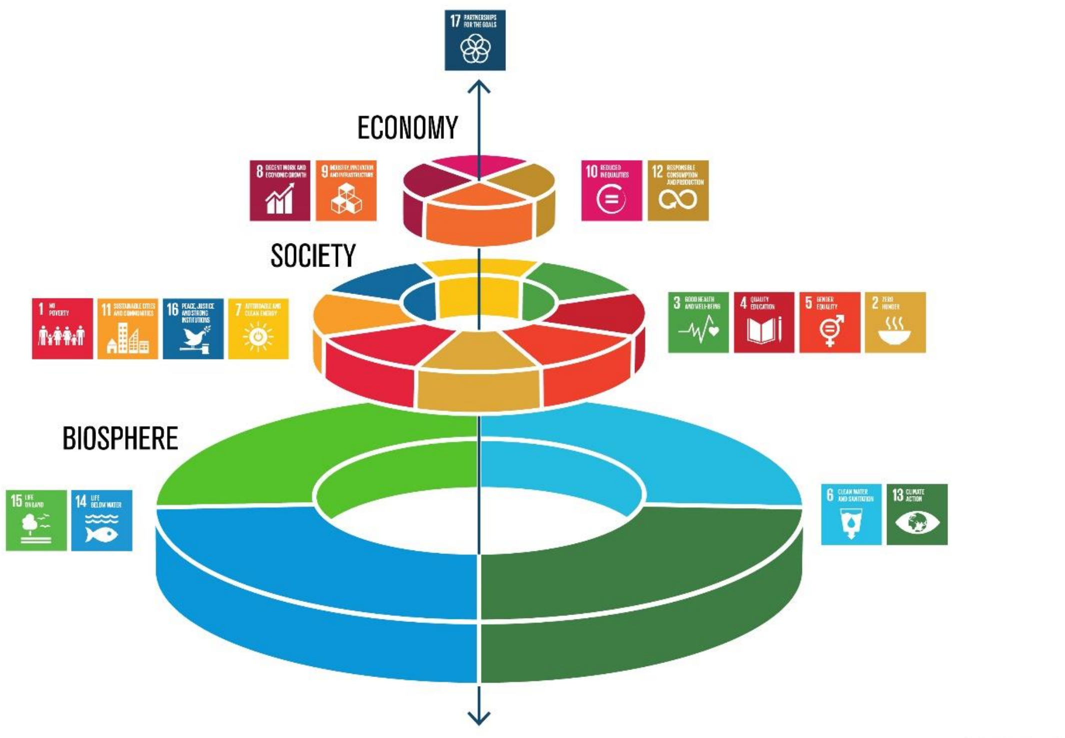
Il 57,6% della popolazione egiziana risiede nelle aree rurali, e il 30% è impegnato in attività agricole. Inoltre, l'agricoltura è il terzo settore economico per importanza in Egitto e genera circa 57 milioni di tonnellate di letame ogni anno. Pertanto, la produzione di biogas attraverso la digestione anaerobica può essere una soluzione estremamente vantaggiosa nella gestione dei tassi crescenti di rifiuti di bestiame non utilizzati nel contesto rurale.

Questo studio esplora la capacità delle cooperative rurali di recuperare in loco il valore intrinseco del rifiuto biologico, per fornire alle famiglie delle comunità locali un accesso facilitato all'utilizzo di biogas. Il biogas ottenuto dalla digestione anaerobica dovrebbe soddisfare le esigenze quotidiane di cottura e riscaldamento dell'acqua. D'altra parte, il digestato prodotto dalla digestione anaerobica può essere usato come biofertilizzante, il che si ritiene aumenti la redditività stessa della produzione di biogas per via dei risparmi sui fertilizzanti chimici.

I risultati mostrano che avere un modello di business che coinvolge più di sei famiglie che condividono un digestore anaerobico in cooperativa sarebbe economicamente sostenibile, una volta adottate politiche adeguate dalle autorità competenti. D'altra parte, è stato dimostrato che i riflessi positivi si estendono oltre gli aspetti economici, poiché i benefici sociali e ambientali possono aumentare l'attrattiva del modello di business per le famiglie rurali.

1 INTRODUCTION

In 2015, a call for action has been raised by all the member states of the United Nations to collaborate equally to enhance the quality of life in all countries alike through the 2030 Agenda for Sustainable Development. The agenda has 17 sustainable development goals (SDGs); each goal focuses on a specific aspect of development; however, they are all interconnected, directly, and indirectly.



This thesis focuses more on energy related goals with respect to the rest of SDGs; as climate change is degrading the quality of life around the globe. Carbon dioxide concentration has increased by 2.2 particle per million between 2016 and 2017 and another 2.5 ppm between 2017 and 2018, reaching the historically highest value of 407.5 ppm in 2018. Additionally, due to the high demand for natural resources like wood, fossil fuels, and other precious metals required for manufacturing. Accordingly, the natural systems designated for maintaining the planet oxygen levels and closing the carbon cycle are under immense stress caused by continuous raw materials extraction and nonrenewable resources exploitation. Looking at deforestation as an example, the planet loses around 18.7 million acres per year according to the World Wildlife Fund. On one hand, Climate change is impacting all countries alike. On the other, developing countries are more vulnerable to climate change given their lack of tools and means to reverse its impacts compared to developed countries. In developing countries, around 1.8 billion people live in deteriorating agricultural land, and the soil is lost 10-100 times more than it is being formed. The loss of agricultural land can magnify problems related to food poverty and income generation, given that 60-75% of people living in poverty relies on agriculture and natural resources for income. In addition, developing countries, still have the potential to contribute more to the global adversity caused by climate change pursuing their own economic growth following “business as usual” (BAU) production systems. Following the SDGs, there is a pressing need for globally cooperative efforts to eliminate poverty, mitigate the potential effects of climate change, and transfer knowledge to the developing world to promote sustainable growth.

In response to the status quo and in compliance to 2030 Agenda, new sustainable production/consumption paradigms such as Circular Economy (CE) and Product service systems (PSS) emerged to replace the existing BAU paradigms to curb the increasing emission and waste generation rates caused by industrial and commercial use. Circular economy is an alternative production system best described as restorative to the earth resources, regenerative to the natural systems, and supportive to a waste free material life cycle. On the other hand, PSS is a system that prolongs the product/service provider responsibility of the product/service through all its life cycle phases including end of life ensuring continuous interaction between the product/service providing firm and the receiving user. Such systems can be effective tools to achieve the SDGs.

The global efforts have seemed to face resistance to fully transition from the business as usual (BAU) paradigm of production and consumption to a more sustainable one despite the urge for the change has been highlighted since “The Limits to Growth” report has been published in 1972. As every systemic change, a complete transition to a CE is facing resistance. Consequently, innovations in regulations, technology, and business models are required. Hence, changing the cultural perspectives toward concepts like waste and product ownership can be achieved through the innovative value propositions of models such as PSS; where the user's needs, behaviors, interests, and capabilities are the main design parameters for the product/service. However, many resistances are brought about by existing technological and operational barriers that can make such model seem costly, risky, and unfamiliar for businesses and governments to adopt and integrate it with their existing operational models.

In developing countries, agriculture is of great importance accounting for 30-60% of the total GDP and employing up to 70% of workers. Sustainable agriculture can provide steady food supply in developing countries where most of the food scarcity exist. However, agriculture requires energy, and energy poverty is still an issue for developing communities especially in rural areas that often do not have access to modern infrastructures and modern energy production technologies. Consequently, accelerating the transition to more circular and sustainable paradigms in the agricultural sector can be a key driver for a sustainable future for developing countries utilizing biological processes such as biogas production from anaerobic digestion that can unlock the agricultural potential by eliminating waste generated through consuming and transforming it to higher value products such as biofuels and biofertilizers.

This thesis, therefore, aims to analyze the potential benefits of applying Circular Product Service Systems to energy production in rural areas in developing countries. It will focus on the case of biogas production from anaerobic digestion in rural Egypt.

Justification

The population in Egypt has just reached the 100 million, 57.6% of which resides in rural areas, and 30% of the labor force are directly employed in agriculture [8]. Many of the rural areas are either lacking operational infrastructures for education, healthcare services, sanitary waters, and waste management and sewage treatment, or these services are delivered with a lower quality than its urban counterparts [9]. Consequently, the low and middle-income families can fall into what is called a poverty trap, where the poor is unable to escape from poverty as they cannot afford proper basic services such as sanitation, education and/or healthcare services; thus hindering their quality of life and their capability to increase their income level [10]. This may suggest that rural areas of

Egypt need developing sustainable models to provide a more fertile, clean, and sustainable ecosystem that offer the farmers a better quality of life.

Agriculture in Egypt has always been a very crucial sector to the national economy, it is Egypt’s third largest economic sector [8]. A sector of this size of production capacity generates large amounts of unutilized agricultural waste. According to Elfeki et al. (2017), only 18% of the agricultural waste is used as fertilizer, around 30% used as fodder for livestock, while the rest 52% is either left unused or directly burned to dispose of; harming the environment and wasting the potential utility of the organic matter residing within that waste.[11]

In 2018, the Egyptian Ministry of Agriculture and Land Reclamation estimated a total of 8.5 million head of cattle in Egypt [8]. In terms of waste throughout the year, the farmer usually keeps manure in a solid state inside the animal enclosure [12]. The solid manure is taken twice a year and is spread in the fields before planting. From the 8.5 million head, there are around 10-25 kg/head of animal manure produced every day that are either accumulated in storage areas or ineffectively reused without capturing its full value as a source of energy and biofertilizer as previously mentioned [13].

Considering that rural areas generates large amounts of waste, as will be further discussed in the following chapters, businesses in rural areas could benefit greatly from recovering the value of the various types of biowaste generated from the agricultural sector by using anaerobic digestion to produce both energy and biofertilizers. Hence, creating a coupling between the appropriate technologies harnessing the value trapped within organic waste, and the business model archetypes that help such technologies to spread across rural areas to benefit both consumers and suppliers.

Accordingly, more businesses in Egypt have started offering some sustainable agricultural solutions focusing their attention on Anaerobic Digestion technologies to tap into the potential of wet biowaste, such as animal manure, food waste, and agricultural waste. They offer small and medium scale biogas plants for rural households and agribusinesses. Given the inability of most rural inhabitants to afford high initial costs, the farmers are offered convenient payment options based on loans or financing options that facilitates the purchase and installation of the plant.

Through the thesis work, different biogas plant sizes will be considered and studied in regard to their applicability in a PSS business model through a comparative analysis between the different sizes considering their economic feasibility and technical limitations within the PSS context.

2 DEFINING KEY CONCEPTS

In this Chapter, the objective is to introduce the defining concepts of the thesis upon which the literature review and the methodology are based. It is important to introduce the principles of both Circular Economy and the Product-Service Systems and how they relate to biogas production. The chapter should clarify the significance of anaerobic digestion in waste reduction and providing better agricultural business solutions for rural communities in developing countries.

2.1 CIRCULAR ECONOMY

Circular economy (CE) has been associated with different definitions and characteristics since the concept has come to light [6]. However, all the definitions agree upon that it is a regenerative and a restorative model that aims to close material loops to retain the value of materials throughout their life cycles [14]. It is primarily developed as a response to resource scarcity, growing waste generation rates, and the rapid environmental degradation caused by the existing linear production/consumption trends. In the linear models, the required resources for production are initially extracted, they go through several production processes to make a consumable product suitable for use. Eventually when a product is no longer of use, it is disposed of as waste and often most of disposed waste accumulate in landfills. The Circular model is an evolution from the current linear models of production and consumption which assumes the abundance of natural capital on earth [15]. This assumption has proven to be needless and leads to an unsustainable perception to production and consumption, which raised the attention for a more regenerative model and depends less on virgin resources [16]. As presented by the Ellen MacArthur Foundation (EMAF[1]) in figure 1; in a linear economy all resources are mixed up within the production system making it more difficult to utilize them after use instead of ending up being wasted. On the other hand, circular material flows are more focused to separate both organic and technical resources feeding it back to the economy as a nutrient for further utility. Figure 1 is inspired by the work of McDonough and Braungart

[1] EMAF: a British entity focusing on accelerating the transition to CE

(2010), in their book “Cradle to Cradle” which is one of the main schools of thought in Circular Economy [3].

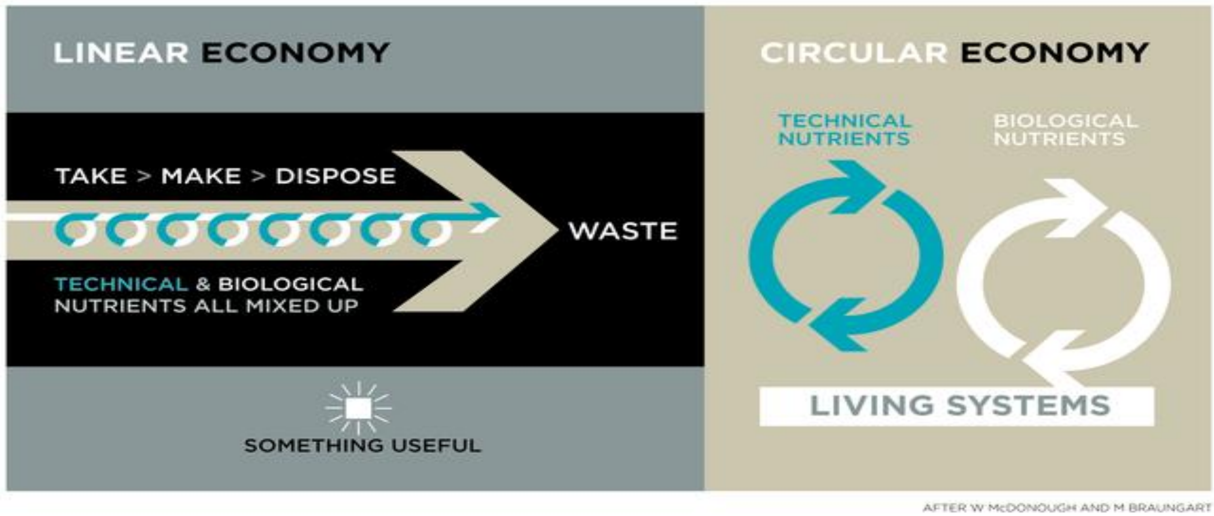


Figure 1- visualizing the difference between circular and linear economies

In CE, new material flows are introduced to close the resource loop designing waste and virgin resources out of the product life cycle, which is clear in the different frameworks and research regarding the application of a circular model [15].

Therefore, applying the circular economy to the energy sector by the same principles discussed, it would be clear that energy must be produced from renewable sources ensuring resource sustainability along the life cycle of the energy source [17]. Naturally, solar, biomass and wind energies are renewable sources and harnessing them will not deplete them from the biosphere. However, the technologies used to harness these energies require rare earth metals for developing and producing solar panels, biomass facilities and wind turbines [18,19]. In addition, the energy demand from renewables is increasing and is expected to increase. Therefore, to ensure resource value retention and prevent the accumulation of waste with respect to the growing demand, there should be sustainable business and production models that ensure a closed resource loop in the value chain for the rare materials to feed the system as input. However, at the end of the life cycle, it gets reintroduced to the value chain as a nutrient to the same system [3]. According to the Ellen MacArthur Foundation (EMAF) as shown in figure 2, it has classified the resource loops into two, a technical and a biological cycle [3];

- On the right side, a technical cycle ensures reintroducing end of life products back to the value chain as a technical nutrient for the system instead of depending on virgin materials. Accordingly, the materials retain or enhance their value, nullifying the costs and effects of mining, processing, and transport of virgin materials.
- While on the left side, a biological cycle takes its inputs from the biosphere, while its outputs return as a biological nutrient for the biosphere, hence, closing the biological resource loop. In short, the biological cycle focuses on regenerating the natural systems by designing out biowaste and pollution, providing sustainable nutrition for the biosphere. Additionally, according to EMAF and various sources of literature, anaerobic digestion is a crucial building block in the biological resource loop as will be shown in following chapters.

