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Barriers for the employment of floating invasive weeds for biogas production in local communities in West African Developing Countries

Otto Maria Jandl
September 2010

Strategic Niche Management

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Preface

For the fulfillment of the Degree in Engineering of the Escola Tècnica Superior d'Enginyeria Industrial de Barcelona (Universitat Politècnica de Catalunya) this thesis has been written at the Technologische Universiteit Eindhoven as a MSc thesis from March till September 2010. For the research I conducted a field study of three weeks in Ghana and Bénin in June/July.

Many coincidences have brought me to Eindhoven and to West Africa. Without the encouraging help of a lot of people my feet would not have had the opportunity to take the steps I was able to take. I want to give thanks to all of you, in the first place Annelies Balkema for supervising my research for half a year, moving everything possible to find a suitable place for a field trip and linking me up to the Fact Foundation, Arjan Kirkels for supervising, Winfried Rijssenbeek for giving me a profound insight into the 'business as usual' of an uprising organization that works for the implementation of technical development projects in developing countries, the Fact Foundation for providing me a desk at their office for the whole research, letting me participate in meetings with partners and funding part of the field trip, Bart Frederiks and Ywe Jan Franken for always constructive feedback, Rik Hoevers for letting his West African contacts play, taking his time to assist my research and making the field trip possible, Digi for giving me his time and effort during the whole trip, for picking me up at the airport at 5am, teaching me essential vocabulary in Twi, sharing his knowledge with me, endless hours in his car, while we were driving throughout almost entire Ghana and much, much more, his wife for letting him stay with me so many days, Peter Neuenschwander, Father Nzamujo, Justaine, Cosme Zounon, Dr. Elias Aklaku, Dr. Gabriel Ameka, David Wilson and Gilbert Salormey for the time they took for interviews, Toni and all of his friends of the Mensah Sarbah Hall's reception for all their efforts of providing me a comfortable stay in Accra, Daniel for the time he took for all the questions I had regarding the biogas units in Porto Novo, Adib for answering the phone when I had fever, Mariah and Béatrice for taking care of me, Cécile and her boyfriend for translating, the colleague of Peter Neuenschwander for driving me for hours through the traffic jams of Cotonou trying to find a hotel for the last night in Bénin, the harvesting group at Kpong for taking their time and carrying out the hedge cutter experiment with me, Ekobor and the community at the Tano Lagoon for welcoming me, all the people I had the pleasure to meet in Ghana, Bénin and the Netherlands, Artur, Agyeiwaah, Toni, Gabin, George, Andrews, Edward, Maartje, Andrews, Josep and Armando, Berta for letting me go abroad for an entire year and my brothers, parents and grandparents for strengthening me continuously. God bless you all!

Enjoy reading this thesis.

Otto Maria Jandl
Eindhoven, September 2010

Summary

Currently many eyes are focussed on and a lot of money is spent in renewable energy projects, because one day they are supposed to substitute fossil fuels and nuclear power. Within renewable energy sources bio fuels have especially been criticized for contributing to the food vs fuel debate. Invasive, floating aquatic weed species like *E. Crassipes* (Water hyacinth) invade water systems in tropical areas without giving a chance of getting rid of them on the long term at the current state of science. They might even hinder local fishermen from carrying out their income creating activities.

This thesis aims to study the viability of combining these two problematiques and of their mutual solving. By using floating invasive weeds for biogas production, no loss in food crops has to be suffered and on the other side there is an extra benefit of harvesting these weeds; the benefit of biogas for the community, that can be used for cooking, lighting and electricity purposes.

The main research question for this thesis is:

“What are the opportunities for the deployment of floating invasive weeds for biogas production in local communities in Western Africa?”

As methodology Strategic Niche Management (SNM) has been adopted since it offers the barriers that an upcoming technologies has to face from three levels; the landscape at the macro level, the regime at the meso level and the niche at the micro level. The landscape refers to the world in which a technology finds itself embedded, consisting this world in the macro economy, the demography, infrastructure and political and social views and structures. A socio-technical regime refers to the procedures and ‚ways of doing‘ of a socio-technical system embedded in the landscape. A niche is a candidate for being part of the regime. When pressure is put by the landscape on the regime, it becomes weak and niches have higher probability to „abuse“ this lability and getting into the regime. For this purpose learning processes, forming of expectations and strategies and network formation play a fundamental role. This thesis focusses on the niche level of biogas production from floating invasive weeds.

This has been done by literature research and complemented by a 3 week field work in Ghana and Bénin, where I was able to meet researchers of both weed control and biogas technology as well as I could visit the only implemented biogas reactor on *E. Crassipes* in Bénin. Due to the fact that most of my contacts were to find in Ghana, I decided to focus on this country.

A brief look into three regimes in Ghana, the weed control regime, the cooking regime and the lighting regime shows that the weeds are usually controlled with bugs, most of the Ghanaian population cooks on firewood and charcoal and everyone without electricity coverage uses kerosene for lighting. Biogas plants are usually installed as a response to waste water problems of hospitals or schools, while the use of other feed stocks is not used in a high number of cases. Literature indicates that the conversion into biogas of *E. crassipes* is possible with a reasonable yield.

SNM analysis reveals that the idea of biogas digestion is not yet set in mind of most of the people, it still is kind of a ‚miracle'. Nevertheless, the knowledge on biogas technology is shared at pilot project sites with decision makers. Biogas technology is growing in Ghana but still has to fight competition with other renewable energy systems and is heavily dependent on lower subsidies on fossil fuels.

Based on observations made in the field trip and on literature, the niche analysis proves the viability of setting up a pilot project, since 12 working people would be able to run a simple system with a grinder, a drying place and a digester, to meet by this the electricity, lighting and cooking needs of a 100 household community. As the financial cost benefit analysis also show absolute positive values, investors and policy protection should be able to be attracted easily and by this the first step towards becoming a niche could be made.

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Acronyms and Abbreviations

AD	Anaerobic Digestion
BG	Biogas
CF	Cash Flow
CFA	CFA Franc (currency in Bénin and 13 other West and Central African Countries, 1 EUR = 655,957 CFA, fix exchange rate)
CSIR	Council for Scientific and Industrial Research (Ghana)
EPA	Environmental Protection Agency (Ghana)
FAO	Food and Agriculture Organization
GHS	Ghanaian Cedi (1 EUR = 1,7 GHS, June 2010)
GSS	Ghana Statistical Service
IEA	International Energy Agency
IITA	International Institute of Tropical Agriculture
IRR	Internal Rate of Return
LPG	Liquefied Purified Gas
NPV	Net Present Value
SME	Small and Medium Enterprises
SME	Small and Medium Enterprises
SNM	Strategic Niche Management
SNV	Stichting Nederlandse Vrijwilligers – Netherlands Development Organization
USD	US Dollars (1 EUR = 1,27 USD, June 2010)
VRA	Volta River Authority

ha	hectare (1 ha = 10.000 m^2)
kgDM	kg of Dry Matter
kgFM	kg of Fresh Matter
TDM	Metric Tons of Dry Matter
TFM	Metric Tons of Fresh Matter

1 Introduction

1.1. Research Problem

In Europe there is a transition from scarce and polluting fossil fuels to renewable ones in order to keep up with increasing energy demand without compromising on the environment. Where electricity is not yet available, mostly in rural areas in developing countries, the use of small scale energy systems based on renewable sources represents an opportunity for local and sustainable development. Due to their great variety and availability bio fuels play a special role in the renewable energy scenario. Nevertheless, the emerged subsidies on bio fuels push farmers to use their land for bio-fuel crops instead of food crops. As a result the food prices rose and the food-versus-fuel debate posed a lot of criticism on bio fuels. This can be avoided by the use of non-food bio fuels or waste products.

The threat of invasive aquatic weeds to the local aquatic ecosystem can be diminished by encountering a useful, sustainable application domain. This could help to solve the problem as a lot of water systems like ponds, lakes and irrigation canals suffer from overpopulation of invasive weeds, either rooted or floating. Besides serving as breeding ground for fishes and ceding oxygen to the organisms in water the floating weeds like *E. crassipes* also harbour various problems. Thus, the water flow is hampered, the produced oxygen is mainly emitted into the atmosphere and less sunlight is let through into the water, threatening the water system's ecology. Boat transport and the application of Micro Hydro Power systems are hindered by the invasive weeds.

One of the solutions in order to maintain the water systems' ecology balanced is to harvest the aquatic weeds. The resulting biomass can be used in different ways. It can be dried and burned for cooking, used as an organic fertilizer and for biogas conversion.

By turning the biomass into biogas the described problem of invasive aquatic plants can be seen as an opportunity; it can be turned into a local source for cooking (biogas), lighting and electricity generation. This thesis focuses on the floating weeds due to their great availability in Africa and the potential of their conversion into biogas for mentioned purposes.

Although it cannot be said that providing energy to everyone is the solution for poverty alleviation, rural electrification can nevertheless enhance living conditions. Table 1 illustrates how infant mortality statistically decreases and the adult literacy rate and life expectancy increase by increasing energy access. These are just numbers measured on a global basis. Local conditions are not considered and may distortion this picture.

Life Expectancy	Infant Mortality (deaths/1000 live births)	Adult Literacy Rate (percent)	Kilowatt-hours (annual per capita access)
80	5	99%	16.000
69	32	88%	2.000

65	53	76%	1.000
61	73	65%	500
55	100	50%	200

Table 1 – Living conditions as function of access to energy[1]

Within rural areas the access to electricity lacks far behind the coverage in urban areas.

1.2. Bio fuels and biogas conversion

1.2.1. Bio Fuels

Together with Hydro and Solar Power, Wind Energy, among others, bio fuels constitute the renewable energies. It is commonly accepted that the global energy landscape will have to switch from conventional fossil and nuclear to abundant renewable energy sources, abolishing so eventual effects on climate change. Nevertheless, the first are still dominating the market and usually the use of renewable energy has today still to be induced by subsidies. In the so called 'Global North' renewable energies face economic barriers for the entry in the energy market and are yet unable to compete with mature technologies that are able to provide electricity at relatively low rates. Here the energy supply scenario is heavily centralized and stable. In countries with less electricity coverage the chance for autonomous energy generating projects based on renewable sources to become part of the energy scenario seems to be higher. In many remote rural areas they present the only way towards affordable electricity. That is why the bio fuel markets in developed and developing countries present enormous differences. This thesis discusses the barriers that bio fuels have to face in rural communities in the 'South', on the example of Ghana.

Under bio fuels we understand any source of energy that uses non-fossil organic input material. The three biggest bio energy carriers are bio ethanol, bio diesel and biogas. While bio ethanol is produced through sugar fermentation derived from wheat, corn, sugar beets, sugar cane, molasses or any other sugar or starch, bio diesel is produced by inter-esterification derived from animal fats, vegetable oils, rape seed, Jatropha, ahua, mustard, flax, sunflower, palm oil, gemp, field pennycress, pongamia pinnata and algae. Biogas is produced through anaerobic digestion derived from organic matter.

Within bio fuels three generations are distinguished, while there are not exact definitions and different authors treat them in different ways. Generally it is accepted that first generation bio fuels refers to sugar, starch, vegetable oil or animal fats converted by conventional technology, second generation bio fuels to the technologically more complex ethanol production from cellulose and third generation (still experimental) bio fuels to algae, that need low input but grow rapidly.[2]

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[1] Data from http://energy4everyone.com/why-energy-matters/
[2] Information from a lecture at TU/e

Figure 1 provides an overview over the types of biomass (green) that can be used as fuels with its different conversion processes (red), bio energy carriers (orange), involved machines (blue) and its final use (green). The way of plants towards electricity and heat is marked in yellow.