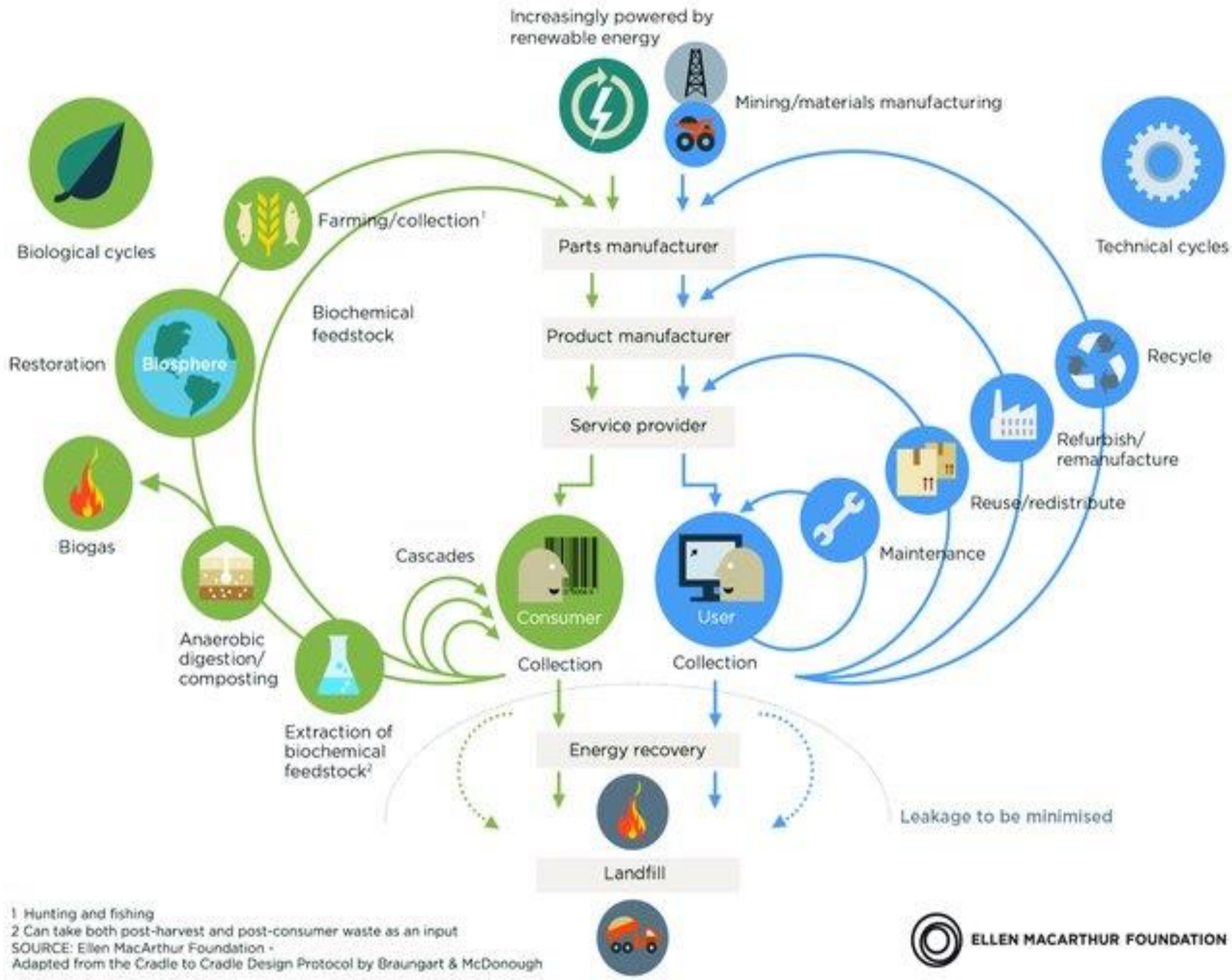


Figure 2- The Circular economy resource loops displayed by EMAF

2.1.1 Anaerobic Digestion in Circular Economy

Anaerobic Digestion can be the heart of a biological cycle in Circular economy, it produces biogas and biofertilizers from low value oragnic waste streams; so it provides electricity and/or heat, processes organic waste, and reduces emissions [20]. As rural areas are often associated with farming and agricultural activities, there will always be abundance of biological wastes on daily basis. More importantly, in rural areas the biological waste coming from livestock farms and agriculture is well sorted and is almost free of inorganic contaminants as opposed to the case of municipal solid waste coming from urban areas [21]. Unfortunately, in many developing countries the watse is neither properly disposed nor treated and poses a hazard for the environment [9]. That being said, biobased technologies such as anaerobic digestion would be a very convenient energy solution for rural areas. Anaerobic digestion takes place in an air free process where organic materials such as animal manure, food watse, agricultural waste, and sewer sludge are used as inputs and converted into biogas [22].

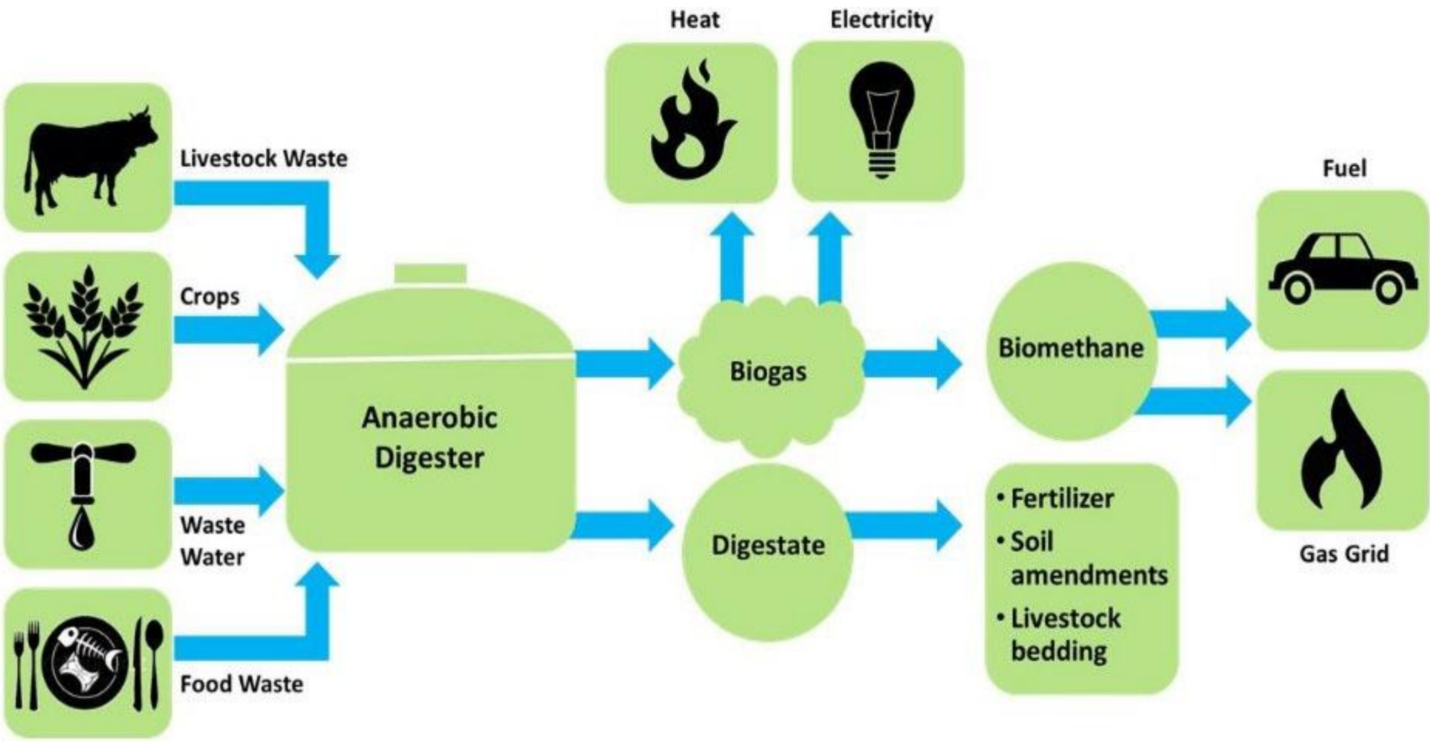


Figure 3 - Anaerobic Digestion Process [Environmental and Energy Study Institute]

In rural areas, the organic materials are often comprised of animal manure and/or agricultural waste, or crops produced for energy production, Energy crops. Accordingly, Anaerobic digetsion can be a very reliable and cheaper option for agriculture dependant communities and it is relatively simple in construction and operation. It produces Biogas (55-75% CH_4, 25-45% CO_2), a clean, accesible, and cheap fuel along with an organic fertilizer, a by-product to the biogas production process[23]. The biofertilizer can be a healthy and sustainable replacement to the traditionally used chemical fertilizers [11]. The prodution of chemical fertilizers is carbon and energy intensive, which makes replacing it with biofertilizers economically and environmentally more viable. Biogas can either be directly used in households as an alternative fuel for cooking and space heating, liquified and stored in gas cylinders, or upgraded to biomethane and injected in the natural gas grid [20]. Additionally, it can be used for power production by gas turbines or using combined heat and power (CHP) plants.

In developing countries, rural areas usually have some difficulties accessing some of their daily needs such as clean water and accesible energy due to the lack of proper infrastructures in such areas [9]. Hence, It would be efficient and less costly to use technologies that require available resources from their surounding environment and give it back as a nutrient at the end of its life cycle to maintain the sustainability and quality of their ecosystem, improving the general health conditions by offering healthier food and water sources as well as clean air [3]. It should be noted that the damage avoided by Anaerobic Digestion for a farmer in the rural areas is not only economic, or sanitary, but it can also be the time saved for an individual who brings their liquid petroluem gas (LPG) cylinders from the nearest centeral distribution facilities to their household [24].

Anaerobic digestion can play a very crucial and decisive role in the biological cycle of circular economy as will be shown throughout the following segments discussing the application of Anaerobic digestion in rural areas using circular business models that provide bioenergy, clean food, and better accessibility.

2.2 SUSTAINABLE PRODUCT-SERVICE SYSTEMS(SPSS)

For circular economy to benefit our societies and markets, there should be a few attractive circular business models that,

- Circulate the resources within a closed loop value chain minimizing waste and pollution [25];
- Ensure the proximity of resources to the location of production and use to minimize the time consumed, financial cost, and environmental impact by transportation [26];
- Offer the stakeholders a more convenient solution to meet their demands sustainably [27].

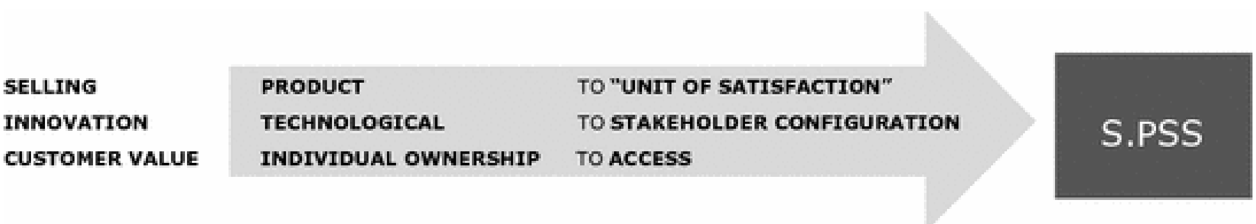


Figure 4 - The shift from traditional offerings to SPSS [28]

Innovative business models should be able to attract industries and consumers to invest in the shift to a circular model of operations. A PSS model can offer a mutual benefit to both the producers and consumers by extending the producers' product responsibility along the entirety of the product lifetime including at the end of its life. Accordingly, it decouples the consumer's utility of the product from the ownership of the product when it is out of order and set for disposal. In that regard, PSS models are believed to play a huge role as a business model in supporting the shift to circular economy [28]. As seen, PSS can be defined as,

"A competitive system of products, services, supporting networks and infrastructure. The system includes product maintenance, parts recycling and eventual product replacement, which satisfy customer needs competitively and with lower environmental impact over the life cycle."
UNEP, 2002

The definition suggests a contained ecosystem that focuses on retaining the value of its resources [29]. Keeping the products under continuous maintenance should prolong its lifetime until it is returned as a product at the end of its lifecycle and reintroduced as input for creating new products in the market [30]. Consequently, associating PSS models with circular economy would be valid as they follow the same principles of value retention of the materials used. On the other hand, PSS models are also associated with sustainability as shown in the following definition of a Sustainable Product-Service System (sPSS),

“S.PSSs are models with a win-win sustainability potential, i.e. they are business models capable of creating (new) value decoupling it from resources consumption and environmental impact increase while extending access to goods and services to low- and middle-income people enhancing social equity and cohesion.” Vezzoli et al., 2018 - Designing Sustainable Energy for All

There are different types of PSS: product oriented, use oriented, and result oriented. Each type has a different communication channels with its users, and their application depend on the product characteristics, the location, the local culture, and the surrounding environment. Product oriented PSS focuses on providing additional services to maintain the product and take it back when it is set for disposal. As for use oriented and result oriented PSS, the offering company retains the ownership and responsibility of the product along its lifetime. The user is then charged a fee for using the product, such as in product sharing models, or a fee for utilizing the performance given by a process, such as pay/lux service system provided by Philips Lighting™ [28].

Focusing on energy solutions, sPSS can offer a wide range of alternative innovative solutions for low and middle-income communities to have access to clean energy, for example applying a result oriented PSS to household solar PV panels, where the user pays for the capacity of the designed energy system, while the components are owned, managed, and recollected by the offering company. Applying such models can increase energy efficiency of household operated energy systems, and it can also expand the skill set of users if a capacity building programs were included within such model. The thesis, hence, looks at how to apply a PSS model to biogas production in rural areas and how it can be a more economic and sustainable solution for households engaged in the agricultural sector.

3 LITERATURE REVIEW

3.1 NATURAL GAS

Natural gas is a relatively clean burning fossil fuel. Despite it being a nonrenewable resource, it still has less negative impact on the environment than its fossil fuel alternatives compared to the energy produced [31]. In Egypt, Natural gas is often used in households for heating and cooking with a small presence of electric and solar alternatives, it is also used as an alternative fuel for transport [8]. In addition, Egypt has just commissioned three 4.8GW Combined Cycle Gas Turbines (CCGT), which implies an increase in the national energy demand [32]. Natural gas constituents vary according to the different natural gas reservoirs. In most cases, natural gas could be assumed to be primarily consisting of methane, often also including other hydrocarbons such as, ethane, propane, or butane.

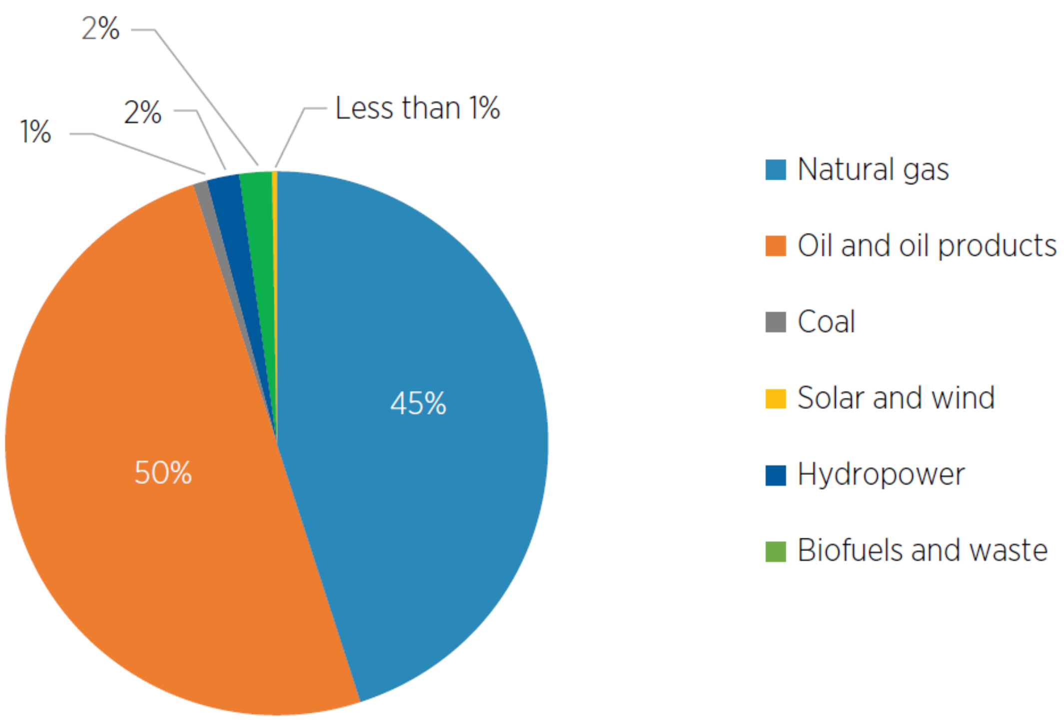


Figure 5 - Total Primary Supply in Egypt 2014/15 [IRENA]

Natural gas is widely diffused in Egypt mainly for heating water and cooking and/or space heating in some specific cases. In most urban areas, natural gas is delivered to the household through the national gas grid and is easily accessible as well as affordable for most households. On the other hand, not all rural areas in are connected to the grid [33]. However, the mostly common alternative to the natural gas grid is usually LPG cylinders available for sale in a central distribution facility, which is often more costly for rural households in developing countries. The purchase and delivery of LPG exert money, time and effort from a household member to bring the LPG cylinder from the facility to the household [34].