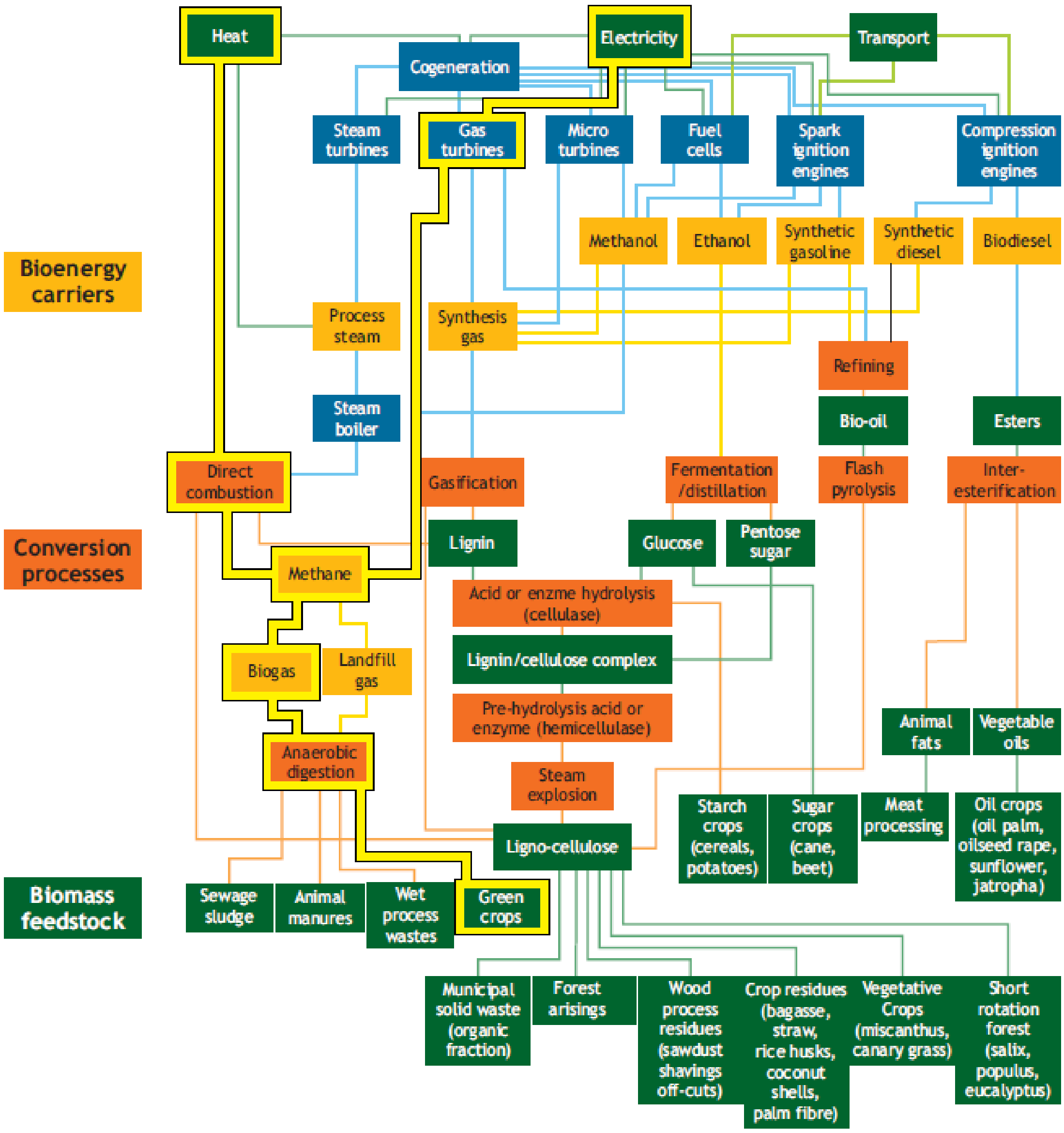

Figure 1: Conversion processes of renewable feed stocks into energy carriers

1.2.2. Biogas conversion

Biogas is one of the bio fuels suitable for heat and electricity production. It is obtained by anaerobic digestion of organic material. In absence of oxygen, in a closed digester, micro-organisms decompose biodegradable material. Biogas conversion is an already mature technology that has been proven to work with different input materials, called feed stocks, and on both household as on large scale.

The gases released by the bacteria in the process of digestion are mainly carbon dioxide (CO_2, 30-60% in volume) and methane (CH_4, 40-70% in volume)[3], being the last one combustible (see Fig. 2). Important factors that determine the biogas outcome per input material are temperature and pressure, at which the material ferments, as well as its moisture content. The yield can be enhanced by increasing the digestion temperature as well as by using enzymes and acids that accelerate the digestion process. The only fermentable material is in the dry matter, the higher the moister content, the slower the digestion process begins. Furthermore, physical pre-treatment forms like shredding, chopping or cutting gives the bacteria more organic surface to attack and consequently increases the gas yield. Feasible pre-treatment options for local independent biogas systems are studied by Stefan Jacobs (TU/e, Fact). As any other gas, its volume depends on its temperature and pressure. While yields of 1 to 2 kWh / m^3 are reported, this value varies within the given conditions. Table 2 provides an overview over determinant biogas factors. The retention time refers to the time organic matter stays in the digester before being taken out again. The values of this table depend on the digester type and size as well as the feed stock and digestion conditions.

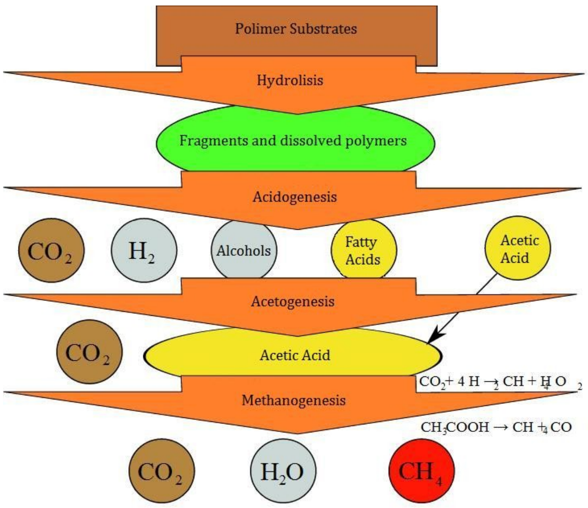

Figure 2: Process steps of anaerobic digestion

Biogas guideline data[4]		
Parameter	*unit*	Value
Suitable digesting temperature	*°C*	20 - 35
Retention time	*days*	40 - 100
Biogas energy content	*kWh/m³*	6
Biogas generation	*m³ gas / (m³ digester volume per day)*	0,3 - 0,5
One Cow yield	*9 - 15 kg dung/day -> m³ gas / day*	0,4
One Pig yield	*2 - 3 kg dung/day -> m³ gas / day*	0,15
Gas requirement for cooking	*m³ / person*	0,1 - 0,3
Gas requirement for one lamp	*m³ / h*	0,1 – 0,15
Gas requirement for engines	*m³ / kWh*	0,6

Table 2: Biogas key figures

3 http://www2.gtz.de/dokumente/oe44/ecosan/cb/en-indian-training-material-biogas-sanitation-2007.pdf
4 http://www.ted-biogas.org/biogas.htm

1.3. Floating Invasive Weeds

Invasive weeds are plants that are introduced to their non-native environments, also called alien species, overtaking non covered water surface or substituting native weeds, leading to a loss of biodiversity. The problem of the high number of infestations to new water systems is not natural, but human made, enhanced by increased travel and trade. Once an invasive weed has infested a wetland it will never abandon it. Best conditions for the fast growth of the species are found in tropical areas (see Figure 6). While through the rain season the invasiveness finds itself enhanced by the introduction of nutrients through the rain in the dry season the invasiveness encounters lower levels, though it never disappears.

Figure 3: E. crassipes

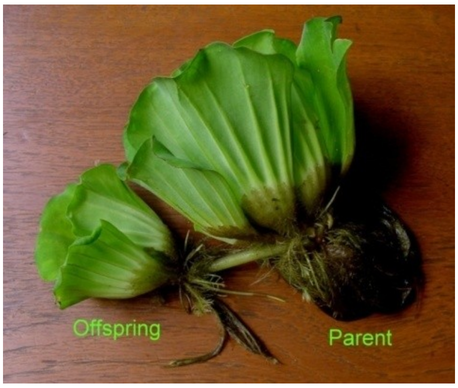

Figure 4: Water Lettuce

Figure 5: Water Fern

The three most invasive floating aquatic species are *Eichhornia Crassipes (Water hyacinth*, Figure 3), *Pistia stratiotes* (Water Lettuce, Figure 4) and *Salvinia molesta* (Water Fern, Figure 5). Among them *E. crassipes* is the most aggressive one, to be found much more than *Pistia* and *Salvinia molesta*. Due to its great availability this thesis will focus on the possibilities for biogas production by *E. crassipes* and floating weed mixtures in general, leaving out Water Lettuce and Water Fern.

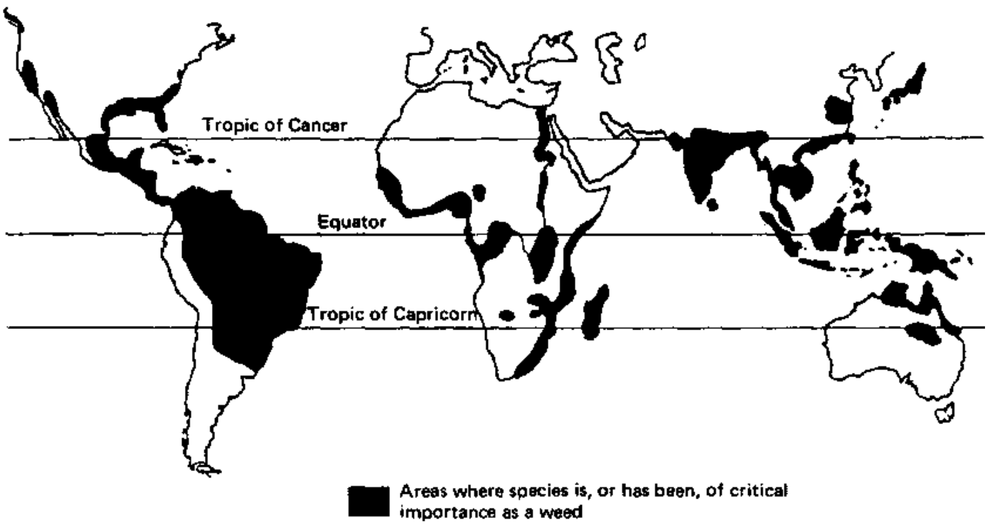

Figure 6: Locations of invasive weeds' infestations

1.3.1. *E. crassipes* (Water hyacinth)

Due to its fast growth and reproduction *E. crassipes* is on the global scale the most problematic floating aquatic weed. Its distribution is enhanced by the flow of water, wind and human propagation. The reproduction rate depends on external conditions like water and air temperature, sun radiation, humidity and the existence of other floating weeds as well as on the density of *E. crassipes*. In perfect conditions the invaded water surface can be doubled in less than a week (Labrada and Parker).
Its high capacity of nutrient absorption makes it interesting for waste water treatment. In other words *E. crassipes* is capable of cleaning dirty water.

Figure 7: the bulk of *E. crassipes*

The composition of *E. crassipes* depends on the composition of the occupied water system. Like other aquatic plants, *E. crassipes* has high water content, ranging in between 90 and 95%. Its high lignin content in the cell walls may suppose a barrier for fermentation since the lignin reinforces the cell wall's structure.

In West Africa *E. crassipes* has been reported in Bénin in the late 70's, in the Accra-Tema region (Ghana), the Ebrié Lagoon (Côte d'Ivoire) and the Lagos Lagoons in the beginning of the 80's and in the Tano Lagoon (Côte d'Ivoire, Ghana) in the beginning of the 90's. It spread so rapidly from canals and urban rivers into the lagoons due to its popularity as an ornamental plant. (Hoevers) The origin of *E. crassipes* seems to be the Brazilian Amazonia. (Labrada and Parker)

1.3.1.1. Problems caused by E. crassipes

The problems that *E. crassipes* causes are already observable where the infestations are.

Reduction of Biodiversity
The introduction of *E. crassipes* causes difficulties in surviving to other aquatic plants. The ecology of the water system finds itself distorted as a range of fauna that relied on the former diversity of plant life face now new conditions. Less sun radiation penetrates the water surface and in highly infested areas this might result in higher water temperatures and less turbidity. The diversity of fish stock and rooted water plants decreases.

Losses in fish yields for fishermen
Besides of decreased fish population and diversity, fishermen face problems in fishing the remaining population. The access to the water system is hampered and fishing tools get stuck in the weeds. Families, whose income relies on fishing face economic problems.