3.1.1 Natural Gas and Sustainability

Literature has agreed that natural gas can be considered a less adversely impactful to the environment and using it in households for cooking and heating is nearly free of harmful air pollutants. Gillessen et al. (2019), have discussed the benefits of gas with low specific carbon dioxide emissions as opposed to coal and oil in the German energy transition to sustainable energy production. The paper explained that the lower emission levels of natural gas and the existing required infrastructure to distribute gas, natural gas would fit into the short-term plan of the energy transition. In the meanwhile, gradual independence from gas supply is suggested for the long-term energy plan which will decrease the import levels to Germany. On the other hand, a main concern to the short-term plan is the risk of lock-in effects to the gas fired applications, which might be uneconomic considering the costs incurred due to the technological switch to a sustainable option [35].

Using Natural gas is argued by different sources of literature to be a cleaner solution to produce less CO_2 than coal and oil unto the atmosphere due to its low carbon content, high heating value and efficient combustion [31,35]. It can also be used as a cleaner solution for transport. On the other hand, commercial natural gas is used in power production and industry in various applications. Industrial gas boilers as an example, has proven to be more efficient and cleaner than its coal and oil fueled counterparts as presented by Tehran and Comakli (2017) when performed energy and exergy analysis to a gas fired boiler in a district heating system [36].

However, considering the life cycle of the natural gas and its environmental impacts as shown in the literature discussing adopting renewable energy sources as a main driving tool for a sustainable and carbon neutral energy production, natural gas is shown to be very convenient only for the transition and not as a long term sustainable source. Based on the work performed by Kazulis et al. 2018 on evaluating GHG emissions from biomass and natural gas co-firing, the paper aimed to study the mixed production that meets the demand with the lowest GHG emissions level through the lifecycle of both fuels. Natural gas emissions start from extraction, production, storage, and distribution to the endpoint of combustion. However, domestically GHG from natural gas in cooking is not really considered in comparison to the overall emissions throughout the production process. Biomass has a fair share of GHG emissions through its lifecycle in process such as wood size reduction in wood mills. The paper displayed that to replace 1 kg of natural gas, 3 kg of biomass are required. In alignment with literature discussing the role of natural gas in the short-term energy transition plan, the paper advocates for the use of natural gas in biomass production until the transition to renewable energy reaches the capacity of fully replacing natural gas in such processes [37].

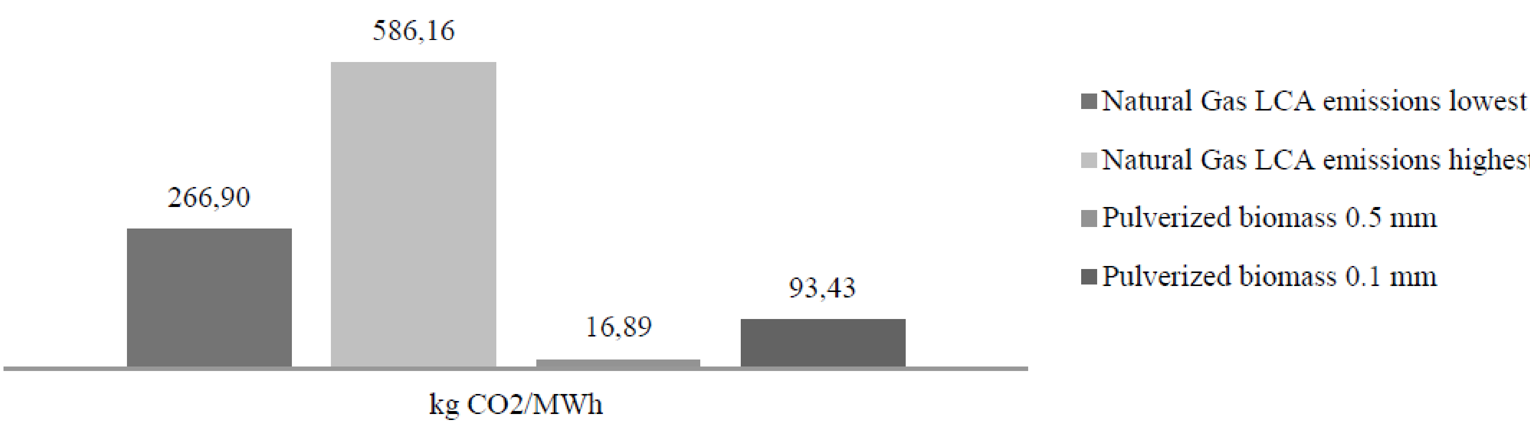


Figure 6 - Comparison between GHG levels of natural gas and pulverized biomass, values are in kgCO2/MWh [37]

According to the U.S Energy information administration [31], natural gas can be a cleaner option as previously mentioned, however, the environmental impact it has due to extraction, production, transportation, and consumption is significant. It shows that exploration can show adverse effects for the land and vegetation, well drilling produces air pollution that would negatively affect people, wildlife, and the water resources. Water is contaminated by the pipes buried in the soil to transport the gas from wells to production site. When extracted gas has lower feasibility of being transported, flaring gas into the environment takes place, wasting the potential benefit of the energy resource, as well as, releasing its contaminants to air contributing to climate change without any useful output [31].

Natural gas is inherently a non-renewable and finite resource, as well as ultimately polluting and its production is abusive to the environment. Hence, the direct use of natural gas for heating or power production is an unsustainable option as the resource will eventually deplete from the biosphere [31]. Nevertheless, given the technological lock-in surrounding the natural gas infrastructure and value chain [35], the global community is facing a barrier transitioning to cleaner and more sustainable energy sources. Even though natural gas can play a pivotal role in the transition from fossil fuels to renewables energy production, there should be a clear pathway to decouple the effects of rising energy demand from the demand of natural gas [35].

3.1.2 The Transition to Biogas as a Sustainable Solution

The production of biogas, or after purification biomethane, can replace natural gas in almost all its applications utilizing the existing gas-based infrastructure [38]. Various pieces of literature have been discussing such possibilities, Elfattah et al. 2016 has discussed in their research the potential of treating biogas from H2S and CO2 upgrading it to biomethane to fit the Natural gas network standards in Egypt and replace natural gas [39].

The existing infrastructure of natural gas networks will still be relevant to the suggested sustainable solutions even beyond the use of biomethane. In fact, Feofilovs et al. 2019 also discussed using the natural gas infrastructure for power to gas applications for energy storage. Through water electrolysis, Power to Gas (P2G) technologies use electricity to separate water into hydrogen and oxygen. The hydrogen output can either be stored as fuel for fuel cells or undergoes a reaction with carbon dioxide to produce methane that can be fed to the gas network as [40]. Currently, this solution would be useful for intermittent energy sources such as wind and solar. Meanwhile, the research discusses the injection of biomethane from biomass into the gas systems eventually substituting natural gas [41]. Therefore, the existing natural gas network will distribute renewable energy on a larger scale, however, the production rates are mainly dependent on the biomass availability. On the other hand, in rural areas the biomass is more abundant and ready to be utilized, especially in cases of anaerobic digestion where the resources are often available in proximity and is often disposed of as waste; agricultural, food waste, and/or animal manure. In case the waste was not disposed of properly and left to decompose, it would lose its biochemical potential, and will lose its organic matter emitting $CH4$ to the atmosphere among other pollutants contributing to the existing legacy of greenhouse gas emissions [11, 21, 22, 23]. Accordingly, biogas production from anaerobic digestion will further be discussed in the following segments explaining the bioconversion process, the system components and requirements, and the possibilities of its applications as a cleaner and sustainable natural gas substitute.

3.2 BIOGAS PRODUCTION FROM ANAEROBIC DIGESTION

Biomass has been attracting attention as a reliable and a renewable biological energy solution in both urban and rural areas. As described in the works of McKendry 2002, biomass is naturally circular because when the biomass is processed properly and is converted to an energy carrier (Fuel) either by chemical or biological processes, and then fully oxidized, it will return CO2 and water to the atmosphere; where the CO2 is available to produce more biomass closing the carbon cycle. This process is the basic natural process through which biomass naturally grows as visualized in figure 7 [42]. Biomass utilizes the sunlight and CO2 in photosynthesis storing the solar energy in the biomass in

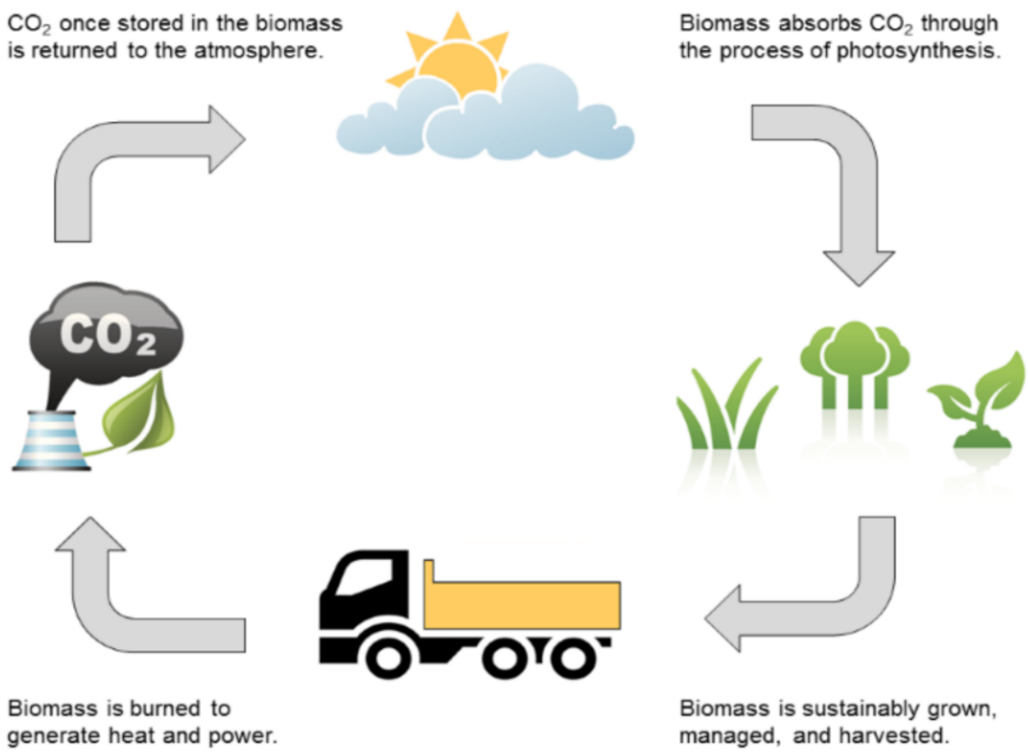


Figure 7

the form of chemical energy. Harnessing the energy can take place by combusting, digesting, or decomposing the biomass substance releasing its energy. There are types of biomass each has its own characteristics and compositions that defines the conversion process used for the specified biomass input [43].

Biogas in specific is produced from anaerobic digestion that treats dry and wet biomass in an air free environment inside an insulated digester, where the bacteria converts the volatile substance in biowaste substrates into biogas and returns the digested mass as digestate slurry. The average Biogas composition is roughly 60-65% methane and around 30-35% of carbon dioxide CO_2, and traces of hydrogen sulfide (H_2S), water vapor, and nitrogen; the H_2S should be scrubbed off the biogas first before any further use. To increase the methane yield from AD, the biogas can be further purified by CO_2 removal and be upgraded to biomethane with a very high concentration of methane (95%) that can be a convenient substitute to natural gas that can be injected into the natural gas grid [20, 22].

It has been widely accepted in several publications that AD processes can digest almost any wet based biowaste, it can be agro-waste, food waste, animal manure and waste, fish waste, and even human sludge as long as the percentage of volatile solids(VS%) in the digested substrate ranges from (7-15%). This inherent advantage works highly for developing countries, as the necessary resources are already available on daily basis and are very cheap, if not free, and it can replace the more polluting and expensive existing fossil alternatives [20, 22, 44, 45, 46, 47].

Anaerobic digestion and Biogas were discussed by Alexander et al. 2019, as an untapped fuel resource in rural areas that can be used on a small scale for single households or as a centralized facility for a larger number of households going up to a farm level where manure, agro-waste, and food waste are collected and co-digested in a the centralized anaerobic digester, producing biogas, and giving/selling fertilizers back to the farms. It also discussed the possibilities of connecting to both the electric and natural gas grids as Natividad Pérez-Camacho et al. 2019 did in assessing the life cycle environmental impacts of biogas replacing natural gas in the grid and in transportation [46]. The paper has investigated three scenarios for biogas adoption, the first is producing electricity from biogas through a combined heat and power (CHP) plant and inject electricity to grid, the second to upgrade the biogas to biomethane and inject it to the national gas network, the third is to replace petrol and diesel in transportation with biomethane. The life cycle assessment showed environmental improvement in almost all the indicators concerning air, water, and land quality in all scenarios. However, the first scenario showed a significant impact from the biogas plant on the agricultural land occupation by the CHP plant. As for the substitution of fossil transport fuel with biomethane has resulted in the highest savings among the three scenarios in terms of environmental impacts [47].

3.2.1 As a circular fuel

Biogas has the potential to be the center piece of the biological energy cycle in Circular economy, its production process is regenerative; it consumes wet biomass to produce biofertilizer from AD that feeds back to the soil. According to Fagerström et al. (2018) discussing the role of anaerobic digestion in circular economy, that the circular economy systems were applied before industrial revolution proposed in the current linear economy. It explains within the context of circular economy how anaerobic digestion is considered a circular system. As it refers to the circular economy resource loops fitting biogas production as a last step of a cascading loop. The organic matter is introduced at the end of its life cycle undergoing the bioconversion process, producing biogas and the digestate used as fertilizer as previously mentioned in literature [20]. However, focusing on the circular nature of the process, in literature relating to circular economy biofertilizer is the biological nutrient feeding the biosphere for growing more crops, while CO2 generated is theoretically within the natural carbon cycle and will be reabsorbed in plants to undergo the photosynthesis process closing both resource loops of the biogas and the biofertilizer [20, 22, 46].

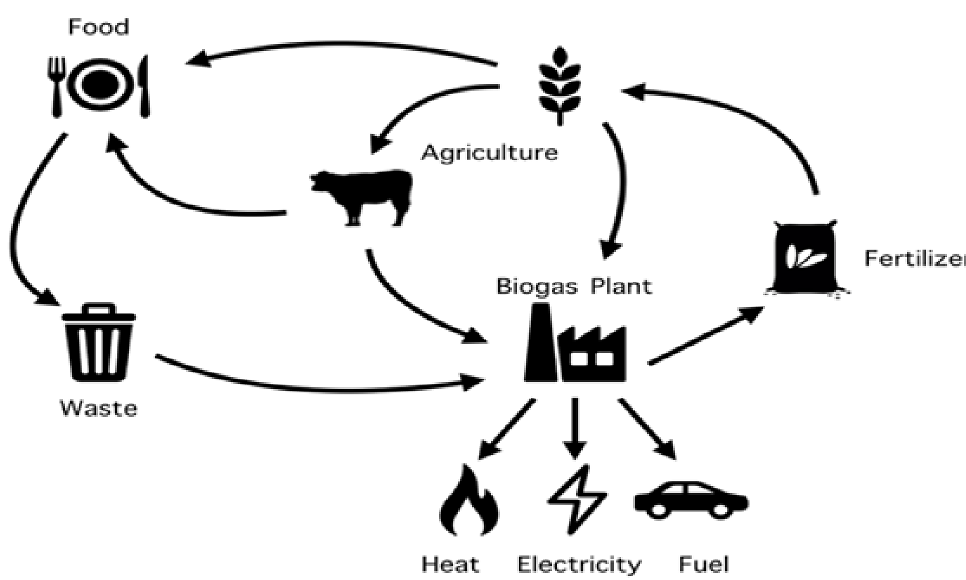


Figure 8 - Resource loop of Anaerobic Digestion

Biogas production is believed to be at the very center of organic waste management in a circular economy, where all low value unusable organic material is to be sent to the biogas plant instead of being classified as waste [20, 48]. While Picardo et al. 2019, discussed district heating based on biogas from water treatment plant as a circular application to water treatment achieving both objectives of treating the wastewater from contaminants in addition to providing district heating and domestic hot water as the end products for the user [48]. Rajendran et al. 2012 displayed the importance of biogas in domestic cooking as one of the main applications of biogas in rural areas, where one cubic meter of biogas is argued to provide energy for cooking three meals a day for a household of 5-6 members. The paper also mentions the average biogas required by a household monthly would be around 30-45 m^3, which coincides with 3-4 LPG cylinders or 20-30 m^3 of natural gas [58].

Through the discussions on the circular nature of biogas production, the literature is aligned even though different research work discusses different application in various settings. They all present biogas production as a very convenient technology for sustainable energy, having many benefits on social, economic, and environmental levels. As discussed, getting rid of accumulating waste would decrease the potential emissions from the decaying waste that cause health issues when left untreated. The resources required are almost always available in the user's reach and were always considered as waste, a material that is ready to be disposed of, but Anaerobic Digestion takes the low value material and creates two high value resources, biogas and biofertilizers which is a strong and direct value proposition for any business model.

However, due to the various scopes of applications of research work, very few in literature has discussed the technologies and their benefits or has provided insights on the marketability of such a product, or the possible innovative business models that can emerge from such opportunities.

3.2.2 Barriers to adoption

In the work of Ramos-Suarez et al. 2019 [45] on the opportunities of biogas in the canary islands, given that the Canary Islands consists of 8 islands and are not connected to neither the African nor European network, the need of distributed sustainable production of energy exists to satisfy the energy demands for each island. The research evaluates the quantity of the manure generated per year by classifying the types of animals in the canary island, their distribution across the country, in addition to the specific amount of manure produced per household. The authors considered the lower limit for operating a biogas plant is 0.5 t/day which is equivalent to about 3 kW_e. It was shown that most of the households produce less than the lower limit and hence couldn't operate their standalone biogas plant. On the other hand, the farms producing more than 0.5 t/day contributed to 80% of the overall animal manure generation in the canary island, hence, it was suggested that the focus should be on nullifying the adverse environmental effects of the larger farms as an initial point, in all cases it was the more economic direction due to the economies of scale applied on biogas plant capacities. As for the small farms, it would then be appropriate and economically beneficial to have their waste processed in the bigger biogas plants, however, the paper has not mentioned the dynamics by which the small farms will be rewarded or incentivized to dispose their waste in such biogas plants [45].

Winquist et al. (2019) has highlighted the fact that biogas technology is not widely adopted in the energy market in Finland until now in contrast to its renewable counterparts [49]. Through interviews conducted with small-scale plants owners and large-scale ones, small scale plants were found to be too expensive as an initial investment, and yields in lower energy price which results in higher payback times, this insight is also aligned with what Ramon-Suarez et al. 2019 has mentioned regarding the small scale plants in small farms [45]. The paper also concluded that even though the potential of biogas exists in Finland, there is a certain misalignment between the technical, social, economic and regulatory context which makes it harder for the market to adopt the technology and accepts its risks [49]. On the other hand, Karlsson et al. 2019, in business modelling farm-based biogas production explains how to create a network level business model (BM) where firms do not operate on its own but in collaboration with other firms working in the same sector, as it has been proven that firms operating in network receive better sustainable value gains. This study offers a new, collaborative approach to the development of network-level BMs for sustainability in farm-based biogas production. Throughout the study, it suggests a collaborative approach in farm-based biogas production provides more customers, expands the business activities, and reflects an increase in value creation [50].

Such issues usually require innovative business models that can appeal to the user, to the market, and to the regulator as well as engage them in the process.

3.3 Sustainable Business Models in Energy Applications.

Sustainable Product service systems (sPSS) models have already found its way to the market and the business model has started to find more traction from service providers and manufacturers as a potential sustainable solution [28]. According to Vezzoli et al. 2018 reporting that sPSS approach can help diffuse sustainable energy solutions to low/middle income stakeholders, mainly because it can reduce or remove the initial costs associated with owning the product which covers the problem reported by both Winquist et al. 2019 and Ramon-Suarez et al. 2019 [28, 45, 49].

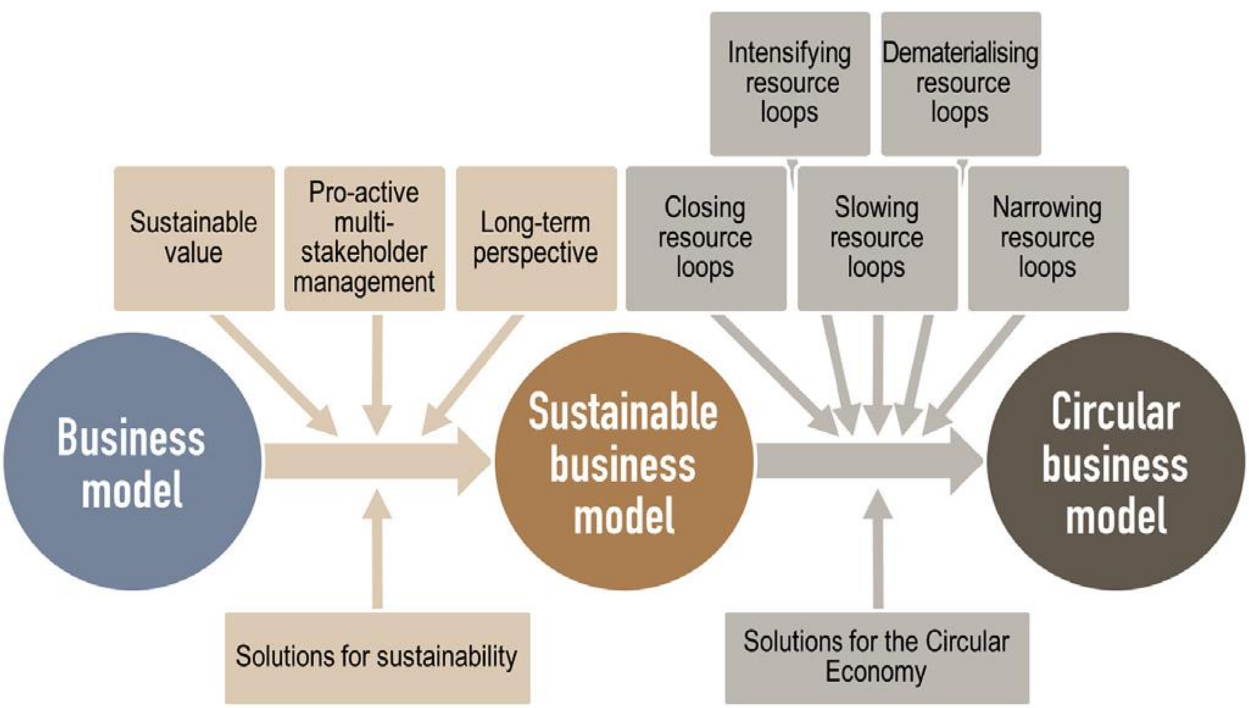


Figure 9 - Main differences between traditional, sustainable, and circular business models [Geissdoerfer et al. 2018]

The literature does not explicitly connect biogas production with sPSS models, and their association is indirect in case of reviewing literature about Distributed Renewable Energy systems (DRES)[2] with biogas production. It shows no specific application to this work's point of focus, however, analyzing the biogas production literature and the sPSS separately would still result in interesting insights that make the connection between both topics clear, especially when discussing Egyptian rural communities.

However, Ceschin, Fabrizio, and Idil Gaziulusoy. 2016 argue that to perform a radical shift of attention in each society to more sustainable solutions, it would require more than just technological improvements. It would require intervention on different levels of a society; on the social, behavioral, and cultural level, which can be expressed in new business models, as well as a change in the way organizations and institutions to make way for the change to take place[].

Karlsson et al. 2017 in his work on business model innovation in agricultural biogas production has concluded that through connecting the private and public sectors to design farm-based biogas investments that would develop rural areas and provide a more fertile agricultural market for SMEs to penetrate the market and innovate as they gain more experience in the biogas production field. In addition, the research highlighted that the investors in biogas should recognize the long-term strategic benefit of its diffusion and adoption for sustainable social, environmental, and financial returns, rather than the short-term financial gain. Additionally, choosing the technically competent partners in biogas production to ensure technological fidelity in the value offered was suggested [50]. It also aligns with the work Bacchetti et al. 2017 on designing a PSS system on a DRES, as the paper also concludes that one of the key elements of this PSS design is involving the stakeholders. It suggests that PSS would provide lower risks that are shared among the network of stakeholders included in the business model. It explains how the model focuses on selling a unit of satisfaction instead of selling a product [52]. This can be applied to rural farm-based biogas plants where the network of stakeholders is benefiting

[2] DRES as defined by Vezzoli et al. 2018 "*a small-scale generation units harnessing renewable energy resources (such as sun, wind, water, biomass and geothermal energy), at or near the point of use, where the users are the producers—whether individuals, small businesses and/or a local community. If the small-scale generation plants are also connected with each other (to share the energy surplus), they become a Renewable Local Energy Network, which may in turn be connected with nearby similar networks*."

from the biogas plant with biogas and fertilizers while providing their specified amount of generated waste. Methods of payment in such a model can be barter based, or a subscription fee every month that entails the use for the monthly biogas demand as well as fertilizers if required, the fees should cover maintenance services, and capital cost. In that regard, Emili et al. 2016 identified 15 archetypes of PSS models for offering decentralized energy services using a classification system in figure 4; linking the different types of PSS, displayed on the y-axis, to their relevant energy systems and their target customer, displayed on the x-axis [63] . Through the classification system, the archetypes were divided into 3 main categories signifying the types of PSS value propositions, payment structures, energy system operation and ownership system each being assess in relation to the target customer, and the energy system. The research aimed to couple between both DREs business models and the PSS business models to design a unified classification system. A system that can express the insights gathered from case studies,

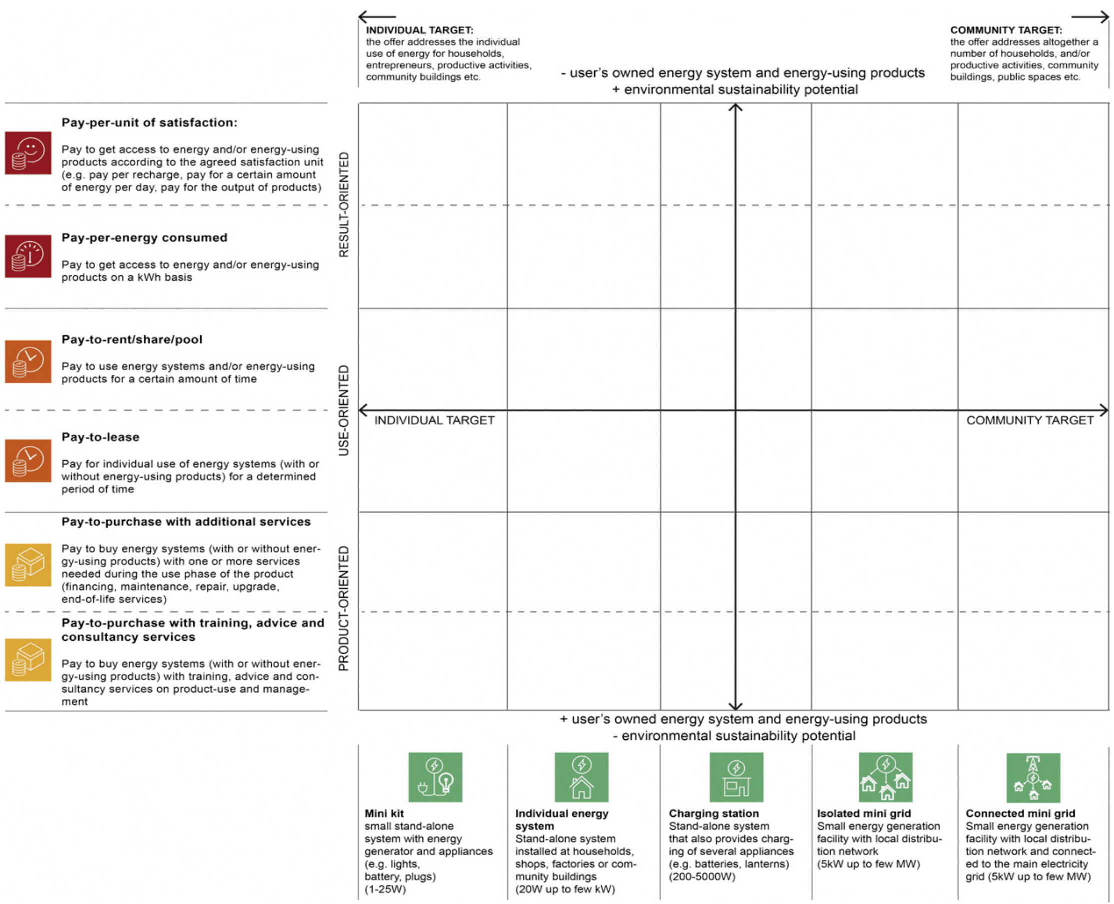


Figure 10-Classification System designed to evaluate each archetype according to its offerings [63]

mostly from developing countries, and used in a conceptual context as a design tool/strategy for companies and practitioners to support the DRE PSS design process. []

In Africa, according to Hamid and Blanchard 2018, the results indicated high technical potential for biogas specifically in central and western Kenya where, in general, land and cattle manure resources are available, however, according to Demirbas and Demirbas 2007, Africa does have the potential but lack the policy instrument that helps such technologies to diffuse [53 ,54]. Similar barriers were discussed by Elfekki et al. 2017 regarding the biogas production from agricultural waste in rural Egypt. However, it also demonstrated that there is a high potential for small scale and semi centralized biogas plants. The produced biogas can be used in households and industry, and the nutrients in the digestate are recycled back to the soil as compost improving soil quality developing the agriculture management in rural Egypt [11].

For further rural development, increased quality of life for farmers, and easy access to clean energy for all users can be achieved though models that relieve the user from the plant ownership and maintenance, which will eventually decrease the expenses on the farmer in addition to the avoided environmental and social costs due to the technology adoption.

3.4 RESEARCH GAP

There is a significant lack of local studies in Egypt about innovation in business models of Energy systems that needs to be addressed as well as a scarcity of open source primary data to provide more insights on the potential of such technologies in Rural Egypt especially when applied within a PSS framework. In addition, an Anaerobic Digestion PSS business model has not been directly explored in previous literature.

3.4.1 Problem Statement

Rural Communities

Rural communities in Egypt are, on average, poorer than urban communities [8], some of which do not possess the proper infrastructures for education, energy, clean water, and waste management systems [67]. The organic waste generated from the agricultural sector in Egypt every year is not properly utilized; it is usually inefficiently combusted, used as fodder, or disposed of wasting its potential embedded value. On the other hand, Egypt's reform program plans to remove all fuel subsidies to establish a fuel price reflecting the cost of production [55,56].

In fact, many rural households depend on the supply of the LPG and CNG cylinders provided by the local outlets which are lately unable to cover the demand of rural communities [62,64,65,66].

Egypt's Energy Strategy

New and Renewable Energy Authority (NREA) in Egypt has no specific regulations that govern biofuel production technologies. Moreover, biofuel production is not as widespread and established in Egypt as solar and wind energy technologies. In addition, biofuel production in rural applications, specifically Biogas by AD, is not the primary focus of NREA in Egypt as displayed in the Renewable energy targets set for 2022 and 2035. The strategy shows that by 2022, 20% of the national production attributes to solar and wind energies, and by 2035, the renewable production will rise to 45% none of which was assigned for biofuel production prospects [57]. Hence, many of the investments and the regulatory effort are naturally allocated towards the development of solar and wind energy markets in Egypt rather than biofuel markets. In fact, Egypt is already working on connecting 1.2 million household annually with the natural gas grid [68].

3.5 RESEARCH OBJECTIVES

This study aims to identify the potential benefits of creating a network of agricultural cooperatives engaging the rural households of Egypt to produce biogas from animal manure. This could lead to the establishment of an infrastructure of organic waste management in rural Egypt. The cooperative design should emulate the PSS frameworks in DRES applications, through creating clusters of cooperatives along the Middle delta and upper Egypt regions where almost all agricultural activities are located. On the short term, the potential benefits should be estimated regarding the direct savings to the rural communities. On the long term, the potential benefits should be addressed regarding possible future developments that could add more value to the biogas value chains. Biogas upgrading for example, where biogas is purified from the carbon dioxide content increasing the methane content to the natural gas pipeline standard, so it can be injected to the national grid.

3.6 RESEARCH HYPOTHESIS

This study aims to prove that creating a network of Anaerobic digestion plants in rural Egypt will be economically more beneficial for rural communities than subscribing to the national gas grid. The benefits will extend beyond the economic feasibility, such a network will increase employment rates, the annual income for a household, and the overall quality of living in both the short and long term.

4 METHODOLOGY

In this study, the aim is to study the feasibility and identify the benefits of distributed biogas production in rural areas across the middle delta and upper Egypt regions from animal manure. To study such effects, there are three separate types of information required to carry out the study.

Firstly, Anaerobic Digestion technical data collected to set the appropriate parameters regarding the estimated capacity of a biogas plant and how many households a biogas plant can provide, the amount of animal manure required to maintain the daily production of biogas. This includes several parameters to be identified through published literature models and technical standards, as well as surveying biogas companies operating in Egypt.