Hindrance to Water Transport
Rivers and canals can become inaccessible for boat transport, the access to harbours and remote communities limited.

Clogging of intakes of irrigation, Hydro Power and Water Supply Systems
Large Hydro Power Systems like at the Volta Lake can be affected by the effects of *E. crassipes*. If the weed invades the areas where the turbines are, they have to be harvested urgently before hindering Power Generation. In canals and rivers *E. crassipes* infestations can lead to flooding. Irrigation and Water Supply systems may suffer from the hampered water input.

Micro-habitat for diseases
E. crassipes serves as breeding place for mosquito larvae (Malaria) and as micro-habitat for diseases like Schistosomiasis (Bilharzia) and Lymphatic Filariasis.

In Ghana as well as in other tropical countries the cultivation and sale of invasive weeds is prohibited in order to decrease its spread.

1.3.1.2. Growth Control mechanisms

The three main mechanisms of controlling the invasiveness are of physical, chemical and biological nature.

Physical Control
Physical control refers to the collection of the water plants. While for bigger areas the deployment of terrestrial and aquatic harvesting machinery is viable, on small scale this is no option. Here the *E. crassipes* can be harvested manually or with tools from boats. Problems with this control option are its low efficiency in fighting the plant's re-growth, its high labour intensity and exposure to health risks (Bilharzias).

Chemical Control
Chemical Control refers to the application of herbicides to the water plants from the air or from the water. It has been found effective on small infestations, but as larger the treated surface becomes the less effect it has on stopping the plants' growth. The deployment of herbicides, besides of being skill requiring, has serious environmental and health related consequences. It is commonly accepted by research organizations that chemical control is no suitable option.

Biological Control
Biological Control refers to the release of natural enemies such as weevils, other insects and fungi to the water plants. These control agents maintain the growth of *E. crassipes* constant, while their own population aligns with that of the plant. Until the moment there has not been reported any overtake of other ecological systems by the control agents. After the release it can take up to years before growth reductions are seen.

The compatible combination of these three control mechanism is called *Integrated Control* that is conducted by *Integrated Weed Management* with the goal of maintaining the nocuous weed population at levels that don't cause economical damage. While chemical control is by no means an option, physical control is the most suitable one for rapid control for small infestations and biological control the most viable option for long term control of bigger infestations.
The control effectiveness is highly dependent on strong policies, awareness of the invasiveness and adequate prevention.

This thesis tries to find out if the usage of *E. crassipes* for biogas production on small scale is in line with already existing control approaches.

1.3.1.3. Applications of E. crassipes

Alternatives to the deployment of *E. crassipes* to biogas production are the following.

Handcraft
E. crassipes can be dried and used to make baskets, chairs and ornamentals. This is mainly already done in the Philippines, but can also become a hindering factor for the deployment of *E. crassipes* for biogas production in African Countries.

Rope
The fibers from the stems of the *E. crassipes* can be used to make rope by shredding the plant lengthways to expose the fibers and letting it dry.

Waste Water Treatment
Although most of them are absorbed by the soil, the characteristic absorption by *E. crassipes* of heavy metal, organic compounds and pathogens from water systems can be used for Wastewater Treatment. This application might be an option for waste water systems or sewages. The release of *E. crassipes* into water is the contrary to the thesis' approach of helping to find incentives for rural communities for harvesting the plants.

Animal fodder
E. crassipes can be fed to animals after having been boiled. This is only an option for a rural community, if there is a nutritional shortage.

Fertilizers
Dried or composted *E. crassipes* can be used as a fertilizer for crop soils. As the side product of biogas production is a sludge that is also highly nutrimental and can also be used as fertilizer, the single deployment as fertilizer only represents a threat to the deployment for biogas production, if the its technology is too expensive or not technically feasible.

Others
E. crassipes can, furthermore, be used for charcoal briquetting and the production of paper and fiber boards. Being the technologies complex and expensive they don't represent an opportunity for rural communities.

The purpose of this thesis is to find out if these alternatives represent a threat to the idea of using the plants for biogas conversion.

1.4. Research Background visited Countries

1.4.1. Ghana

Ghana is one of the most prosperous countries of the African Continent, situated at its West Coast with borders to Ivory Coast, Burkina Faso, Togo and the Gulf of Guinea (see Figure 8). Having been a British economy, in 1957 Ghana was the first sub-Saharan country to become independent. Since 1992 it is a constitutional democracy. The GDP per capita (PPP) is estimated at 1.500$, what is almost the double of the poorest West African Countries. Ghana historically suffers from inflation, which is currently at a rate of 19,6%.

Figure 8: Geographical location of Ghana in Africa

Although it is well endowed with natural resources Ghana still depends strongly on international technical and financial aid as the balance of payments remains being negative (the import value almost doubles the export value (mainly constituted by gold and cocoa)). The main income source continues being agriculture, contributing a third part to the GDP with half of the working force.

A 28,5% of the 24,3 million habitants (growth rate 1,9%) lived below the UN poverty line in 2007. The age structure is the opposite of a Western country like Germany, being the median age 21 years, 36,8% of the population younger than 15 and 40% of the people elder than 15 can't read or write[5]. A 56% of the people lives in rural areas, while a constant decrease can be observed. Main sources of lighting are kerosene with 55% and electricity with 44%. In remote rural areas the dependence on kerosene for lighting is total. Main sources of cooking fuel are wood with 56%, charcoal with 30% and gas/electricity/kerosene with 9%.[6] The rate of electricity access in rural areas is not published in statistics, but seems to be relatively low, compared to urban electricity coverage rates.

A curiosity, Ghana has built the world's largest artificial lake, the Volta River that is used for Hydro Power Generation, giving 1.072MW.[7]

In Ghana most of the people do speak English.

[5] Data from https://www.cia.gov/library/publications/the-world-factbook/geos/gh.html, estimated taking into account high disease rates due to AIDS

[6] Data from Ghana Statistical Service

[7] Data from Volta River Authority

1.4.2. Bénin

Bénin is situated closely in the East of Ghana with borders to Togo, Burkina Faso, Niger and Nigeria. (see Fig. 9) Bénin became independent in 1960 and changed its political system from dictatorship into democracy in 1991. The GDP per capita (PPP) is with 1.500$ about the same as in Ghana and thereby relatively high compared to other West African Countries. The currency is linked to the Euro, leading to a relatively low inflation rate of 4%.
Cotton, cashews, shea butter and textiles as main export commodities don't keep up with the imports (foodstuffs, capital goods and petroleum), 50% higher in value. Also here agriculture contributes a third part to the GDP.
Bénin's population (growth rate 3%) is about 9,1 million, 59% of which live in rural areas and 37,4% below the poverty line. The age structure is similar to Ghana with a median age of 17,3 years, being 45% of the population younger than 15. 48% of the male and only 23% of the female population over 15 can read and write[8].
In Bénin few people speak English, official language is French.

Figure 9: Geographical location of Bénin in Africa

The central Bank discount rates are in both countries slightly higher than the respective inflation rates.

1.5. Research Aim

The research aim is to derive the reasons for the non existence of national networks of biogas plants using floating invasive weeds in African countries, whose water systems face the plants' invasiveness problem. Furthermore the study aims to find out the possibilities and barriers for the set up of experiments that could provide technical and organizational enhancement as well as increase positive local perception of bio gas as source for cooking, lighting and electricity.

1.6. Research Question

The research question is:

"What are the opportunities for the deployment of floating invasive weeds for biogas production in local communities in Western Africa?"

[8] Data from https://www.cia.gov/library/publications/the-world-factbook/geos/bn.html, estimated taking into account high disease rates due to AIDS

Included sub questions are[9]:

- What is the state of problems related to invasive aquatic weeds in African countries and how can these be solved?
- How is the invasiveness of *E. crassipes*, Pistia and Salvinia Molesta treated today, particularly in Ghana and Bénin?
- Is the implementation of digesters technically feasible for local cooking and electricity generation?
- What is the state of small scale biogas conversion technology from similar materials to aquatic weeds?
- Will there be enough floating weeds to feed a biogas installation in the long term?
- Is the implementation of digesters economically feasible for local cooking and electricity generation compared to local alternatives?
- Are other local uses of floating weeds than biogas conversion economically more promising?
- Are other local small scale systems for cooking and electricity generation economically more promising?
- What actors play what role and how can they contribute to successful implementation?
- How is the knowledge about biogas conversion technology being shared?
- What do the local communities expect from the deployment for biogas conversion?
- Do local communities have high expectations on other technologies, for instance grid connection, that may hinder the implementation of small scale biogas projects?

1.7. Research Method

After a study of literature on biogas, its conversion technology, its development and deployment as well as on the treatment of floating invasive weeds in the recent past in Africa, a multilevel Strategic Niche Management (SNM, explained detailed in chapter 2) framework based on *"Strategic Niche Management in an unstable regime: biomass gasification in India"* (Verbong et.al., 2010) is used in order to analyze the literature and answer the research question. Looking into the dynamics of the local cooking fuel, lighting, electricity and invasiveness control regimes, biogas conversion from aquatic weeds is treated as candidate for niche innovation. Its possibilities to become successfully part of the niches in the mentioned regimes will be studied by looking who the important drivers are for a successful introduction in the local communities. Through literature and expert interviews the research will study how the invasiveness of the three most important invasive species has been treated so far. In order to determine the technical and socio-economic feasibility as well as to elaborate an actor analysis a field study in Ghana and Bénin has been carried out, using both SNM and Cost Benefit Analysis.

[9] The sub questions are of different importance, the question's order does not represent priorities.

2 Research Method: Strategic Niche Management

Objective of this tis to determine the barriers and opportunities to use *E. crassipes* and other floating invasive weeds as resource for biogas production in rural energy supply in West African Developing Countries. Since these plants are hardly used as feed stock for digestion, biogas as cooking fuel, as source for lighting and for electricity generation have still to become niches before being able to fight for entry into the corresponding regimes. SNM gives an insight into the critical factors of successful niche creation.

This thesis uses the young theoretical framework of Strategic Niche Management (SNM), an analytical method that studies the introduction, development and diffusion of totally new sustainable technologies through societal experiments (Caniëls, Romijn, 2006). SNM has been defined by Weber as "The creation, development and controlled break-down of test-beds (experiments, demonstration projects) for promising new technologies and concepts with the aim of learning about the desirability (for example in terms of sustainable development) and enhancing the rate of diffusion of the new technology" (Weber et. al., 1999). These experiments, though, have to take place in a protected environment that enhances the chances of the new technology to prosper before it has to face the challenges of competition with other technologies. During the experimentation phase the technical and economic feasibility in comparison to already existing technologies and the desirability of the new technology can be studied and improvement in these factors can be managed.

In order to study the chances of a new technology to become successfully spread, SNM utilizes a multi-level framework. The three included levels are the socio-technological landscape at the macro-level, the technological regimes at the meso-level and the technological niches at the micro-level. (see Figure 10) Factors in all of these three levels are determinant for the success of a new technology. A new technology, after having become a successful niche, can find itself enhanced or threatened by changes at the landscape- and regime level. These three different levels are explained in the following section.

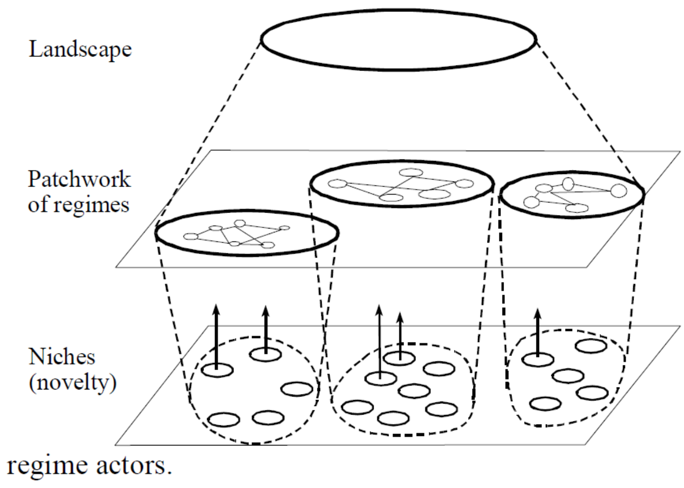

Figure 10: Multi-Level Perspective (Geels, 2001)

2.1. Landscape

The most global analysis level is the socio-technical landscape. Determinant factors of the socio-technical landscape are

"Material and immaterial elements at the macro level:

material infrastructure
political culture and coalitions
social values, world views and paradigms
the macro economy
demography

In the three dimensional model the landscape is the most stable level, developments occur slowly and cannot be influenced by actors. Technological developments at the regime and niche level find themselves embedded in the given conditions of the landscape, which can enhance or hinder the development of a certain technology that is part of the regime. In this way the landscape can put the regime under pressure and give a path for niches to become a new part of the regime. Figure 11 illustrates the way that a technology (part of a regime) has to find through the landscape.

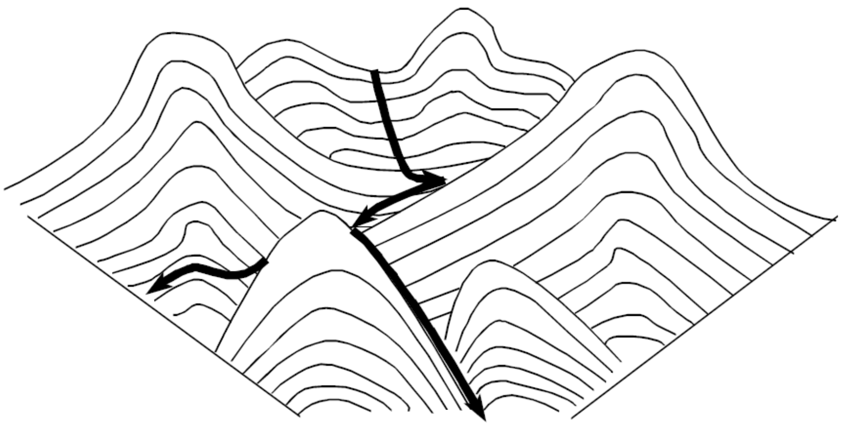

Figure 11: Topography of technological development (Sahal, 1985 in Geels, 2001)

This thesis will focus on the Niche Analysis, being the Landscape Analysis a simple overview.

2.2. Regimes

At the meso-level there is the patchwork of socio-technical regimes. Rip and Kemp give the following definition:

"A socio-technical regime is the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artifacts and persons, ways of defining problems; all of them embedded in institutions and infrastructures." (Rip and Kemp, 1998)

Changes in the regime and innovations tend to follow a trajectory set by the regime itself. Once a technology forms part of the regime, its main beneficiaries (in social and economic terms) may generate a protective environment in order to save the role as part of the regime from competition from other technologies. An example for a regime could be the audio player sector, where currently the IPod by Apple is dominant. Another example is the leading role of fossil fuel power generation in the global power generation regime.

Regimes can on the one hand develop by substitution. An example could be the car in the late 19th century that substituted horse carriages for long distance transportations. On the other hand regimes can transform by accumulations, when the regime is not dominated by only one technology. The existing regime is in this case not replaced, but varied. An example is the global power generation regime, where the main forces, fossil and nuclear sources, get more and more accompanied by renewable ones, that having been niches successfully entered the regime.
Nevertheless, according to the model, the regime gives only path to niches, when it is living internal tensions or it is being put under pressure by the socio-technical landscape.

While there is infinity of regimes, one regime itself has also multiple involved facets, that themselves shape the regime. According to Raven main elements of the regime are three: *technological configuration*, the *actors* and the *set of rules* (Raven, 2005)
Actors involve primarily producers and users, but also public authorities, the financial and the research networks as well as suppliers. (See Figure 12) Within these actors the power can shift.
By technological configuration is meant the technologies and its infrastructures.
Attributes of the regime, that can be analyzed, are its alignment and visions. The more aligned the three elements of a regime are, the more difficult it is for a new technology to enter the regime. The less aligned they are the more permeable and weak the regime becomes. Visions of the regime actors about the regime's future development play a role in the sense that the more they differ the more vulnerable becomes the regime.

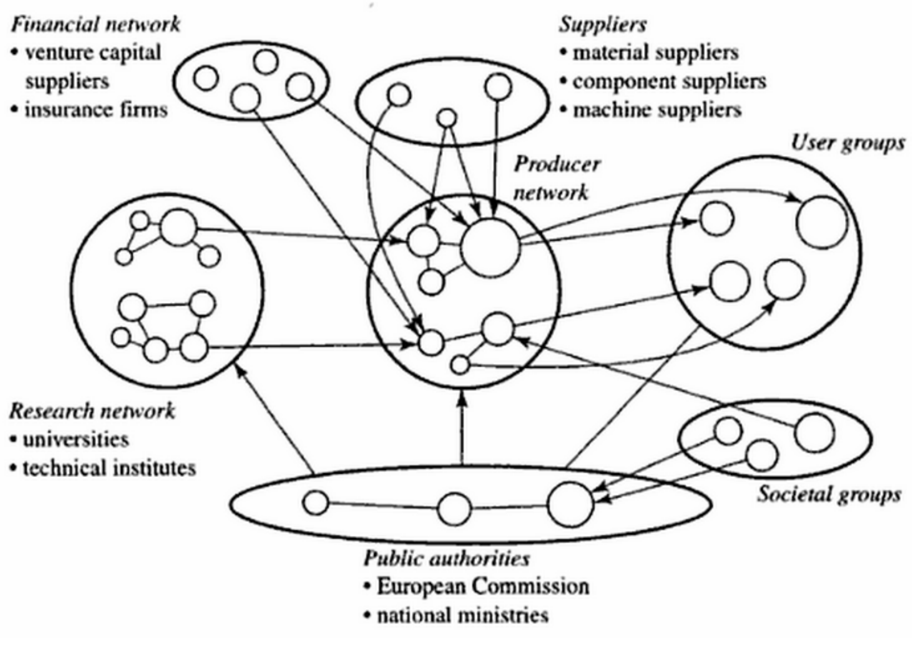

Figure 12: multi-actor network involved in socio-technical systems (Geels, et. al., 2004)

The short analysis of the electricity, lighting, invasiveness control and cooking fuel regimes will give an insight on the involved actors in planning, implementing and using biogas systems as well as the actors involved in invasiveness control. It will provide a rough overview over what is done (or what is used) by the actors in the regimes.

2.3. Niches

At the micro-level the niches are to find. The first step of a new technology consists in experimentations and testing in the niches. By means of economies of scale and high initial costs (radically) new technologies are usually not able to enter the regime directly.
One can distinguish between two types of niches. Both *technological* as well as *market niches* try to provide the new technology protection from the existing regime's technologies by allocating the experiments geographically separated or by testing the niche technology in a completely new application domain. While technological niches are provided by certain actors that see potential of a technology in a certain market, market niches are not created but existing by demands that a market cannot satisfy. Niches are also called '*incubation rooms*' or '*breeding places*'. Raven defines a niche as follows:

> "A loosely defined set of formal and informal rules for new technological practice, explored in societal experiments and protected by a relative small network of industries, users, researchers, policy makers and other involved actors" (Raven, 2005)

Only after a successful niche development phase a technology can face the regime's competition and try to invade it.
Three internal processes are determinant for the success of a niche (Caniëls, Romijn, 2006):

- *articulation and stabilization of expectations* and visions (matching of promises of the innovation and the stakeholders needs)
- building of a cooperating actor *network*
- experimentation based *learning processes* (about the technological and environmental possibilities and constraints of the innovation)

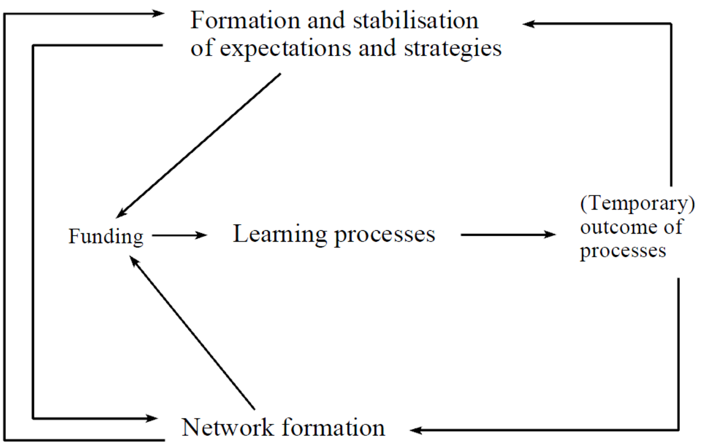

Figure 13: Linkages between internal niche processes (Geels and Kemp, 2000)

These three processes are inter-dependent (see Figure 13). According to Kemp "experimentations are a way to stimulate articulation processes that are necessary for the new technology to become socially embedded." (Kemp et.al, 1998 in Caniëls, Romijn, 2006). For a successful niche creation the participating actors should share a common core view about the technology, its applications and the way of managing its introduction. (Caniëls, Romijn, 2006). If one project is successful it gains external attention and increases expectations. Other projects are, then, more likely to be introduced, what makes the social network grow. In that way the technology is being tested in different environments and scales, lessons learned by the trial and error technique enhance the technology, what makes the expectations grow again, besides by attracting funding (see Figure 13). Each of the three processes is essential for successful niche creation. Innovations may find its most suitable application domain after having been used in others.

2.3.1. Niche Analysis

SNM, having been developed recently, has been used for explaining the success or failure of experiments on new technologies. The technology of converting organic manure into biogas is already mature, being implemented systems on all kind of feed stocks. Biogas technology itself, using *E. crassipes* and additional material, works out with similar technical problems to other input materials. More important pattern to discuss may be its alignment to the social, economical and environmental conditions in a rural African community. SNM is, thus, in this case used in order to find out the technology's barriers for successfully becoming a niche innovation, while factors for success are observed from the only running project found in Africa.

Caniëls and Romijn in their review of SNM literature describe the niche creation process as divided in the following five steps:

- Choice of technology
- Selection of the experiment
- Set up/implementation of the experiment
- Scaling up of the experiment
- Breakdown of protection by means of policy (Caniëls, Romijn, 2006)

Biogas technology using floating invasive weeds such as *E. crassipes* is globally already at the third step, but generally in Africa at the first one. The use of SNM in this thesis is, thus, narrowed down to the barriers of the first three steps on an observational basis and the expectations on the fourth and fifth steps.

2.3.2. Cost Benefit Analysis

A Cost Benefit Analysis (CBA), based on observations of the only implemented project and another site, where invasive weeds are being harvested and sold, will be part of the niche analysis. The reflection of drivers and barriers for the different actors and their expectations is, in this way, complemented by an insight into the economic viability of the project. The CBA will study in which way the expected benefits outweigh the initial and ongoing costs. In developing countries initial investment cost may suppose one of the major barriers for a project's success.

Therefore it will be studied if an implementation of a project for the introduced purposes is not only economically viable, but also seen as an option by the local stakeholders. Although the improvement of social benefits is the main goal of such a project, it could fail due to its focus on the long term, where benefits arise only after a certain period that might seem too long to the beneficiaries if the project's benefits are not visible on the short term.
Questions that arise are:

- How high are the investment, maintenance and labour costs?
- Who will bear the costs and who will enjoy the benefits?
- Is it reasonable to ask for full (or partly) subsidy for a biogas project on floating invasive weeds or should the beneficiaries bury (or part of) the costs?
- Under what conditions are these kinds of projects commercially feasible? (Who else might be willing to pay if governmental agencies and local stakeholders cannot bury the whole costs?)

A Sensitivity Analysis will reflect whether the expectations of the involved actors, research institutions, government agencies and local stakeholder, seem realistic or not.

2.3.2.1. Costs of biogas projects using floating invasive weeds

Besides the initial costs that are constituted by planning, buying the necessary equipment and the construction of the system, the added involved recurrent labour and maintenance costs of a biogas system that uses floating invasive weeds as main feed stock can be divided in the steps from plant collection, transport, pre-treatment, biogas conversion, gas storage and electricity conversion.

2.3.2.2. Benefits of biogas projects using floating invasive weeds

Financial benefits
The directly visible financial benefits can only arise if the community is able to sell parts of the products of the chain as there are the harvested plants (with or without treatment), eventually produced compost, the biogas or electricity. As the dimensions of the system will be the smallest to still fit the community's energy needs, there will be no surplus in gas or electricity. Savings in expenditure on cooking and lighting fuel are, though, accountable. The investment has to be repaid by the mentioned savings and / or sells of the fertilizers. To make a local entrepreneur be willing to invest, the time span of the project is set to five years.
Possible gains in increased yields of agriculture when using the weeds as crop fertilizer will not be accounted.