Secondly, Cost estimation data can be gathered from literature relevant to the specified technologies preferably reflecting the local cost estimates, however in case such estimates were not available, the cost would then be represented according to literature reflecting the international market. Even though it might not properly reflect the potential local prices, however, it is offers acceptable estimates. In this study, the cost estimates data sets from the Egyptian market were scarce, since the biofuel production market in Egypt has not been fully developed. Hence, the cost structure and insights which limits the variety of sources. However, the data and insights were collected from one company including breakdown costs for five different sizes of plants. The cost estimation will compare the expenses that a rural household is expected to pay for connecting to the national grid against the estimated costs of creating a community-scale digester for six households.

Finally, based on the results and the literature review, a the last section is describing the business model based on the data collected to discuss the applicability of the project in relation to the local context. The data is mostly collected from annual reports provided by relevant governmental institutions, and international organizations that specializes in agriculture, energy, and rural development. However, culturally specific details, insights, and data were also gathered by semi structured interviews with experts working closely with rural households and agribusinesses providing information about the potential stakeholders and the main beneficiaries. Accordingly, a business model is suggested to assess the possible advantages and barriers, and to provide a solution that is relevant and in synergy with the local conditions.

The coupling of the three research components aim to estimate a convenient amount of funds required from each household annually to sustain the cooperative and its activities. The annual fund provided by households will be presented as a share (%) of each household's annual income as a component of the household expenditure.

4.1 BIOGAS PRODUCTION

This section will display from where the data was extracted, and the models that have been chosen to estimate the technical daily biogas yield. In addition, the selection criteria of operating conditions for this study prefers simplicity of operation to ensure that operating the plant fit the skill level of rural areas inhabitants of Egypt at the time being.

Initially in order to estimate daily production, the daily natural gas consumption was used as the energy reference for production, assuming the monthly cooking gas consumption per month can either be in unit volume of daily Methane consumption (CH4) (m^3/day), and unit energy demand (kWh_{th}/day). Given the composition and calorific value of both natural gas and biogas, it is simple to obtain the volume of biogas required to provide the same amount of energy. Natural gas contains 90-95% methane and its energy content 35-38 MJ/m^3, compared to biogas having 60-65% and 20-22 MJ/m^3, from which the maximum values were selected to undergo the study.[57] [58] Accordingly, after defining the standard operating conditions for the plant shown in, the daily waste input required for producing the required daily biogas yield. Accordingly, defining the proper assumptions for the parameters was the initial step for realizing the estimates.

4.1.1 Hydraulic Retention Time (HRT)

It is the average amount of days the organic substrate resides inside the digester produce a steady flow of biogas. It can be determined knowing the substrate volumetric flow rate and the digester volume, The shorter the HRT, the lower the biogas yield, the smaller the digester size and accordingly the plant is economically less costly. However, deciding HRT depends on the operating conditions of the digester, mainly the system temperature.

4.1.2 Temperature

The temperature of the substrate inside the digester is one of the most crucial parameters of anaerobic digestion, because microorganism formation and stability depends on the operating temperature of the system. The literature suggests that mesophilic (20-42^{o}C) and thermophilic (43-55^{o}C) conditions are most suitable for high biogas yields. Thermophilic conditions have proven to be very efficient in terms of biogas yield and low HRT, 15-20 days. The efficiency and yield of high temperature conditions overshadows the extra cost considering the required substrate heating system. However, it will be dismissed in this study to avoid additional complexity and cost in the construction and operation of the digesters. On the other hand, mesophilic conditions suit best the conditions in Egypt given that the average ambient temperature is recorded around 22^{o}C in Egypt requiring no additional heating components in the digester. Under mesophilic conditions the optimal HRT in such conditions are between 25-40 days [59].

4.1.3 Total and Volatile solids (TS%, VS%)

Total solids are measured as the percentage of organic or inorganic dry matter in the substrate. TS% content for different types of waste is measured in lab, by heating a sample of wet substrate ridding it off its moisture content. As a parameter, it is crucial for choosing the size of the digester and the appropriate operating conditions; for example, substrate with high values of TS%, yield better biogas compared to lower TS% at the same HRT [60]. As for VS%, is the amount of organic volatile matter within the substrate, it displays the amount of organic matter that can be converted into biogas. VS% can be expressed as a percentage of the Total Solids, or of the overall mass. The average optimal TS% in cow manure has been estimated to be around 8-10% (kgTS/kg) while VS% is around 85% (kgVS / kgTS), and 7-9% (kgVS/kg).

4.1.4 Biogas yield

As previously mentioned, the biogas yield from the plant was estimated by defining either the energy requirement for cooking for each household, or the average volume of cooking fuel consumed monthly per household, and accordingly estimating the equivalent of biogas required to cover the same level of consumption. Defining the amount of organic matter present in the cattle manure as well as the water requirements for mixing the manure, it is estimated that the best practice is adding a ratio of 1 kg of manure to 1 kg of water to dilute the TS% to the required the 10% range. The estimation of the yield follows the following simplified relation, $DY = Fd \times VS\% \times SY$; *DY* being the Daily biogas yield in units of cubic meter per day, *Fd* being the daily feedstock to the digester expressed in units of kilograms per day, VS% is the percentage of volatile substance expressed as a weight fraction of organic substance from the feedstock, and *SY* being the specific biogas yield for the given type of waste in units of cubic meter per kilogram of the feedstock.

4.2 COST ESTIMATION DATA

Biogas production in Egypt is a growing market, the number of companies are still limited, and, in addition regulations regarding biofuels are few in Egypt. However, the "Egyptian Association for Anaerobic Digestion" (EGAAD) is one of the few companies that operated in rural areas and had the cost estimation data for five different small-scale plant sizes. The provided cost structure for each plant included the construction cost, modification of stoves and piping costs, and the labor cost of construction the estimates provided purely signified the cost of materials in detail.

Given the limited sources of information, the data was verified by comparing the international prices of plants with similar specifications. The data was collected from different pieces of literature. Accordingly, a simpler financial assessment is made to clarify the payback time and compare it to the household's expected expenditure on natural gas or butane LPG.

To assess the cost structure of installing a biogas plant, the capital investments as well as the operational cost are reported. The operational costs are defined mainly as the manure cost which comprises the transportation and collection cost of manure, while the O&M costs were assumed to be 3% of the capital cost. Accordingly, a financial statement was estimated along the lifetime, 15 years, of the plant to determine whether the cooperative will be able to sustain only by the shared fund provided by the members of the cooperative.

4.3 COOPERATIVE BUSINESS MODEL

To build a business model for the cooperative the local context needs to be identified. It should include the main aspects of the ecosystem in a rural area, the household and their livelihood, the levels of GHG emissions, and the amount of water required for the AD process. The data were collected from annual country reports concerning and academic literature, the annual income of households, their expenditure, their consumption, and their carbon dioxide emissions can then be estimated from the daily consumption of cooking fuel, and from the amount of unutilized organic waste produced daily. However, some of the required data to estimate these changes are either unavailable or somewhat inaccurate, which then were evaluated qualitatively.

Concerning the application of anaerobic digestion for households, the measure of its feasibility covered the estimated savings of the lifetime of the plant from biogas and biofertilizer. In addition, the possible income generation opportunities created from the logistics of the plant, such as transportation, waste handling and collection, and plant monitoring and operation. Hence, such a project should aim to include capacity building trainings that prepares the rural worker for participating in the activities created by the project. Additionally, many of the habits and traditions of the rural households have been studied by agribusinesses that provided a sound cultural context, in addition to the provided in reports published by international organizations.

For the assessment to be relevant to the local context a Stakeholder Analysis is necessary; identifying the main players in the current situation, the beneficiaries of the plant, the entities that will support and empower the implementation of sustainable businesses, and the stakeholders that are at risk as a result of implementing the plant.

All the beforementioned business parameters should be reported within the business plan of the cooperative, where the household is positioned as a direct business partner, as opposed to a consumer or a producer. In that sense, a business model was designed similarly to other models designed for low-income markets (Base of the Pyramid) even if the description might not always be accurate for all rural markets in Egypt. Within the context of BoP business models, as mentioned by Ceschin, Fabrizio, and Idil Gaziulusoy. 2016, that less privileged communities participating in a business should be perceived as consumers, producers, or potential business partners, instead of victims that require aid. Accordingly, the business model is being designed to accommodate the rural households.

4.3.1 The Business Model Canvas

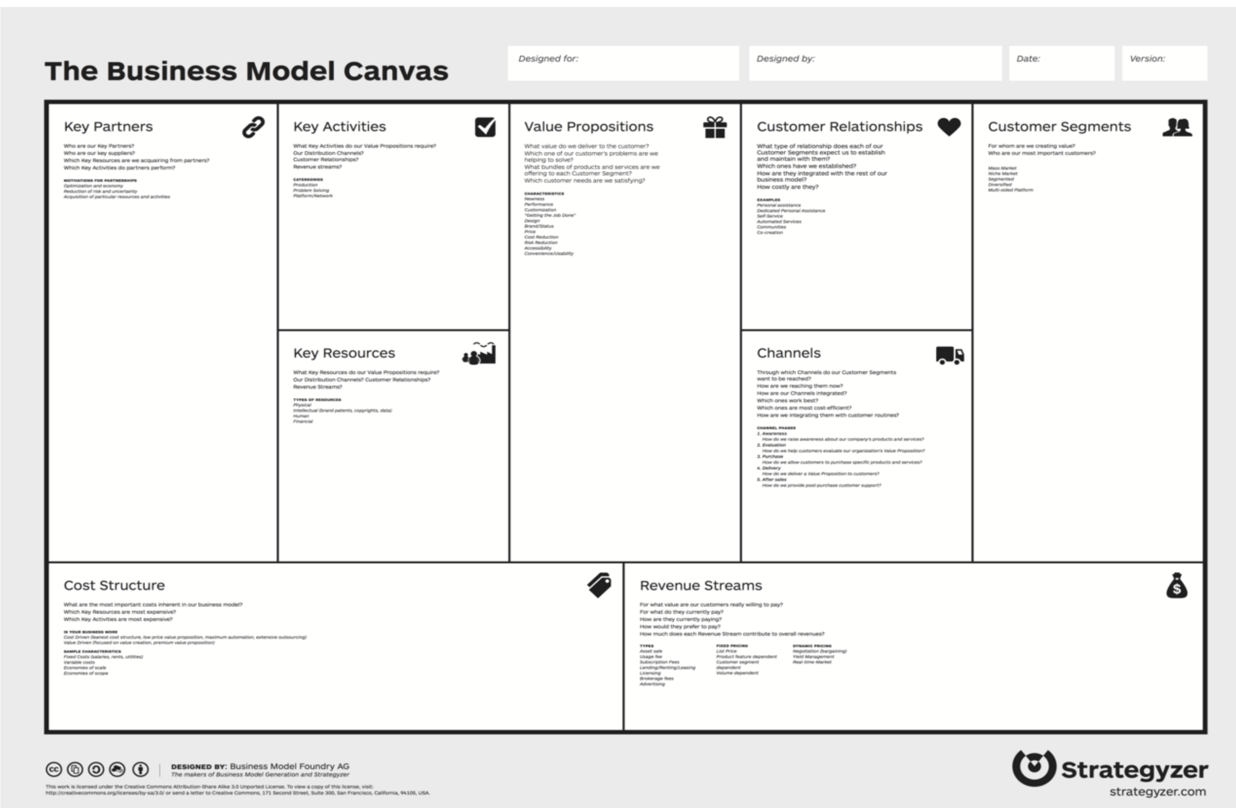


Figure 11 - Business Model Canvas

Using the collected data from news articles, academic papers, semi structured surveys from biogas plant suppliers and experts from the field of agriculture in Egypt, the cooperative business plan was designed using the nine business model components suggested by Osterwalder, Alexander 2004 as guideline to identify the key elements of that defines cooperative in relation to the its contributors and potential partners. The nine elements are widely used in different disciplines and they constitute the business model canvas in figure 11, which has become a very important tool for designing business plans.

The nine elements of the canvas are mostly interrelated, and they mostly revolve around the main offering of the designed business. The business offering can be determined by defining the **Value proposition**, which is the value of products and services that will be delivered to the customer to cover a specific need or to provide a solution for a problem that the customer cannot solve. Value proposition can be displayed in many different forms, as a new design, a better performing, or a more usable and accessible product/service. Hence, after defining the value proposition, the other eight elements will have a base upon which the business plan can be displayed. In this study, the remaining eight elements can be divided into 3 groups:

1. **Communication:**
    a. Customer Segments, the type of customers for whom the value proposition is designed
    b. Customer Relationship, explains the nature of the interaction between the business and the customer before and after the sale
    c. Channels, describes the method by which the communication between the business and the customer will take place
2. **Operational Infrastructure:**
    a. Key partners, which displays who the main stakeholders are and what they offer/demand for/from the business
    b. Key Activities, looking at the main activities the business will take part in to create and deliver the value proposition, and the activities required maintain the relationship with the customers
    c. Key Resources, which are the expected processes and materials required to operate the business

3. **<u>Financial Fidelity:</u>**
    a. Cost structure, which defines the most significant fixed and variable costs to operate the business, which can be considered as the outflow of cash
    b. Revenue streams, the amount and type of main cash inflows to the business.

5 RESULTS

The following chapter discusses the estimated results of the thesis work considering the stated assumptions. This chapter is divided into three main sections:

The first section will examine the estimated production capacity of the plant according the number of households sharing the plant and the amount of daily manure required to supply the daily demand. The second section will analyze the economic feasibility of the project considering the overall estimated cost of the plant. The final section will present a business model canvas illustrating the viability of the chosen cooperative model

5.1 BIOGAS PRODUCTION

Using the technical data collected either from literature or semi structured interviews with agricultural professionals, it was possible to obtain some realistic estimations of the biogas production in the chosen anaerobic digesters. However, further field experimentations would be necessary for validating the estimated data on the production capacity and the expected costs.

The average monthly demand of a rural household in Egypt is estimated to be around 30 m3, which is equivalent to three Butane LPG cylinders and 45 m3 of biogas. Hence, a biogas plant is estimated to supply the daily demand of domestic gas for each connected household.

Table 1 - Average consumption per household

Household Average Monthly Consumption		
Natural Gas	LPG cylinder	Biogas
30 m3	3 cylinders	45 m3

For the purposes of the study, the specific biogas yield is the average of cattle manure which ranges around 0.2-0.45 m3/kg, and the HRT was assumed to be 30-45 days, given that the operational temperature was assumed as of a mesophilic fermentation process as per EGAAD’s regular operations. In addition, VS% is assumed to be around 7-9%

(kgVS/kg) of the daily manure input. These data and operational limits have been obtained across different publications and literature concerning best practices for biogas production from Anaerobic digestion of cattle manure. On the other hand, the estimates are coherent with the estimates and the operational data of plants that are designed to operate in Egypt.

Table 2 - Technical Estimations

Households	Natural Gas Consumption	Thermal Output	Biogas Equivalent	Waste Input	Cattle	GHG Emissions	Digester Vol.
#	m3/month	kWh/month	m3/month	kg/day	#	kCO2/yr	m3
3	87	768	132	146	10-14	74	11
4	116	1024	176	195	13-20	99	14
5	146	1280	219	244	16-23	124	18
6	175	1536	263	293	20-28	149	21

In table 1, following the average monthly natural gas consumption in Egyptian households and EGAAD's technical specifications, the biogas required to cover the monthly thermal demands was estimated according to the following list of assumptions:

- Natural gas LHV = 31.7 Mj/m^3
- Biogas LHV = 21 Mj/m^3
- Total Solid % = 10%
- HRT = 30 days
- Specific Biogas yield = 0.3 m^3/kg_{waste}
- Water to Waste ratio = 1 kg_{waste}:1kg_{water}
- Livestock manure generation = 10-15 kg/head
- Operational Temperature = Mesophilic conditions (20-40oC)

To ensure a certain level of daily fuel demand, a consistent daily supply of manure should be available as well. It was estimated that for one household the daily waste supply would be around 48 kg of manure. One cattle will generate around 10-15 kg of manure on daily basis. Hence, each household will require at least three cattle, which is the average number of livestock available for a rural family.

In this study, determining the estimate of the daily required supply depends mainly on the number of households. The estimations will focus on a small-scale community biogas plant supplying up to 6 rural households, producing 9 m3/day the requiring a daily waste feed of 290 kg of manure, which requires 10-15 of livestock.