Socio-economic benefits
The socio-economic benefits can be divided into the three major applications of biogas (cooking fuel, lighting, electricity generation), referring mainly to savings in time and money. The saved money of those can give women and children that are normally involved in the activities, more time to dedicate to other income generating activities, for attending school and building up, improving and participation in social organization in the community. The savings can normally not be accounted and are based on estimations. The socio-economic benefits for the community or society as a whole can be a reason to subsidize the project.

Using biogas for cooking can safe considerable time spent on collecting fire wood lowering in this way deforestation. If charcoal is used as cooking fuel, the money spent on it is saved. Furthermore the workload on cooking and the indoor air pollution are reduced.[10]
Using biogas for lighting can abolish the dependence on other lighting sources, such as candles, kerosene lamps and battery lamps. With an economically sustainable biogas system, money spent on these sources is saved and can be inverted for other purposes. Furthermore the time effort on buying mentioned lighting material can be lowered.
Using biogas as source for electricity increases the independency on other electricity sources, such as Gasoline or Diesel.

[10] Given that biogas is equally or even more contaminant to the environment than combusted wood, eventual reductions in green house gas emissions are here not taken into account.

3 SNM applied to invasive weeds for biogas production

3.1. Field Work Description

Literature had shown that there are biogas digesters working on floating weeds, but only outside Africa and not necessarily on community scale (see insights into landscape). During months it was hard to find a project that fitted for the thesis' purposes. Finally, the main criteria for a project I was looking for, as no community scaled biogas system on floating weeds was to find in Africa, were narrowed down to the following ones:

1. A biogas digester fed with invasive weeds (without necessarily being on community scale)
2. An *E. crassipes* treatment framework (anything is done with the weeds, may it be organized harvesting or control activities)
3. An implemented digester on community scale on any other similar feedstock

After this decision in a first place the idea was to go to Mali, where Fact has contacts with a local organization that implemented digesters on another feedstock than floating weeds and at the riverside not far away the infestations of *E. crassipes* seemed to be a sufficient threat for the riverside communities. The idea was to go there and find out if it was possible to set up a framework between the communities. While starting organizing the field trip, through contacts of Rik Hoevers from LinQ I found out that in Bénin there are implemented digesters at a training centre for the enhancement of local farmer's agricultural activities. Rapidly it was decided to refuse to go to Mali focus on those digesters and link up with other contacts from Rik Hoevers in Ghana that are working on the control of invasive species for years already. A flight was booked, visa and vaccinations organized for a 3 week field trip. 3 weeks do not allow a profound insight, but can, though, give a quick overview about how the invasiveness of *E. crassipes* is treated today (in Ghana) and what the critical factors for biogas conversion of this weed are (in Bénin). In order to determine the improvement in cutting efficiency I brought a hedge cutter from the Netherlands.

The main contact in Ghana was Amoako de Graft-Johnson, an aquatic ecologist-botanist and specialist in aquatic weed management, currently national Project Coordinator of the "Removing Barriers to Invasive Plant Management in Africa" of the Global Invasive Species Program. He linked me up with various professors of the University of Ghana in Accra, Dr. Gabriel Ameka of the Botany department, Patrick Ekpe of the Ghana Herbarium, also Botany department, whose expertise are plants and its locations. Having asked for Kpong, where I planned to do the hedge cutter experiment with a group that harvests and sells aquatic weeds as fertilizer to a local bananer plantation, both de Graft-Johnson and Dr. Ameka commented that what is harvested is not WH, but a mixture of aquatic weeds (*"E.c. 32kgFM/m^2, weed mixture 116kgFM/m^2")*. Nevertheless, as no pure *E. crassipes* infestations were known, I decided to carry out the experiment there later on. It has been commented that in Tema (close to Accra) people are producing BG by aquatic weeds. De Graft-Johnson agreed to contact people in order to establish contact to a remote community that suffers from invasive weeds and is only accessible by boat. At Tema, unfortunately, the "BG plant" was not working anymore. We arrived there and found constructed rectangle ponds where the sewage of the surrounding communities were sent to and treated with floating weeds. A resident explained that the neighbours complained about the bad smell from the system and succeeded in giving it up, althoug large amounts of fundings must have been necessary.

Figure 14: former Waste Water Treatment Plant in Tema

Without having established contact a priori, de-Graft Johnson and Dr. Ameka went with me to Kpong. When we arrived a group was pulling rooted plants out of the water with a rope connected to a net. The place where the floating weeds were was round about 100m away from the shore. Here the hedge cutter experiment was carried out in order to find out how much time it takes to cut and transport the weeds as well as their actual fressh matter weight (the results are to find in the Appendix). The group was highly emphasized in its use. It could be observed that they cut with machetes and collect the weeds with fishing boats. Further, interviews on income and energy consumption were carried out. Nevertheless, it was not possible to determine the price paid by the banana plantation's company for the weeds.

Figure 15: harvested weeds at the shore in Kpong

Figure 16: community group pulling out aquatic weeds in Kpong

The same day we visited the Volta River Authority (VRA) that has governmental power in the region of the Volta Lake and as this lake is also invaded by alien species they collaborate with CSIR (de Graft-Johnson) in the control programme. The Akosombo Hydropower dam, in the VRA's territory, provides a huge amount of electricity for Ghana, what makes the infestations of invasive weeds in this lake especially dangerous.

Figure 17: fishermen entering the lake in Kpong

Furthermore I was able to meet Dr. Aklaku, professor at the University in Kumasi (KNUST). I was linked up to him by Carina Gunnarsson, who wrote a literature review about the use of *E. crassipes* in Agriculture and for Energy. He is a biogas expert and could provide me with technical information. Currently, he collaborates with the Food Research Institute and GTZ in the set up of a biogas pilote plant with Ananas crowns for heating purposes for further commercialization. He linked me up to the Environmental Protection Agency for further interviews for the thesis' purpose, the contact was Roger Leh. In the end it was not possible to meet him.

Later I had the chance to interview Dr. David Wilson from the Zoology department. It was him who launched the biological control programme.

On the same day, de Graft-Johnson and I went to Sogakope (lower Volta River). It was said that there local fishermen were collecting the weeds and used them for biogas production. We drove there without having contacted the local people on beforehand. De Graft-Johnson had been there about two years ago at a meeting that was held in the district assembly for introducing the community into the problems of the weeds. So we went there again and talked to the district engineer, who had not heard anything of a biogas plant. As de Graft-Johnson had heard that the local fishermen were involved and so we were brought to the head of the "South Tongu Fish Farmers Association", Mr. Domi and talked to him. He explained that they have to get rid of the weeds on the shore as they want to continue doing fish farming there. For the removal of the plants they are trying to get funding from BUSAC of the Government. No further use of the weeds is foreseem by them.

Figure 18: ***E. crassipes*** **held in canal, Songai Centre, Porto Novo**

Figure 19: ***E. crassipes*** **held in waste water canal, Songhaï Centre, Porto Novo**

After one week and a half I went to the Songhaï Centre in Porto Novo, Bénin that was established in the 80's as an agricultural training center for local farmers. Now it has become an own village. About 400 people are being trained in agriculture, machinery and commercialization. At the trainings end (after 1,5 years) the participants elaborate and defend a project proposal (business plan) for their home community to establish what they've learned at Songhaï and Songhaï gives smaller or higher loans depending on the project's quality. Another 450 people are working here. The project is based on the so called "Zero Emission Research Initiative". Nothing is thrown away but utilized for other purposes. The "droppings" of the "layers" (chicken) are used as fertilizers, but also mixed with *E. crassipes* and Maringa for Biogas production, the water of the effluent is used for irrigation of the soils for agriculture, the larves that mosquitos leave at the effluents water surface are given to the fish as feed, and so on. *E. crassipes* had been imported from the close Lagoon and is now available in ponds and small canal systems at Songhaï in order to absorb the nutrients of human wastewater and serve as input for biogas digestion. The technical values of the digesters are to find in the Appendix. Two former trainees are setting up biogas plants in collaboration with SNV Bénin, was stated by Justaine, the responsible for energy at the project centre. I got the chance to talk to the founder of the project, Father Nzamujo, about the idea of using *E. crassipes* for biogas production and the chances for more implementations of projects of such kind.

Figure 20: man chopping *E. crassipes* manually, Songhaï Centre, Porto Novo

Figure 21: Chopped E. Crassipes as feed stock in the biogas inlet tank, Songhaï Centre, Porto Novo

Figure 22: trainees and workers at the digester units, Songhaï Centre, Porto Novo

I decided to contact SNV Bénin and was finally able to talk to Cosme Zounon and Toni Marcel, finding out that the planned projects, in collaboration with three Béninese ministries, Songhaï and SNV Bénin, aim at biogas digesters at household scale, since they are convinced that it brings less problems than a community scaled one.

Later I visited IITA in Cotonou and talked to Peter Neuenschwander, who has been working in biological control of invasive species for a long time.

Back to Ghana I further met Gilbert Salormey of the Institute of Industrial Research (CSIR) to interview him about the biogas network in Ghana. He linked me up a private biogas entrepreneur, Kofi Akinkorah, who has already being collaborating with them. The contact to Mr. Akinkorah was established, but it was impossible to meet him.

In the last days in Ghana de Graft-Johnson went with me to the Tano Lagoon in the South West. Here, thanks to him, we were able to establish contact to a rural community that is only accessible by boat and does not have electricity. We went there, they showed me the village and I could interview the community's eldest.

Figure 23: *E. crassipes* at the Tano Lagoon

Figure 24: part of the visited community in Asukro

Figure 25 provides an overview over the contacts I made before and during the field trip. Sander van der Wal is a private biogas entrepreneur who works in the Netherlands and in Tanzania and is an external advisor for the Fact Foundation. From a meeting with him I derived some technical numbers. Nguelo Colince is an Agricultural and Rural Engineer working on the planning of a biogas unit using *E. crassipes* for next year in Cameroon. Through literature I got contact to Oumarou Almoustapha, who implemented a digester for a maternity using *E. crassipes* in Niamey, Niger, that due to maintenance problems is not running anymore. When I found the implemented digester in Bénin I decided to focus on that one. Both have, nonetheless, knowledge on biogas using floating weeds and should be considered when planning such a system.

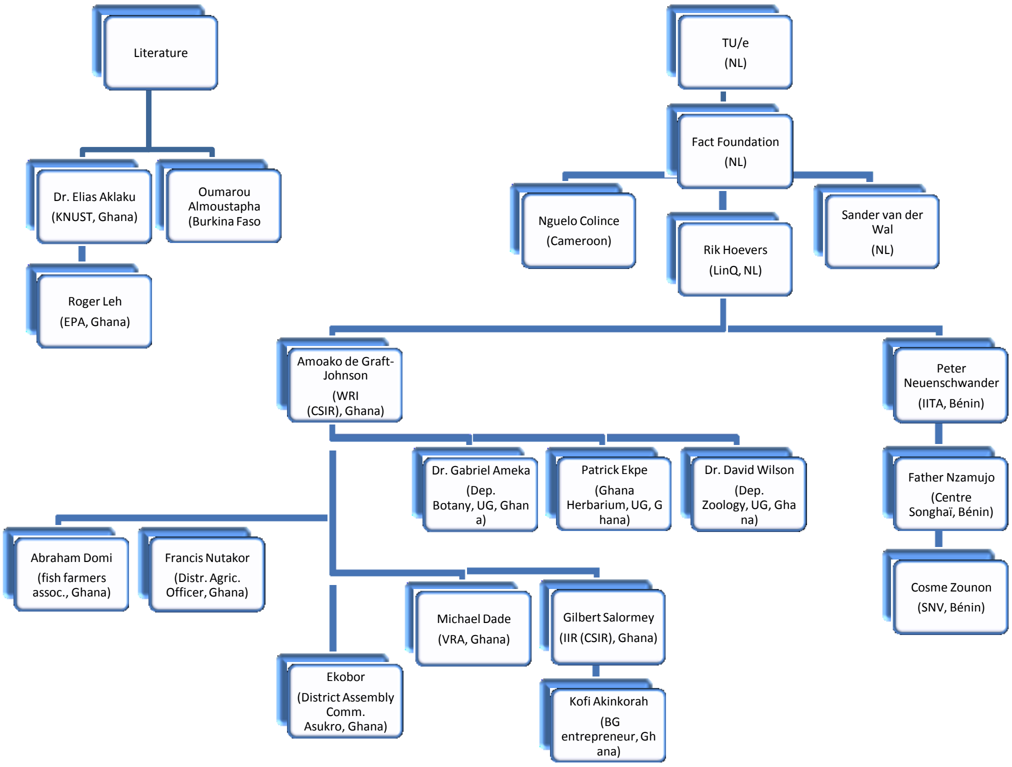

Figure 25: Research Network

3.2. Insights into Landscape and Regimes

3.2.1. Insights into Landscape

Changings at the macro level may put the energy regime in Ghana under pressure.