5.2 Economic Feasibility

In order to assess the economic feasibility of the cooperative model, it is crucial first to verify the local prices to the international prices. It helps understand the potential of communal biogas production in Egypt. Hence, the cost estimates collected from EGAAD

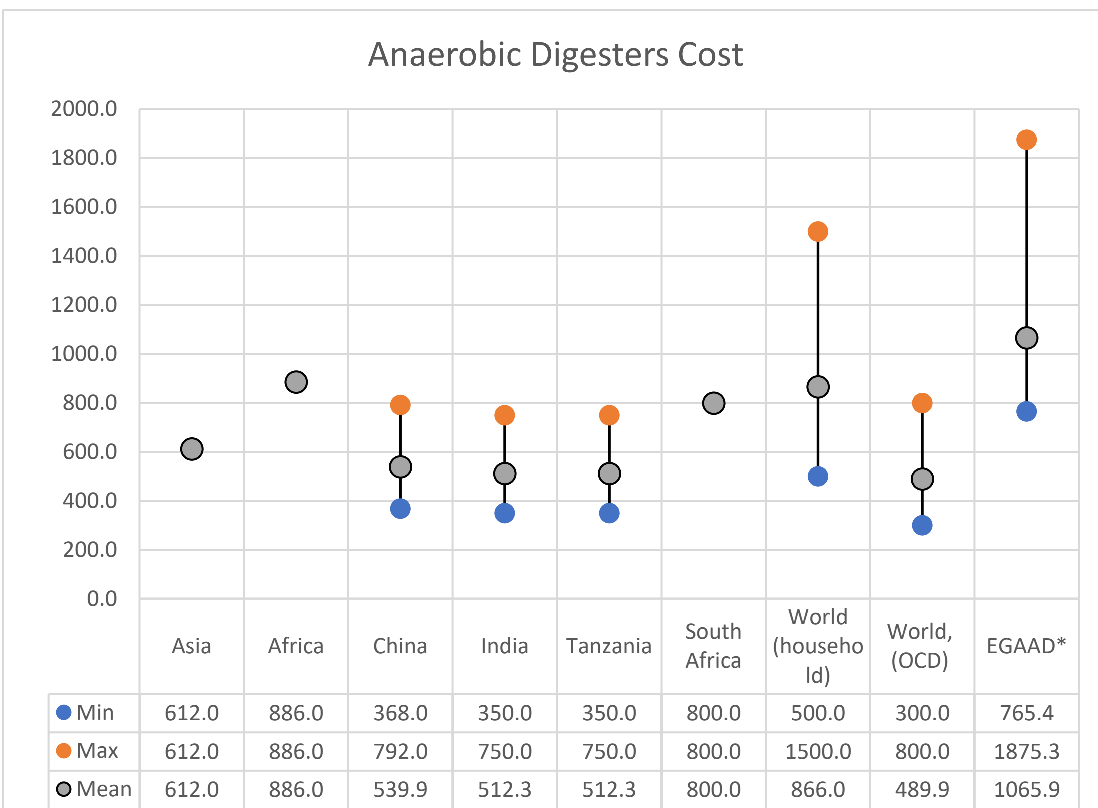


Figure 12 - Comparison between reported costs of Anaerobic Digesters [61] and the collected data from EGAAD (all reported in US $)*

were verified by other international prices of similar communal biogas plants by the costs reported in US dollars[3] in figure 5 [61].

Accordingly, the results in this section will be divided into two main scenarios:

A. An energy-based scenario assuming no policy changes or fertilizer savings
B. An incentive-based scenario with a 5-year tax abatement for biogas plants

According to these prices, the necessary capital investments for the biogas plant can be identified. As for the operational costs concerning collection and transportation of manure to the plant, they are reported with the capital costs in table 1. Table 1 reports all the technical and financial results obtained for the various cooperative configurations.

The financial feasibility is determined by the NPV and payback time in figure 14, assuming that a rural household cannot dedicate more than 10% of their expenditure on domestic fuel production. However, in the study fertilizers sale or savings are not taken into consideration, given the limited sources of information about the fertilizer market in Egypt.

Scenario A

Table 3 - The costs of anaerobic digesters

Households	Biogas	Waste Input	CAPEX	OPEX	Cooperative Funds	NPV	IRR[4]
#	m3/day	kg/day	EGP	EGP/year	EGP/year	EGP	%
3	4	146	12047	8451	15600	-19570	-12%
4	6	195	16471	10670	20800	-7970	1%
5	7	244	19648	13561	26000	-7742	3%
6	9	293	29517	16116	31200	9,160	15%

As shown in table 2, considering that the willingness to pay of each household cannot exceed 10% of the income. The estimations show that with energy savings only, the investment for plants supplying less than 6 households are not considered a profitable investment according to the estimated Net Present Values and internal rate of returns. The negative figures are a result of the cooperative funds being only dependent on the

[3]US dollars to Egyptian pound conversion ($1 = EGP 15.74)
[4] Discount rate = 10%

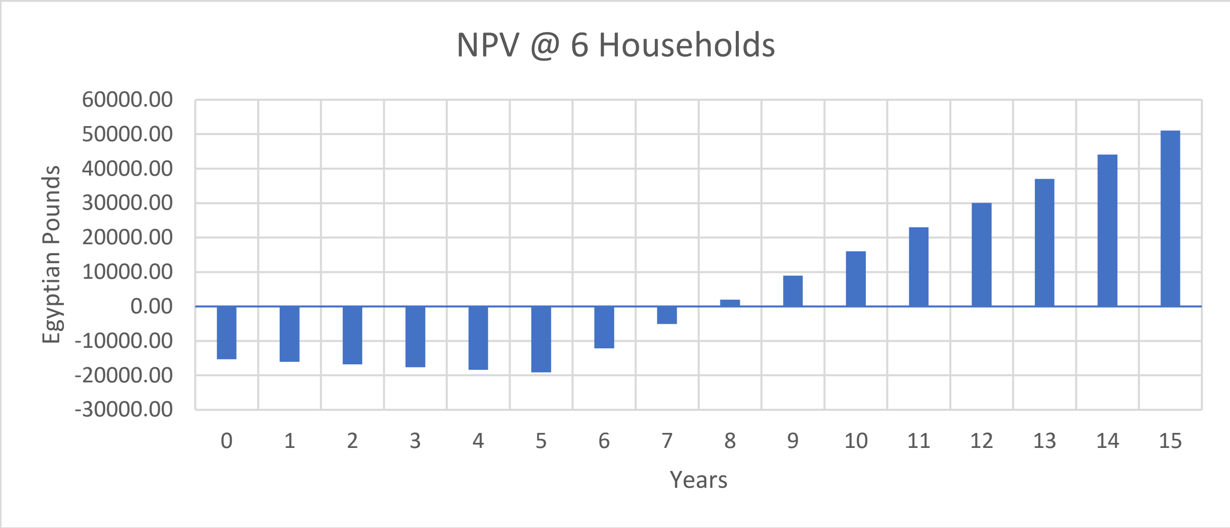


Figure 13 – Payback period

willingness to pay of each household. For system shared by less than 6 households, it proves financially difficult for households to sustain the cooperative. On the other hand, figure 13, shows the estimated payback period for the most profitable scenario with 6 households to be around 7 years. On average 7 years can prove to be very inconvenient for rural households, especially as the revenue streams of these households are not diverse and rural households cannot afford to wait for that amount of time. In addition, there is a level of uncertainty that comes with time, that can be perceived as a high risk for a rural household given that the income from agriculture can vary depending on different uncontrolled variables that can change from season to season.

A financial comparison was also made between two possible alternatives, that of owning the biogas plant and that of connecting to the natural gas grid, as shown in figure 14. It shows that according to the current energy market in Egypt, connecting to a natural gas grid is more convenient for a household. This comparison does not consider the effect of tax and depreciation on the investment, it mainly tests the cost of ownership of both alternatives.

However, when considering the potential savings in chemical fertilizers and incentivizing the production of biogas, biogas production would be a more attractive investment for rural households.

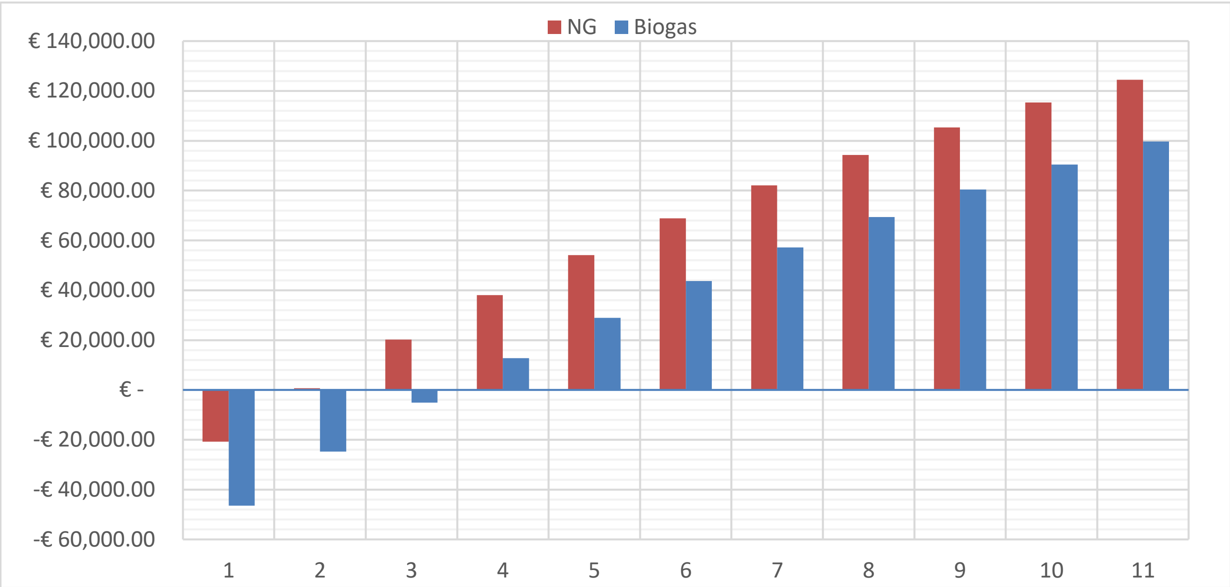


Figure 14 - Comparison between Natural Gas and Biogas payback periods

Scenario B

In that sense, a policy framework for biogas production could prove effective to encourage rural households to rely on biogas rather than natural gas. For example, assuming that the capital cost will be amortized for 5 years, a 5-year tax abatement policy can be set in place to release rural households from the tax expenses until the debt is fully paid. Figure

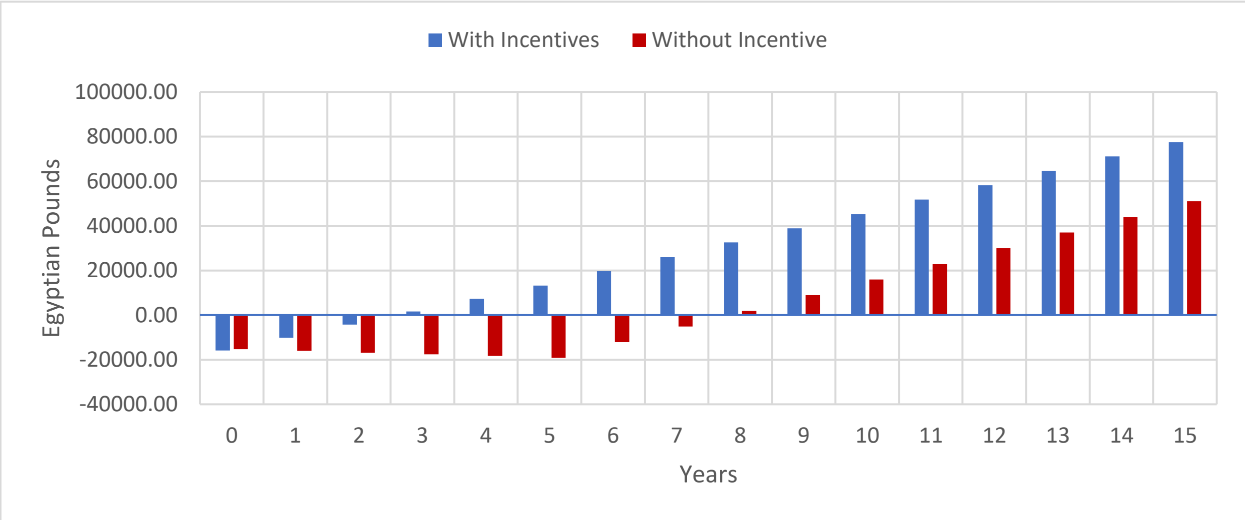


Figure 15 – A comparison between Payback periods under tax abatement and no incentives (Scenario B)

15 displays the possible effects of tax abatement on the profitability of biogas production in comparison to basic scenario.

On the other hand, following Egypt's current renewable energy tax incentives issued in 2015 by a presidential decree no17/2015 offers 5-10% tax trimming. In addition to the tax trimming, the decree states non-tax incentives in form of refunds on expenses paid to develop the existing infrastructure, subsidies on technical trainings programs for employees, and possible free allocation of land owned by the government [69]. Whereas, on the Egypt Renewable Energy Law (Decree no 203/2014) provides the private sector an incentive to develop renewable energy projects including feed-in tariffs, and third parties to work on bilateral electricity contracts with consumers for direct electricity sales using the existing grid network [70]. Given that both policies were primarily designed for electricity production projects, which makes them legally inapplicable in the cases of alternative domestic fuel production. However, using them as a reference to new biogas production policies can be a starting point for a comprehensive renewable energy policy framework that includes both electricity and fuel production.

It should be also considered that the economic and technical aspects are not the only indicators to the success of the plant. A sound business model will be designed in the final section to put these results into context, study its relevance to the potential stakeholders, and estimate the social impacts of the business.

In the following section, the nine elements of the business model canvas will be further discussed in relation to the cooperative as a business, analyzing the potential benefits and identifying the key elements of the cooperative to tackle the issues facing a rural household regarding the accessibility of domestic fuel to adopt anaerobic digestion in managing waste.

5.3 THE COOPERATIVE BUSINESS PLAN

This chapter provides a detailed analysis of the nine business model canvas elements displaying the results of the thesis work within the context of the cooperative and its expected interactions with the households and the rest of the community.

5.3.1 Value Proposition of the Cooperative

Figure 16 - Value Proposition

The following section will discuss the estimated results of the thesis work considering the stated assumptions as the main offerings delivered to the participants of cooperative.

The estimated production capacity of the plant according to the number of households sharing the plant and the amount of daily manure required to supply the daily demand.

The average monthly demand of a rural household in Egypt is estimated to be around 30 m3, which is equivalent to three LPG Butane cylinders and 45 m3 of biogas. Hence, a biogas plant is estimated to supply the daily demand of domestic gas for each connected household from livestock manure. In other words, the cooperative is offering access to alternative domestic fuel through better utilization of the daily manure waste generated by tapping into its potential energetic value, as well as saving the users the labor and time wasted on queuing for LPG cylinders. In addition, the plant offers some savings on the chemical fertilizers, reducing the expenses for the household

5.3.2 Communication within the cooperative

This section discusses the type of interactions taking place between the beneficiaries and the cooperative, determining the potential participants of the cooperative, and the appropriate methods of communication between them.

Customer Segment

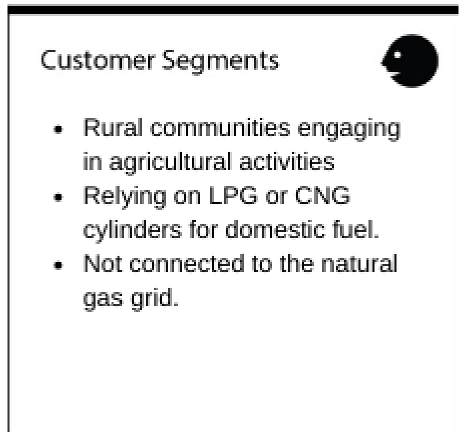


Figure 17- Customer Segments

Defining the customer segment for a biogas plant depends mainly on the type of waste chosen. Hence, for the cooperative the defined customer segment of the cooperative will mainly consist of the rural communities participating in agricultural activities that generate organic waste. Given that manure is primarily generated on daily basis 52% of which is either wasted or directly combusted, it appears as a very viable option for consistent daily feedstock for the biogas plant. The rural communities in Egypt are around 57% of the population which is a huge market segment that needs to be supplied with locally appropriate solutions.

Customer Relationship

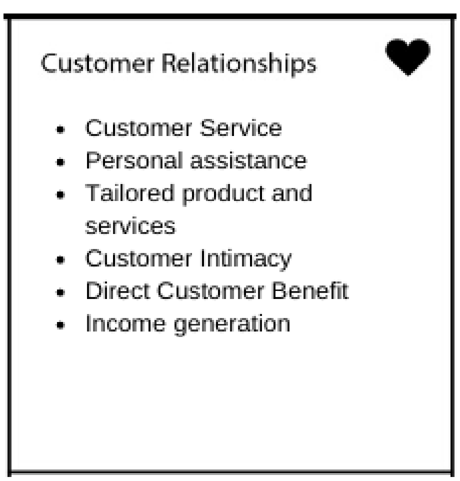


Figure 18 - Customer Relationships

Anaerobic digesters need to be fed consistently to maintain the bacteria responsible for digesting the organic waste and producing Biogas. It is crucial for the cooperative to provide a solution that is communicative with its customers and beneficiaries to ensure the sustainable operation of the biogas plant. One of the main reported issues of household anaerobic digestors in Egypt is that the operation of the plant is self-serviced by the owners. Anaerobic digesters owners found it difficult to sustain the consistency to operate their household plants as they were required to personally collect the manure and feed the plant on daily basis. Accordingly, there were several anaerobic digesters that has seized to operate. The biogas users found it difficult as it required extra daily physical labor that some households were not able to provide that labor consistently. Hence, it is crucial to devise a relationship with the biogas plant owners that either encourages to put in the effort or provide a daily assistance service. That service should ensure that the biogas plant is being operated daily, especially in a cooperative framework where the outcome of each participant actions have an impact on the collective benefit of the business.

In fact, in the cooperative design collection and transportation of manure needs to be within the responsibility of the cooperative. In that sense, it is expected that it would provide the room for at least two part time job opportunities for collection and transportation of manure and digestate from/to the households. Another two job opportunities for operating the plant to ensure the operational sustainability of the plant. Such a relationship should maintain the communities' interest in adopting the technology if it provides equal benefit to each household, and accordingly ensuring that the cooperative is socially sustainable and accepted.

Channels

Figure 19 - Channels

The channels between the communities and the cooperative network should be direct, simple, and time efficient. I should also make it easier for the households to receive the value proposition and gain their trust in the operations of the cooperative. Initially, the channels are expected to be difficult to build from scratch. Assuming that the participants of the cooperative have not been exposed to the concept beforehand. However, reaching out to the communities should start from a place of trust to spread awareness successfully. It is suggested to initiate contact with the highest influential local members. These members can be the head of the village, a local organization that has been working alongside the local community in a previous project, or through governmental policies that provides incentives for adopting such projects. However, this alone would not be sufficient if the community members were not able to be part of the design process itself. The community members should be part of evaluating the decisions and cooperating with the business in tailoring the project to meet their communal needs.

Considering delivering the offering, as an initial estimation the delivery of manure to the plant is assumed to be equal from all households involved in the cooperative. The amount of digestate returned should be as well equally distributed upon the users. As for the biogas delivery is assumed to be meet the average demand of household for domestic fuel. The cooperative is considered to bear the liability of maintaining and operating the plant after sales as well as contracting with a supplier to design and install the plant according to the community needs.

5.3.3 Building the infrastructure

The operational infrastructure for the cooperative should include the main actors whose activities affect and are directly affected by the project, as well as the potential tasks and materials required to have a base of operation where a supply chain is operated.

Key Partners

Key Partners

- The Egyptian Ministry of Agriculture and Land Reclamation (MoALR)
- Food and Agricultural Organization (FAO)
- United Nations Development Program (UNDP)
- United Nations Industrial Development Organization (UNIDO)
- Egyptian Association for Anaerobic Digestion (EGAAD)
- Community members

Figure 20 - Key Partners

The cooperative should have a list of trusted bodies that would provide continuous aid, supervision, and advice to operate and sustain the business. The main partners should consist of relevant governmental authorities. They will facilitate the legal requirements regarding permits and incentives, which should ensure a long-term based trust between the households, the cooperative, and the governmental authority. While at the same time it should go hand in hand to partnering with relevant international organizations who are involved in the field work in agriculture. The Food and Agriculture Organization (FAO), United Nations Development Program (UNDP), and United nations Industrial Development Organization (UNIDO) can be very appropriate for such international partnerships. These partners should provide the guidelines by which the cooperative should operate, as well as the Macro level requirements the cooperative should take into considerations.

On the other hand, the main key partners are the community members and the supplier. In the case of this study the supplier is mainly EGAAD as an association that supplies and installs biogas plants in rural Egypt.

Key Activities

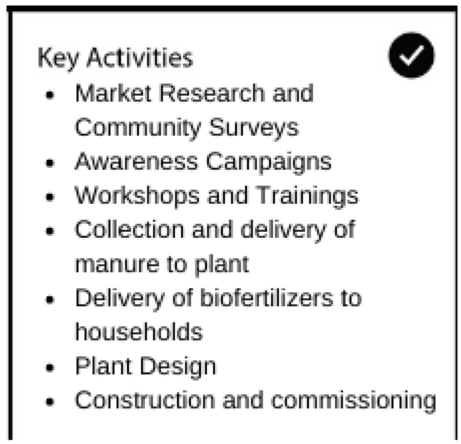


Figure 21 - Key Activities

The main activities the value propositions require would revolve around sustainably operating the plant, ensuring that daily feedstock is being collected and transported to be fed to the digester. This includes the preliminary field research required to understand the requirements of the community and assess the possible impacts that might have been overlooked during the design phase.

In addition, with the aid of the key partners the customer relationship activities should be undergone to raise awareness to the benefits of participating in the cooperative. Initially, workshops will be necessary to train the local personnel responsible for the operations of the cooperative.

Finally, the activities pertinent to the installation and commissioning of the plant which includes the design of the system and construction of the plant and applying the required modifications to the domestic appliances connected to the biogas line.

Key Resources

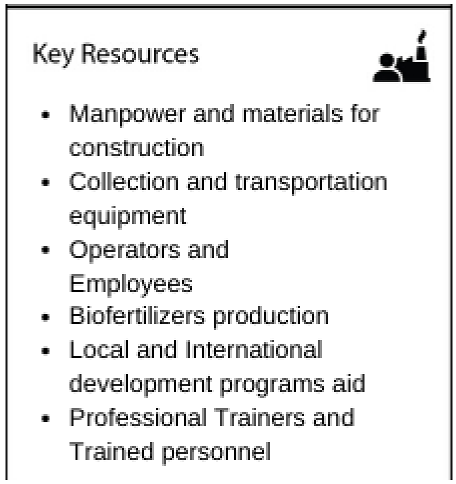


Figure 22 - Key Resources

The physical materials and the manpower necessary for the plant should be made available by the supplier for the construction of the system. On the other hand, one of the main resources for the cooperative would be the collection and transportation equipment required as well as the personnel operating them. Moreover, for the initial period of implementation, local and international organizations will be expected to aid the cooperative with the expertise available at their disposal to provide proper training and orientation to the new paradigm being introduced to the community. Eventually, the local community should be capable of taking over training potential workers. This should lead the prospective communities to be self-sufficient regarding having well trained personnel who can pass on the knowledge to neighboring potential new cooperatives with similar requirements.

5.4 Financial Fidelity

In this section, an income statement was estimated along the lifetime of the plant to determine whether the cooperative will be able to sustain only by the shared fund provided by the members of the cooperative. The shared fund is presented as a share of the rural households' annual income, to be compared to the current domestic fuel expenditure by rural households. It has been reported that each rural household requires around three butane gas cylinders per month, each of a subsidized price of around 80-100 EGP, where the actual cost has been reported at 160-180 EGP. The indicated price includes the extra cost of home deliveries of the cylinders. On the other hand, a household connected to the natural gas grid will require around 30m3 monthly, which will cost around 70 EGP. In case the household if off the natural gas grid, the household will be required to pay around 2200 EGP to connect to the grid and subscribe to its service [68]. Accordingly looking at the results section 5.2, the biogas plant is less profitable than natural gas as a fuel production plant, however, including the potential avoided costs of fertilizers the investment will be more beneficial. It was estimated by EGAAD that every household will be able to save EGP 1500 yearly by using the plant's digestate as a biofertilizer, which is quite a fair value, however, no data so far has verified that estimation.

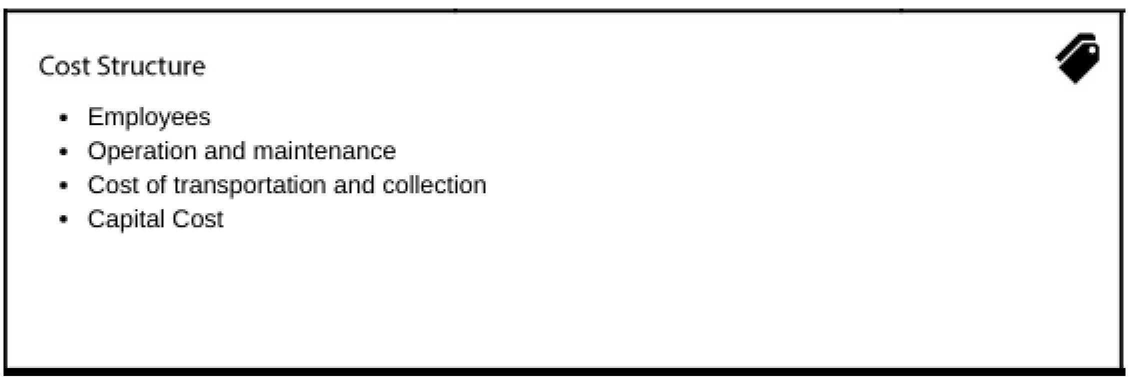


Figure 23 - Cost structure

Cost Structure of the cooperative contains the employees' monthly fees such as those of plant operators and administrative positions. Operating and maintaining the plant are also an important element of the costs incurred to ensure the sustainable productivity of the plant. In addition to the fuel cost for transportation and the cost of collection equipment as well as the capital investment required for installing the plant.

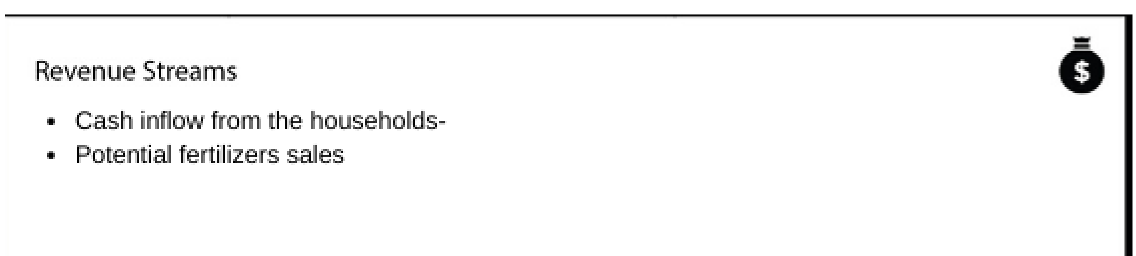


Figure 24 - Revenue Streams

As for the Revenue Streams of the cooperative, the sources of cash inflow are mainly sourced from the contribution of each household share 10% of the income as well as the potential sales of biofertilizers, however, biofertilizers will all be assumed to be used by the household for their agricultural activities.

5.5 SUMMARY OF BUSINESS PLAN

Following the analysis of the business model canvas elements seperately, this section provides an overall look on the business model elements compiled in the business model canvas shown in figure 25.

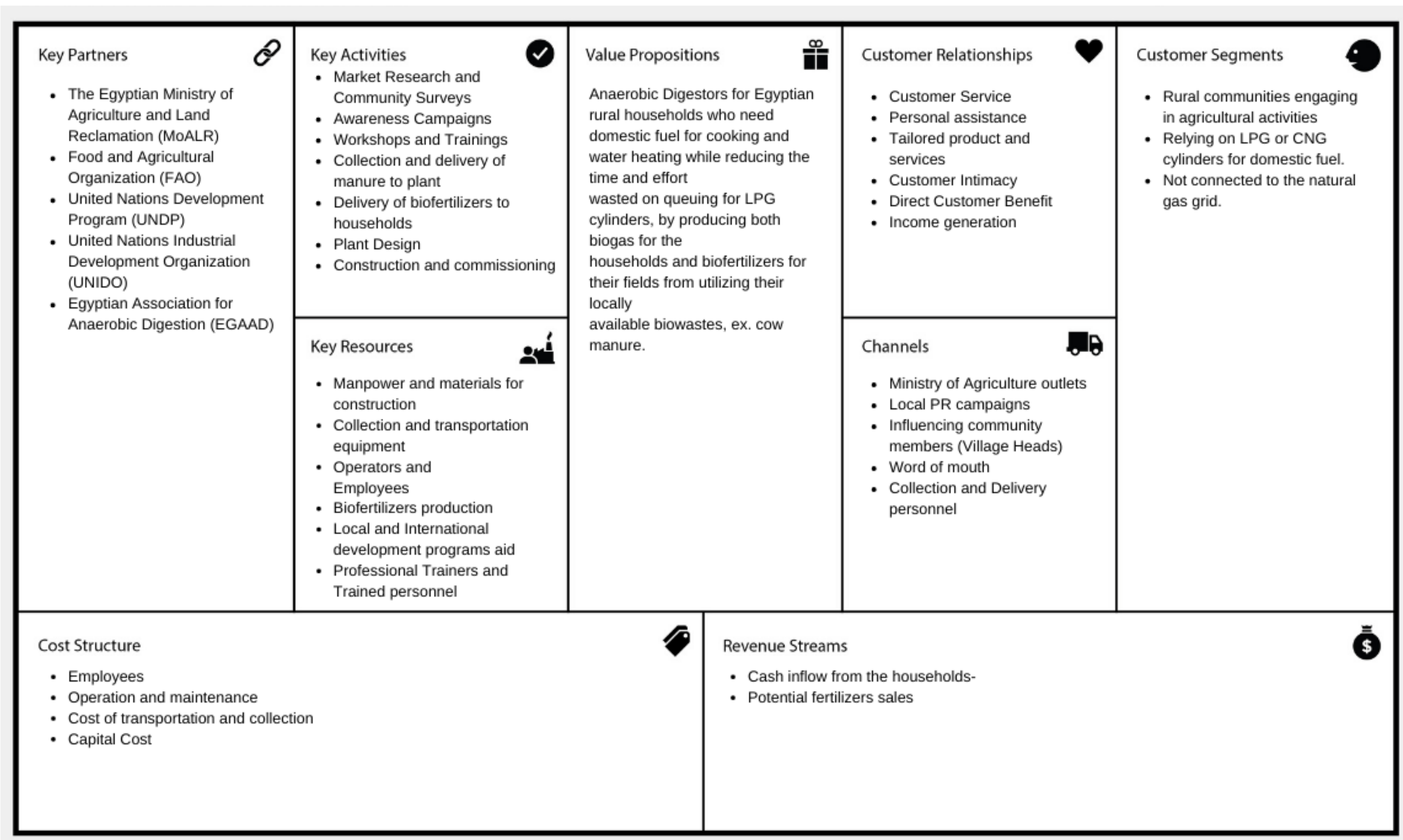


Figure 25 - Summary of Business Model Canvas

6 CONCLUSIONS

Anaerobic Digestion in Egypt can be an important organic waste management method, and a main supplier of domestic fuel and biofertilizers for rural communities. However, to tap into the biogas production potential in Egypt, appropriate policy frameworks, locally accepted sustainable business models, and active community engagement are necessary to make the biogas production more attractive.

Business innovation in Agricultural activities in Egypt is academically unexplored, which can pose limitations for investments and sustainable development programs for rural areas. In the thesis, one of the main objectives was to highlight that knowledge gap between the market and academia. It presents a business solution that would fit into the local context of rural Egypt, and act as a starting point for further research developments.

In the business model, a cooperative is expected to provide the rural community with access to biogas as an alternative to LPG cylinders for households that are not connected to natural gas grid. This should supply the households with their daily cooking and water heating demands. On the other hand, the digestate produced from the anaerobic digestion can be used as biofertilizer, which is argued to increase the profitability of biogas production due to the savings on chemical fertilizers.

On the long term, if the cooperative model is widely adopted by several rural communities, there should be a network of cooperatives that can be able to have a positive influence on the awareness of the community towards sustainable rural solutions. The community is expected to have an increasing level of competence for operating biogas plants, which can eventually generate more innovative solutions for the community. On the other hand, the cooperatives can provide around 4 job opportunities for operating a plant increasing the income generation opportunities in rural communities.

In addition to the potential social benefits, the environmental impact of one biogas plant providing 6 households with their daily demand of biogas will comprise of a yearly avoided methane emission of 149 tCO2/yr, which is around 1.4 kgCO2eq for each 1 kg of manure digested. Utilizing the manure will also rid the communities of the possible diseases as well as removing the general unattractive odor of unmanaged manure.