If the government changes, another policy on renewable energies might be implemented, and a change in government does not seem impossible as the difference of the last elections' result,s for the two candidates was less than half a percent. Increasing population leads necessarily to increasing electricity consumption, what may both enhance or hinder the upcoming of renewable energy sources, depending on the energy policy. The dependence of the industry on the import of fossil fuels makes the energy prices on the Ghanaian market susceptible to changes in fossil fuel prices. Increasing global interest in renewable energy sources and in environmental sustainability backs up the renewable energies in the energy regime. (World Fact Book)

3.2.2. Insights into Regimes

An electricity regime has not been considered for rural remote communities without electricity access.

Weed control

Throughout research institutions like IITA (Bénin) and WRI that have been working in invasiveness control since the 80's, it is agreed that at the moment the *biological control* is the most promising option on the long term. Bugs have been released to water systems and a decrease in growth of *E. crassipes* has been proven (de Graft-Johnson).

Physical control is being induced by awareness campaigns and trainings for river- or lakeside communities, but does not reduce the infestations due to the relatively low harvested mass in comparison to the whole infestation.

Chemical control is not an option for the scientists (Hoevers).

Figure 26: Biological control agents on *E. crassipes* leaves (Zoology Department, University of Ghana)

Cooking

Charcoal (56,8%), firewood (30%) and LPG make out the majority of the cooking fuel regime[11]. These numbers of the World Fact Book could be proven by interviews in Kpong. In rural communities sometimes Coconut shells are also used (observation, Asukro). If firewood is not freely available, the only choice for the poorest people is to buy firewood, since charcoal is sold only in larger quantities, not affordable for them (observation, Kpong).

[11] http://www.statsghana.gov.gh/KeySocial.html

Lighting

Where electricity is not available, kerosene is the only other reported source of lighting.[11]

Figure 27: cooking on Coconut shells (Asukro)

Figure 28: Kerosene lamp (Asukro)

Actor Network

Based on figure 12 (p.19), figure 29 shows the involved actors in the biogas and weed control regimes I was able to observe in Ghana. It is to remark that after a short field study this local image is surely not complete, but could be completed by longer research.

International Funding Organizations and NGOs are also to consider as actors in the financial and research network as well as suppliers. Global institutions like the United Nations Development Program (UNDP) or the International Union for the Conversation of Nature (IUCN), furthermore, influence the actors through funding and awareness campaigns.

The connection for biogas purposes between the shown actors is usually started by hospitals,

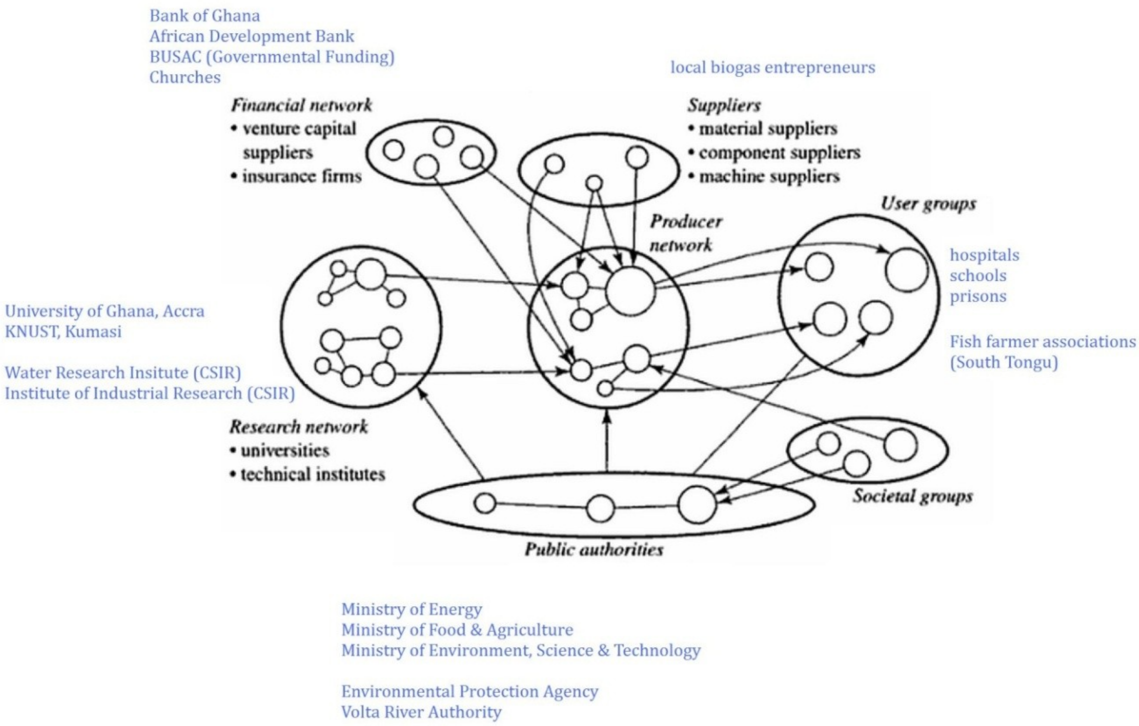

Figure 29: Observed actors in biogas technology and weed control in Ghana

schools or prisons with sanitation problems. (Salormey) They ask public authorities like the Ministry of Energy, whose energy policy considers biogas, and the Ministry of Environment, Science and Technology for solutions of their problems. These authorities, then, contact universities like the University of Ghana or the Kwame Nkrumah University of Science and Technology or other research institutions like the Institute of Industrial Research for Project Proposals. They contact local or international suppliers of the required material and establish a business plan that for which funding is demanded of the actors in the financial network like the Bank of Ghana, the African Development Bank or churches. After the implementation of a system, the maintenance, operating and supervising responsibility is step by step given from the participating research institutions to the local stakeholders. (Salormey)

This is not the only way how the actors interact. The direct application for funding from the user groups are also possible, as the efforts of the South Tongu Fish Farming Association, in order to achieve funding for mechanical removal of weeds, show. (Domi)

The invasive species control program carried out by CSIR and EPA with funding of the African Development Bank provided fish farmers with fiber boats and training for the manual removal of floating weeds. This has shown that successful network creation between research institutions and local fish farmers is possible.

Awareness creation is an important responsibility of research institutions, although they depend on funding (Nzamujo). Nevertheless, in Appolonia, a celebrated community scaled biogas system based on manure that served as example for the dissemination of biogas technology, recently failed after having worked for 20 years due to low local commitment. The set up of a network, thus, does seem to be easier than the success on the long term.

The Environmental Protection Agency is setting up a policy in order to push renewable energies, but finds its efforts restricted by the Ministry of Energy, as the industry is depending on fossil fuel subsidies. *"If the EPA wants to be strict in its policies then whole industries (breweries, slaughter houses, etc) would have to shut down"*. (Dr. Aklaku)

Within the CSIR, different research institutes are embedded like the WRI that, among other activities, works in the field of aquatic weed control, and the IRR, among others, in biogas. In order to set up a framework including both weed control and biogas technology these, two institutes should be involved as they share their knowledge in the same institution.

3.3. Niche Analysis

As no working biogas projects using *E. crassipes* or other floating weeds implemented on community scale were found throughout West Africa, this technology is not even a niche technology in this area for any regime. While renewable energy systems are at the niche level and trying to invade the energy regime, biogas technology is part of the renewable energy regime competing with other renewable energy systems (Dr. Aklaku). Within the variety of feed stocks for digestion into biogas, *E. crassipes* is not yet playing a role. At this micro level, floating invasive weeds represent a niche, represented at Figure X as "invading product" (product in terms of technology) at the initial stage T(1). The current usual feed stocks for biogas production, like animal and human manure, are represented as "established product". (see Fig.

30)

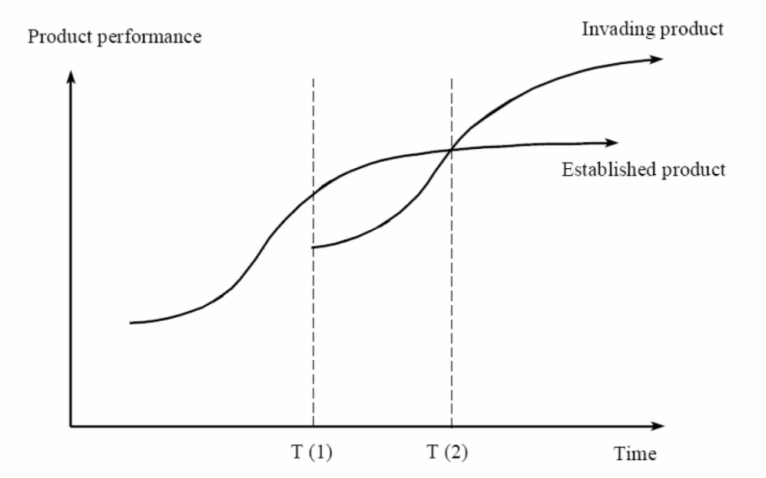

Figure 30: Competition between an established and invading product (Utterback, 1994 in Geels and Kemp, 2000)

The only way to become part of the feed stock regime is by subsidized protected pilot projects. Once implemented, floating invasive weeds have to prove its feasibility for this purpose. If this is the case, the systems can be scaled up and protection can be lowered until the technology stands on its own feet.

A technical feasibility analysis and a cost benefit analysis have been carried out in order to show if invasive weeds have the numbers to become attractive to subsidies and protection,

3.3.1. Technical Feasibility

Since the existence and growth of *E. crassipes* does not seem to decrease in the mid-term future, literature indicates the appropriateness of *E. crassipes* for biogas production and no implemented project on the community scale has been found in West Africa, this variant of a technical feasibility analysis tries to give an idea on how such a system could work out in the local conditions, based on observations and interviews of the field trip. Furthermore, it aims to evaluate if one isolated rural community is capable of running a system that is supposed to provide them with enough biogas to meet their energy needs.

For the dimensioning of the system there are two possible approaches. One can depart from the available amount of aquatic biomass and calculate how much biogas for cooking, lighting and electricity can be derived from it. The other approach is starting with the biogas needs of a community for mentioned purposes. Since the availability of *E. crassipes* varies from one location to another, but the energy needs of a community might be more constant throughout remote rural communities, I opted for the second approach.

Consequently, the required harvested biomass is determined for self subsistence in biogas for one isolated community and not for commercial purposes as theoretically no surplus is produced. Although it would be preferable to use a mix of *E. crassipes* and manure, since there is no data of the biogas yield in West Africa, the feasibility is studied for project that use the floating plant only. Other assumptions are explained step by step with the calculations. In the following tables values with blue background represent input variables while those with green background are the output values, which are required for the calculations of the next step and the understanding of the project's dimensions. To give a more complete overview the interesting values are given also on an annual basis.

3.3.1.1. Dimensioning of the biogas needs in a rural community

3.3.1.1.1. Community Dimensions

COMMUNITY DIMENSIONS				
parametre	unit	value	value/day	value/annum
number of households	#	100		
people in one household	#	6[12]		
community population	#	600		

The community is assumed to consist of 100 household with an average of 6 persons per household. At Asukro, the remote village I was able to visit, the population coincides with this estimation.

3.3.1.1.2. Biogas needs for Electricity

In order to determine the required biogas for electricity use in a first step the electricity need of the community is calculated. In a second step this need in kWh is translated into the m^3 of biogas that are required to meet this electricity need, assuming one fridge per household and not taking into account electricity coverage for potential village facilities like school, church, assembly center or SME.