For further academic development, studying the impact of building biogas networks on a national level can estimate the national residential consumption of natural gas in rural areas. In addition, further research on the transition from relying traditional fuel sources to using sustainable and renewable materials as fuel sources. Future studies can also identify the potential benefits of biomethane production from biogas upgrading as a modular addition on the existing natural gas grid, hence, creating more sustainable biofuels value chains in rural Egypt for domestic use, commercial use, and transportation as well as for electricity generation.

LIST OF FIGURES

LIST OF TABLES

REFERENCES

1) Solid Waste Management [WWW Document], n.d. World Bank. URL https://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management (accessed 10.21.19).
2) PWC, n.d. SDG12: Responsible consumption and production Ensure responsible consumption and production patterns.Towards the Circular Economy. Accelerating the Scale-up across Global Supply Chains. 2014.
3) McDonough, W., Braungart, M., 2010. Cradle to Cradle: Remaking the Way We Make Things. Farrar, Straus and Giroux.
4) Meadows, D.H., Club of Rome, Potomac Associates (Eds.), 1974. The limits to growth: a report for the Club of Rome's Project on the Predicament of Mankind, 2. ed. ed. Universe Books, New York.
5) Schweiger, S., Stouten, H., Bleijenbergh, I.L., 2018. A System Dynamics Model of Resistance to Organizational Change: The Role of Participatory Strategies: A system dynamics model of resistance to organizational change. Systems Research and Behavioral Science 35, 658–674. https://doi.org/10.1002/sres.2509.
6) Lewandowski, M., 2016. Designing the Business Models for Circular Economy—Towards the Conceptual Framework. Sustainability 8, 43. https://doi.org/10.3390/su8010043
7) Ritzén, S., Sandström, G.Ö., 2017. Barriers to the Circular Economy – Integration of Perspectives and Domains. Procedia CIRP 64, 7–12. https://doi.org/10.1016/j.procir.2017.03.005
8) Capmas, n.d. URL https://www.capmas.gov.eg (accessed 10.21.19).
9) Better Sanitation Services Improving Lives and Livelihoods in Rural Egypt [WWW Document], n.d. . World Bank. URL https://www.worldbank.org/en/news/feature/2018/09/21/better-sanitation-services-improving-lives-and-livelihoods-in-rural-egypt (accessed 10.21.19).
10) "Poverty Trap" Merriam-Webster.com. 2019. https://www.merriam-webster.com (21 October 2019).

11) Elfeki, M., Elbestawy, E., Tkadlec, E., 2017. Bioconversion of Egypt's Agricultural Wastes into Biogas and Compost. Pol. J. Environ. Stud. 26, 2445–2453. https://doi.org/10.15244/pjoes/69938
12) FAO- Egypt Evaluation
13) Source: Author's Survey
14) Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J., 2017. The Circular Economy – A new sustainability paradigm? Journal of Cleaner Production 143, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048
15) Winans, K., Kendall, A., Deng, H., 2017. The history and current applications of the circular economy concept. Renewable and Sustainable Energy Reviews 68, 825–833. https://doi.org/10.1016/j.rser.2016.09.123
16) Korhonen, J., Honkasalo, A., Seppälä, J., 2018. Circular Economy: The Concept and its Limitations. Ecological Economics 143, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041
17) Tomić, T., Schneider, D.R., 2018. The role of energy from waste in circular economy and closing the loop concept – Energy analysis approach. Renewable and Sustainable Energy Reviews 98, 268–287. https://doi.org/10.1016/j.rser.2018.09.029
18) Jensen, J.P., Skelton, K., 2018. Wind turbine blade recycling: Experiences, challenges and possibilities in a circular economy. Renewable and Sustainable Energy Reviews 97, 165–176. https://doi.org/10.1016/j.rser.2018.08.041
19) Sica, D., Malandrino, O., Supino, S., Testa, M., Lucchetti, M.C., 2018. Management of end-of-life photovoltaic panels as a step towards a circular economy. Renewable and Sustainable Energy Reviews 82, 2934–2945. https://doi.org/10.1016/j.rser.2017.10.039
20) Fagerström, A., Al Seadi, T., Rasi, S., Briseid, T, (2018). The role of Anaerobic Digestion and Biogas in the Circular Economy.
21) Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2018: 8 Mohee, R., 2007. Waste management opportunities for rural communities - Composting as an effective waste management strategy for farm households and others. Food and Agriculture of the United Nations.

22) McKendry, P., 2002. Energy production from biomass (part 2): conversion technologies. Bioresource Technology 83, 47–54. https://doi.org/10.1016/S0960-8524(01)00119-5

23) Demirbas, A.H., Demirbas, I., 2007. Importance of rural bioenergy for developing countries. Energy Conversion and Management 48, 2386–2398. https://doi.org/10.1016/j.enconman.2007.03.005

24) Developing Rural Markets for LP Gas - Key Barriers and Success Factors, 2005. . World LP Gas Association.

25) Michelini, G., Moraes, R.N., Cunha, R.N., Costa, J.M.H., Ometto, A.R., 2017. From Linear to Circular Economy: PSS Conducting the Transition. Procedia CIRP 64, 2–6. https://doi.org/10.1016/j.procir.2017.03.012

26) Whalen, K.A., 2019. Three types of circular business models that extend product value and their contribution to resource efficiency. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2019.03.128

27) De Vivo, M., Rondini, A., Pezzotta, G., 2018. Assessing PSS from a multi stakeholders' perspective: the application of the EVA method in the airport context. Procedia CIRP 73, 15–20. https://doi.org/10.1016/j.procir.2018.04.015

28) Vezzoli, C., Ceschin, F., Osanjo, L., M'Rithaa, M.K., Moalosi, R., Nakazibwe, V., Diehl, J.C., 2018. Designing Sustainable Energy for All, Green Energy and Technology. Springer International Publishing, Cham. https://doi.org/10.1007/978-3-319-70223-0

29) Reim, W., Parida, V., Örtqvist, D., 2015. Product–Service Systems (PSS) business models and tactics – a systematic literature review. Journal of Cleaner Production, Special Volume: Why have 'Sustainable Product-Service Systems' not been widely implemented? 97, 61–75. https://doi.org/10.1016/j.jclepro.2014.07.003

30) Sousa-Zomer, T.T., Magalhães, L., Zancul, E., Cauchick-Miguel, P.A., 2017. Lifecycle Management of Product-service Systems: A Preliminary Investigation of a White Goods Manufacturer. Procedia CIRP 64, 31–36. https://doi.org/10.1016/j.procir.2017.03.041

31) Natural gas and the environment - U.S. Energy Information Administration (EIA) [WWW Document], n.d. URL https://www.eia.gov/energyexplained/natural-gas/natural-gas-and-the-environment.php (accessed 10.23.19).
32) Completion of world's largest combined cycle power plants in record time | Press | Company | Siemens [WWW Document], n.d. URL https://press.siemens.com/global/en/feature/completion-worlds-largest-combined-cycle-power-plants-record-time (accessed 10.23.19).
33) Kyriaev, 2018. Egypt Natural Gas Connection Project [WWW Document]. International Cooperation and Development - European Commission. URL https://ec.europa.eu/europeaid/blending/egypt-natural-gas-connection-project_en (accessed 10.23.19).
34) Source: Author Survey
35) Gillessen, B., Heinrichs, H., Hake, J.-F., Allelein, H.-J., 2019. Natural gas as a bridge to sustainability: Infrastructure expansion regarding energy security and system transition. Applied Energy 251, 113377. https://doi.org/10.1016/j.apenergy.2019.113377
36) Terhan, M., Comakli, K., 2017. Energy and exergy analyses of natural gas-fired boilers in a district heating system. Applied Thermal Engineering 121, 380–387. https://doi.org/10.1016/j.applthermaleng.2017.04.091
37) Kazulis, V., Vigants, H., Veidenbergs, I., Blumberga, D., 2018. Biomass and natural gas co-firing – evaluation of GHG emissions. Energy Procedia, International Scientific Conference "Environmental and Climate Technologies", CONECT 2018, 16-18 May 2018, Riga, Latvia 147, 558–565. https://doi.org/10.1016/j.egypro.2018.07.071
38) Singlitico, A., Goggins, J., Monaghan, R.F.D., 2019. The role of life cycle assessment in the sustainable transition to a decarbonised gas network through green gas production. Renewable and Sustainable Energy Reviews 99, 16–28. https://doi.org/10.1016/j.rser.2018.09.040
39) Elfattah, S.T.A., Eldrainy, Y.A., Attia, A., 2016. Upgrade Egyptian biogas to meet the natural gas network quality standard. Alexandria Engineering Journal 55, 2279–2283. https://doi.org/10.1016/j.aej.2016.05.015

40) Liu, W., Wen, F., Xue, Y., 2017. Power-to-gas technology in energy systems: current status and prospects of potential operation strategies. J. Mod. Power Syst. Clean Energy 5, 439–450. https://doi.org/10.1007/s40565-017-0285-0
41) Feofilovs, M., Gravelsins, A., Pagano, A.J., Romagnoli, F., 2019. Increasing resilience of the natural gas system with implementation of renewable methane in the context of Latvia: a system dynamics model. Energy Procedia, Innovative Solutions for Energy Transitions 158, 3944–3950. https://doi.org/10.1016/j.egypro.2019.01.848
42) E.G.E.C. Ltd, n.d. Biomass [WWW Document]. Eco Green Energy Centre Ltd - Biomass Installers in Cumbria. URL https://www.ecogreenenergycentre.co.uk/about/biomass.html (accessed 10.24.19).
43) McKendry, P., 2002. Energy production from biomass (part 1): overview of biomass. Bioresource Technology 83, 37–46. https://doi.org/10.1016/S0960-8524(01)00118-3
44) Picardo, A., Soltero, V.M., Peralta, M.E., Chacartegui, R., 2019. District heating based on biogas from wastewater treatment plant. Energy 180, 649–664. https://doi.org/10.1016/j.energy.2019.05.123
45) Ramos-Suárez, J.L., Ritter, A., Mata González, J., Camacho Pérez, A., 2019. Biogas from animal manure: A sustainable energy opportunity in the Canary Islands. Renewable and Sustainable Energy Reviews 104, 137–150. https://doi.org/10.1016/j.rser.2019.01.025
46) Alexander, S., Harris, P., McCabe, B.K., 2019. Biogas in the suburbs: An untapped source of clean energy? Journal of Cleaner Production 215, 1025–1035. https://doi.org/10.1016/j.jclepro.2019.01.118
47) Natividad Pérez-Camacho, M., Curry, R., Cromie, T., 2019. Life cycle environmental impacts of biogas production and utilisation substituting for grid electricity, natural gas grid and transport fuels. Waste Management 95, 90–101. https://doi.org/10.1016/j.wasman.2019.05.045

48) Picardo, A., Soltero, V.M., Peralta, M.E., Chacartegui, R., 2019. District heating based on biogas from wastewater treatment plant. Energy 180, 649–664. https://doi.org/10.1016/j.energy.2019.05.123
49) Winquist, E., Rikkonen, P., Pyysiäinen, J., Varho, V., 2019. Is biogas an energy or a sustainability product? - Business opportunities in the Finnish biogas branch. Journal of Cleaner Production 233, 1344–1354. https://doi.org/10.1016/j.jclepro.2019.06.181
50) Karlsson, N.P.E., Hoveskog, M., Halila, F., Mattsson, M., 2019. Business modelling in farm-based biogas production: towards network-level business models and stakeholder business cases for sustainability. Sustain Sci 14, 1071–1090. https://doi.org/10.1007/s11625-018-0584-z
51) Karlsson, N.P.E., Halila, F., Mattsson, M., Hoveskog, M., 2017. Success factors for agricultural biogas production in Sweden: A case study of business model innovation. Journal of Cleaner Production 142, 2925–2934. https://doi.org/10.1016/j.jclepro.2016.10.178
52) Bacchetti, E., 2017. A Design Approach with Method and Tools to Support SMEs in Designing and Implementing Distributed Renewable Energy (DRE) Solutions Based on Sustainable Product-Service System (S.PSS). Procedia CIRP, 9th CIRP IPSS Conference: Circular Perspectives on PSS 64, 229–234. https://doi.org/10.1016/j.procir.2017.03.064
53) Hamid, R.G., Blanchard, R.E., 2018. An assessment of biogas as a domestic energy source in rural Kenya: Developing a sustainable business model. Renewable Energy 121, 368–376. https://doi.org/10.1016/j.renene.2018.01.032
54) Demirbas, A.H., Demirbas, I., 2007. Importance of rural bioenergy for developing countries. Energy Conversion and Management 48, 2386–2398. https://doi.org/10.1016/j.enconman.2007.03.005
55) Breisinger, Clemens, Askar Mukashov, Mariam Raouf, and Manfred Wiebelt. 2019. 'Energy Subsidy Reform for Growth and Equity in Egypt: The Approach Matters'. Energy Policy 129 (June): 661–71. https://doi.org/10.1016/j.enpol.2019.02.059.

56)'BEFS Assessment for Egypt - Sustainable Bioenergy Options from Crop and Livestock Residues'. n.d., 168.

57)Eriksson, Ola. 2010. 'Environmental Technology Assessment of Natural Gas Compared to Biogas'. In Natural Gas, edited by Primoz Potocnik. Sciyo. https://doi.org/10.5772/9837.

58)Rajendran, Karthik, Solmaz Aslanzadeh, and Mohammad J. Taherzadeh. 2012. 'Household Biogas Digesters—A Review'. Energies 5 (8): 2911–42. https://doi.org/10.3390/en5082911.

59)Al Seadi, Teodorita, Dominik Rutz, Heinz Prassl, Michael Köttner, Tobias Finsterwalder, Silke Volk, and Rainer Janssen. 2008. Biogas Handbook. Esbjerg: University of Southern Denmark Esbjerg.

60)Meegoda, Jay, Brian Li, Kush Patel, and Lily Wang. 2018. 'A Review of the Processes, Parameters, and Optimization of Anaerobic Digestion'. International Journal of Environmental Research and Public Health 15 (10): 2224. https://doi.org/10.3390/ijerph15102224.

61)IRENA, 'Biogas for Domestic Cooking: Technology Brief'. n.d., 32.

62)Medhat, Samar 'هل يحل مشروع مضاعفة غاز البوتاجاز أزمة الأنابيب فى الصعيد؟' [Will the increase the butagas production resolve the LPG cylinders shortage in upper Egypt?] . n.d. جريدة الدستور.. https://www.dostor.org/2625927.

63)Emili, Silvia, Fabrizio Ceschin, and David Harrison. 2016. 'Product–Service System Applied to Distributed Renewable Energy: A Classification System, 15 Archetypal Models and a Strategic Design Tool'. Energy for Sustainable Development 32 (June): 71–98. https://doi.org/10.1016/j.esd.2016.03.004.

64)Musa, Heba. 2020. ' أزمة في أنابيب الغاز بطوخ.. والمحافظة تتابع التوزيع بالتعاون مع التموين'. بوابة اخبار اليوم. https://akhbarelyom.com/news/newdetails/2978004/1/أزمة-في-أنابيب-الغاز-بطوخ..-والمحافظة-تتابع-التوزيع-بالتعاون-مع-التموين.

65)'برلمانى يطالب بتوصيل الغاز الطبيعى لمطروح لمواجهة أزمة الأنابيب بالمحافظة'. 2020. اليوم السابع. 17. https://www.youm7.com/story/2020/1/17/برلمانى-يطالب-بتوصيل-الغاز-الطبيعى-لمطروح-لمواجهة-أزمة-الأنابيب-بالمحافظة/4590422.

66)‘نائب البحيرة يطالب بتوصيل الغاز الطبيعى لـ21 قرية لتخفيف معاناة المواطنين’. 2020. اليوم السابع. 16 January 2020. https://www.youm7.com/story/2020/1/16/نائب-البحيرة-يطالب-بتوصيل-الغاز-الطبيعى-لـ21-قرية-لتخفيف-معاناة/4587710.
67)‘«الوزراء» يوجه بسرعة تنفيذ «البنية التحتية» لأراضى «الريف المصرى» - جريدة البورصة»’. n.d. https://alborsaanews.com/2020/02/09/1294175.
68)Ghandour, Mai El. 2019. ‘Egypt to Link 1.2 M Households to Natural Gas Grid Annually’. Egypt Oil & Gas. 9 June 2019. https://egyptoil-gas.com/news/egypt-to-link-1-2-m-households-to-natural-gas-grid-annually/.
69)‘Egypt Renewable Energy Tax Incentives (Presidential Decree No 17/2015) – Policies’. n.d. IEA. https://www.iea.org/policies/6105-egypt-renewable-energy-tax-incentives-presidential-decree-no-172015.
70)‘Egypt Renewable Energy Law (Decree No 203/2014) – Policies’. n.d. IEA. https://www.iea.org/policies/6104-egypt-renewable-energy-law-decree-no-2032014.