ELECTRICITY NEEDS				
parametre	unit	value	value/day	value/annum
refrigerator power	*W*	100		
average load	*% of peak consumption*	25%		
daily time of consumption	*h / day*	8		
security factor load	-	1,5		
peak load / household	*W*	150		
average power use / household	*W*	37,5		
electricity requirement / household	*kWh*		0,3	110
electricity requirement / community	*kWh*		30	10.950

In order to assure that a fridge can be used in the household, a load of 100 W for every household is assumed to be required[13], being the peak load 50% higher (security factor of 1,5), 8 hours of daily use (meaning a generator that runs 8h a day) and an average load of 25% of the peak load, the electricity requirement for the community is 30 kWh / day.

[12] See ratio persons/household: https://www.cia.gov/library/publications/the-world-factbook/geos/gh.html

[13] Based on non efficient fridges, that consume about 2kWh a day in Europe, thus being its power 2kWh/24h=83,3W

BIOGAS REQUIREMENT FOR ELECTRICITY				
parametre	unit	value	value/day	value/annum
brut energy content biogas	kWh / m³ BG	6,1		
efficiency conversion biogas electricity	%	20%		
net energy content biogas	kWh / m³ BG	1,2		
biogas needs for electricity generation / community	m³		25	8.959

The brut energy content of biogas is 22 MJ / m^3, equivalent to the value given in kWh / m^3. The net energy content of BG is stated between 1 and 1,8 kWh / m^3.[14] Nevertheless I assumed a relatively low efficiency of the biogas conversion into electricity in order to not underestimate the biogas needed for electricity.

3.3.1.1.3. *Biogas needs for Lighting*

BIOGAS REQUIREMENT FOR LIGHTING				
parameter	unit	value	value/day	value/annum
lamps / household	-	1		
time lamp use	h/day	3		
biogas requirement / lamp max	m³ / h	0,15		
biogas requirement / lamp min	m³ / h	0,1		
security factor biogas for lighting	-	1		
biogas requirement / lamp	m³ / h	0,125		
biogas needs for lighting / household	m³ / day	0,375		
biogas requirement for lighting / community	m³		38	13.688

Assuming one lamp per household with a daily use or 3h for lighting in the evening and knowing that one lamp consumes on average 0,125 m^3 of biogas a day[15] and taking in account a security factor of 1 in order to determine the minimum needs, the community would require 38 m^3 of biogas every day.

3.3.1.1.4. *Biogas needs for Cooking*

BIOGAS REQUIREMENT FOR COOKING				
parametre	unit	value	value/day	value/annum
biogas requirement for cooking / person max	m³ / (person * day)	0,12		
biogas requirement for cooking / person min	m³ / (person * day)	0,08		
security factor biogas for cooking		1		
brut energy content biogas	MJ / m³BG	22		
biogas requirement for cooking / person average	m³ / (person * day)	0,1		
biogas requirement for cooking / household	m³ / day	0,6		
biogas requirement for cooking / community	m³		60	21.900

For cooking on 0,1 m^3 is needed per person per day, which is based on own calculations that are to find in the Appendix. Here for the same reason a security factor of 1 is taken into account, that will only serve for further calculations in the excel calculation sheet. The brut energy content of

[14] Dr. Aklaku: 1,75, http://www.ted-biogas.org/biogas.htm: 1,67
[15] http://www.ted-biogas.org/biogas.htm

biogas is a known value from literature. The conclusion is that for cooking 60m^3 of biogas is needed daily.

3.3.1.1.5. Reflection on total Biogas needs and Recalculation

The total biogas requirement is, thus, 121 m^3 per day, consisting of 25 m^3 for electricity, 38 m^3 for lighting and 60 m^3 for cooking. While the amounts for cooking and electricity seem reasonable, 38 m^3 for lighting results elevated. This induces thinking of making the system more efficient by not using biogas lamps but low consuming LEDs. As in the calculation of the electricity needs there is given space between the 83,3W fridge and the total assumed load of 100 W, a LED of 5 W can be used without effects on the total electricity requirement in kWh and its equivalent in biogas. Consequently, the total biogas requirement is in this new case 83 m^3 per day.

3.3.1.2. Dimensioning of the Biogas Generator

In order to feed the community with electricity a generator is needed.

GENERATOR POWER REQUIREMENT				
parametre	unit	value	value/day	value/annum
peak consumption / household	W	150		
security factor generator power	-	1,5		
peak power / community	kW	15		
generator power requirement	kW	23		
chosen generator power	kW	25		

For its dimensioning the worst' case scenario is taken into account, meaning that all the households are consuming the peak load simultaniously. Although it is unlikely to happen, still a security factor of 1,5 has been added. This might result in an over dimensioned generator, but will surely be able to feed all the households during the project's lifetime. The result is, then, a power of 23 kW, chosing, since no 23 kW generators are on the market, a generator of 25 kW.

3.3.1.3. Dimensioning of the amount of the daily harvesting requirement

The following table shows the calculations of the required biomass if the biogas needs have to be met.

BIOMASS REQUIREMENT (WH)				
parametre	unit	value	value/day	value/annum
efficiency conversion biomass - biogas	%	70%		
biogas yield max	l / gDM	0,291		
biogas yield min	l / gDM	0,19		
biomass dry matter content	%	5%		
biogas needs / community	m³		85	
biogas yield average	l / gDM	0,2405		
biomass needs / community	kgDM		352	128.312
biomass needs / community	kgFM		7.031	2.566.245
harvesting working days / week	days / week	5		
biomass to be harvested daily	kgFM / day		9.843	

Departing from biogas yields from literature it is shown that 9,8 metric tons of fresh matter (TFM) have to be harvested on a daily basis[16]. This value is recalculated in the following table in means of equivalent plant surface, the surface of the mass that has to be harvested to arrive to 9,8 TFM.

PLANT SURFACE REQUIREMENT				
parametre	unit	value	value/day	value/annum
biomass density max	kgFM / m² water surface	70		
biomass density min	kgFM / m² water surface	30		
biomass density average FM	kgFM / m² water surface	50		
biomass density average DM	kgDM / m² water surface	2,5		
harvested surface requirement	m²		197	51.325

The measuring of the floating weeds harvested at Kpong, although not *E. crassipes*, showed an average weight of 50 kg of fresh matter (kgFM) per m^2. Based on this 9,8 TFM are equivalent to 197 m^2 that have to be harvested daily, that is a quadrate of 14 m edge.

The calculations of the next and last step determine how big the infested area of *E. crassipes* has to be in order to guarantee these daily harvested 197 m^2.

GROWTH OF WATER HYACINTH				
parametre	unit	value	value/day	value/annum
biomass growth	TDM / ha			30
biomass growth	kgDM / ha		82	
	kgFM / ha		1644	600.000
necessary area	ha			4,28

The growth of *E. crassipes* is given by literature in two ways. One is the doubling time; it is to say the time that an invaded area of *E. crassipes* needs to duplicate its area. The other given value by literature is the amount of grown plants per hectare per year. These vary and some state growth rates of up to 100 TDM / (ha * year). Expert interviews, though, suggest a reasonable value of 30 TDM/ (ha * year). I opted for the second calculating way since the growth is not linear; it is to say a bigger infestation duplicates its area faster than a smaller one, which makes the first approach not very significant for these calculations. Nevertheless, the growth is sensibly dependent on local conditions. As a result, an area of 4,28 ha is necessary in order to guarantee the harvesting needs.

3.3.1.4. Overview technical Data

The following table gives an overview over the resulting technical values to be considered.

---

[16] Considering 5 working days per week. In 5 days, thus, has to be harvested the need for a week.

Technical Data overview years								
population growth	%	2,5%						
parametre	population	electricity req.	pow.req.	chosen pow.	Biogas req.	Biomass req.	
unit	*#*	*kWh / day*	*kW*	*kW*	*m³ / day*	*TFM / day*	*m² / day*
year							
1	600	30	23	25	85	9,8	197
2	615	31	23	25	87	10,1	202
3	630	32	24	25	89	10,3	207
4	646	32	24	25	91	10,6	212
5	662	33	25	25	93	10,9	217

As the dimensioning considered the current needs, but may change over time, the technical values have been forecasted for the following five years, considering an annual population growth of 2,5%[17]. Although this growth refers to Ghana as a whole country and rural population growth might be smaller, this image might be realistic since increasing energy consumption per household is neither taken into account.

It can be concluded that for the mentioned purposes, a model community requires 33 kWh of electricity on a daily basis, and 93 m^3 of biogas for its production and the use for cooking and lighting. This can be achieved by harvesting 10,9 TFM of *E. crassipes*, or the same, 197 m^2 a day and implementing a 25 kW generator.

When purchasing the generator, attention has to be paid to its biogas absorption capacity. The biogas generator, when purchased, has to stand a biogas flow of 93 m^3 / 8 h = 11,6 m^3 / h.
For this scale ramp conveyors or terrestrial harvesting machines, as they are used in North and South America, are not appropriate.

3.3.2. Proposal of a biogas project based on floating weeds

In order to find out if it is viable that one community can run and maintain a biogas system on its own for its own needs it is necessary to know how many people would be required. With the goal of maintaining the system simple and affordable the proposed system is the following.

E. crassipes is cut out with hedge cutters of an infestation and dragged by boats from the water to the shore (if they are not there to find), where they are cut down into smaller pieces, brought to the grinder, grinded, brought to the drying place, dried for one day[18] and fed to the digester tank (see Figure 31). The grinding and drying part are the simplest ones among the different approaches of feed stock pretreatment. I refused taking into account preheating systems that enhance the digestion. Later, in the CBA, it is studied if the investment of the grinder has a high impact on the economic feasibility of the project.

[17] World Fact Book, CIA
[18] in order to increase the DM content from 5% to 10%, at scale to the observations made by Oosterkamp, figure to find in the Appendix.

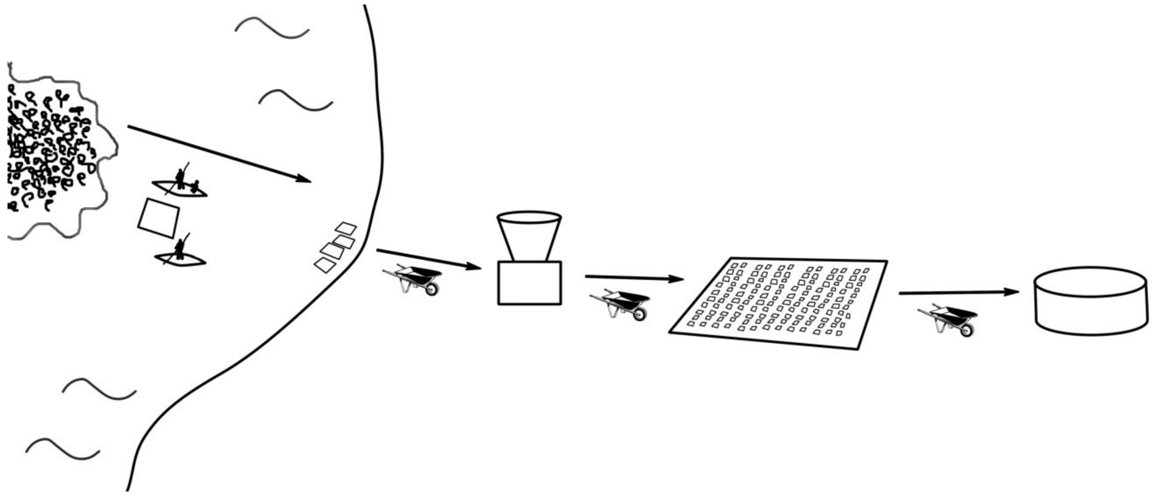

Figure31: Sketch of proposed system (not at scale)

This proposal is based on the way how the harvesting group in Kpong was collecting, transporting and cutting down the weeds at the shore. As there the weeds stay at the shore and are sold as fertilizer, the 'terrestrial' part of the project is designed to be the least complex. In this case I chose the grinding before the drying, but it is to be studied if inverting the sequence would be more efficient. No water press has been considered as the labour effort is tried to be held. A grinder, though, has been considered necessary since the manual chopping of almost 11TFM daily is difficultly done manually as at the Songhaï Centre. Smaller pieces of about 2cm*2cm give the micro bacteria far more surface to attack than non grinded pieces; it is to say that the digestion takes place faster.

The calculations of the required labour force (to be found detailed in the Appendix) have shown that with 12 workers it is possible to run the system with the required biogas output. 12 people of the community would have to cancel their fishing or other commercial activities for providing the whole community with electricity and biogas for cooking, what sounds reasonable. This required labour force could be narrowed down if after some time the cutters get used to the cutting machines and cut faster. This could not been proven experimentally as for the experiment it was the first time the worker used a hedge cutter.

As the digester should be fed two or three times on a daily basis, the responsible workers for the feeding part have to feed 10,9 TFM / day * 5 / 7 = 7,8 TFM / day, while the rest of the workers do the work for one week in five days. This has to be kept in mind if implementing a project with five harvesting days per week.

The biogas digestion unit itself would contain two bag digesters (of 26m length each, see Calculations in the Appendix) since for the local needs one would be too big. Figure X provides an overview over this system with one inlet tank, one effluent tank, a water filter, the generator and the grid. Again, to keep the costs down, I refused to consider a gas storage tank since it would require a compressor and signify extra investment. In this case the bag digesters serve directly as biogas storage tanks.

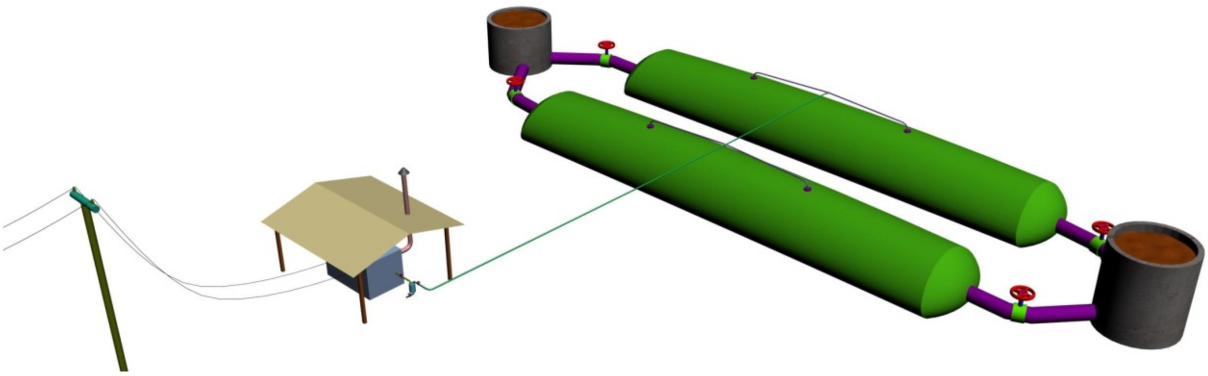

Figure 32: Sketch of the proposed biogas unit

As the proposed system requires little training for the workers, boats are already owned by the riverside or lakeside communities and therefore no training for driving boats nor the acquisition of boats is required and with a relatively small group of people this system can be run, the system can be considered as technically feasible. Nevertheless, a pilot project would give an insight into surely occurring technical problems.

3.3.3. Cost Benefit Analysis

In order to determine the economic feasibility of a biogas project using floating invasive weeds at a remote community an analysis of its costs and benefits has been carried out. If the benefits outweigh the investment and ongoing costs in a reasonable time span (here 5 years) investors might be willing to invest in the project.

This analysis makes reference to a Ghanaian remote community of about 100 households without access to electricity and wants to serve as an example for West Africa. In order to determine if the project is attracting local investors, the monetary unit is GHS and the local values of inflation (consumer prices) and interest rates are taken into account. Since the inflation in Ghana is historically high and fluctuating, this CBA might suffer from changes in a short amount of time. The GSS announced a drop below 10% for June 2010.[19] Nevertheless, to give international readers also a comprehensive insight, the CBA discussion will provide the monetary terms in USD too and two full CBA overviews in USD are to find in the Appendix, considering both local and international values of interest and inflation rates[20], what in “times of crisis” might result interesting. The non-financial Cash Flow, referring to all the expenditures and incomes of the project except the loan and interest payments, is given in constant prices. The prices rise annually only due to population growth; it is assumed that the village population grows at the same speed as the country’s average. This might not be accurate, since rural populations tend to grow slower than the urban population. Nevertheless, overestimating the rural population growth might outweigh a non considered growth in energy consumption per household.

In order to hold the costs down and make the project more attractive for the investor the required new appliances – fridge, cooking stove and LED – are not supposed to be delivered by the investor. Since the rural remote communities live in absolute poverty, they can also not burden the costs. Another stakeholder has to be found, which could be a governmental department, for example. Furthermore, it is assumed that the savings made in expenditure for cooking and for lighting are paid from the community to the investor and the investor pays the workers. The payment should be done on the harvested biomass and not per working time to ensure that there is enough feed stock every day. Potential income by selling the sludge as a fertilizer is not taken into account due to the difficulty to find a purchaser that is willing to visit the community and buy it directly there. The transport of the sludge to a market would, thus, suppose extra work effort and time for the community. Sells of electricity or gas are also not involved since the dimensions of the project have been designed for the local needs.

The detailed calculations and discussions of the costs and benefits are to find in the Appendix.

[19]Source: http://www.statsghana.gov.gh/docfiles/news/INFLATION%20FALLS%20BELOW%2010.pdf

[20] Source inflation rate Netherlands: https://www.cia.gov/library/publications/the-world-factbook/geos/nl.html (World Fact Book, CIA) , source nominal interest rate Netherlands: http://www.ecb.int/stats/money/long/html/index.en.html (European Central Bank)

3.3.3.1. CBA Data Overview

COSTS BIOGAS PROJECT

parametre	unit	value
Investment		
biogas generator	*GHS*	16.473
electricity grid	*GHS*	13.386
biogas digester	*GHS*	10.709
pipes, other assecoires	*GHS*	5.354
grinder	*GHS*	1.700
hedge cutters	*GHS*	918
wheelbarrows	*GHS*	255
shovels	*GHS*	66
TOTAL INVESTMENT		48.861
Operational Costs		
labour costs	*GHS / year*	13.728
Gasoline Cost for Cutters	*GHS / year*	1.713
Diesel Cost for Grinder	*GHS / year*	793
maintenance	*GHS / year*	2.443
TOTAL COSTS	*GHS / year*	18.676

ECONOMIC & FINANCIAL VALUES

parametre	unit	value
project duration	*years*	5
inflation rate (p)	*%*	19,6%
nominal interest rate (i)	*%*	25%
real interest rate ®	*%*	4,52%
population growth	*%*	2,50%

BENEFITS BIOGAS PROJECT

parametre	unit	value
Savings		
cooking	*GHS / year*	25.757
lighting	*GHS / year*	36.500
TOTAL SAVINGS	*GHS*	62.257
Income		
fertilizer	*GHS / day*	0
gas	*GHS*	0
electricity	*GHS*	0
TOTAL INCOME		0
TOTAL BENEFITS	*GHS / year*	62.257

NON FINANCIAL Cash Flow *Constant Prices*

year	Costs	Benefits	Net Cash Flow	Discount factor	non-fin CF	cum. non-fin CF
	GHS	*GHS*	*GHS*		*GHS*	*GHS*
0	48.861		-48.861	1,00	-48.861	-48.861
1	19.143	63.813	44.670	0,96	42.740	-6.121
2	19.622	65.409	45.787	0,92	41.916	35.796
3	20.112	67.044	46.932	0,88	41.108	76.904
4	20.615	68.720	48.105	0,84	40.316	117.220
5	21.130	70.438	49.307	0,80	39.538	156.758

FINANCIAL Cash Flow *Current Prices*

year	Loan	Repayment	Interest on loan	Discount Factor	financial CF	cum. Financial CF
		GHS	*GHS*		*GHS*	*GHS*
0	65.148			1,00	65.148	65.148
1		-13.030	-16.287	0,80	-23.453	41.695
2		-13.030	-13.030	0,64	-16.678	25.017
3		-13.030	-9.772	0,51	-11.674	13.342
4		-13.030	-6.515	0,41	-8.005	5.337
5		-13.030	-3.257	0,33	-5.337	0

TOTAL Cash Flows *Current Prices*

year	CF	cum. CF
	GHS	*GHS*
0	16.287	16.287
1	19.287	35.574
2	25.238	60.813
3	29.434	90.246
4	32.310	122.557
5	34.201	156.758

Investment Values

parametre	unit	value
IRR	*%*	89,71%
Pay Back Period	*years*	2
NPV	*GHS*	156.758

Values in USD:	
TOTAL INVESTMENT:	36.502 USD
TOTAL COSTS:	13.952 USD

TOTAL BENEFITS:	46.510 USD
NPV:	117.107 USD

Where:

Real interest rate $= \frac{1+i}{1+p} - 1$

Discount factor in constant prices: $DF = (\frac{1}{1+r})^{year}$

Discount factor in current prices: $DF = (\frac{1}{1+i})^{year}$

3.3.3.2. CBA Discussion

The results of the CBA suggest an economically highly feasible project. The IRR is with about 90% far higher than the real interest rate (4,52%). The investment of 48.861 GHS (36.502 USD) is repaid within less than two years and the NPV after five years is 156.758 GHS (117.107 USD). These positive characteristics can be explained by the fact, that the benefits of the first year already overtop the investment, being the annual costs only about a third of the benefits. Furthermore, the project does not present any liquidity problems, since the total cash flow that takes into account financial and non financial benefits and costs, is always positive. It might even be suggestible for the investor to take a lower loan (paying attention to an always positive total cash flow).

The highest costs are the labour costs. If one wants to make the project even more feasible, these costs have to be studied deeper in order to find out how less workers can do the same work more efficiently. In this way the labour costs are a direct function of the project's scale. The more that has to be harvested, the more labour force is needed and the higher the costs become. The worker's loan in Ghana normally rises linearly with the inflation rate of consumer prices. The fact of using LEDs instead of kerosene lamps makes the community resistant to the characteristic fluctuation of the kerosene price.[21]

The cost of harvesting are 98 GHS (74 USD)[22] per harvested TDM. Comparable studies have shown a reasonable value of 20 USD.[23] A reason for this high value might be the high effort required of harvesting and transporting masses of water (water content of *E. crassipes* (95%)). Nevertheless, it has to be studied, why this costs is so high compared to other biogas crops.

If the community pays its savings in cooking and lighting expenditure to the investor, then these payments can be seen as the price that the community is paying for the electricity and the biogas for cooking. If only the savings for lighting (that is now covered by electricity) are picked out and divided with the total amount of energy consumed in one year, then the price paid for electricity

[21] See http://news.peacefmonline.com/social/201004/42476.php

[22] Cost of harvesting = $\frac{13.728\frac{GHS}{year}}{\frac{10,7TFM}{day} * \frac{0,05TDM}{TFM} * \frac{5\ working\ \ days}{7\ days} * \frac{365\,days}{year}} = \frac{98GHS}{TDM}$

[23] Comment Winfried Rijssenbeek

is 3,18 GHS / kWh (2,38 USD / kWh)[24]. This cost is far higher than the electricity price for grid connection (0,195 GHS / kWh in 2009) and might also be higher than the cost of electricity of other small scale energy systems like a Diesel Generator or ones based on renewable sources like PV. It has to be accounted, though, that before the project implementation no electricity was used at all, but after the project implementation the village and every single household is covered with it, no time has to be spent anymore on firewood collection or kerosene transportation and the community enjoys all the other benefits described in the introduction, that are not accountable in monetary terms.

Sensitivity Analysis

The Sensitivity Analysis determines how sensitive the project's economic feasibility is to changes in costs and benefits. A project is economically feasible if the NPV is positive at the end of the project (or the same: the real interest rate does not overcome the IRR (if calculated with current prices, then the nominal interest rate is not higher than the IRR)). This would happen if one of the following scenarii occurs:

- The investment cost rises 205.619 GHS (153.609 USD) (rise of 321%), which is unlikely to happen.
- The annual labour costs rise to 46.953 GHS (35.077 USD) (rise of 242%), which is also not very probable.
- The annual total savings drop to 29.032 GHS (21.689 USD) (drop of 53%). That means that with a fall to 47% in total savings the project would still be feasible for the investor.

This last case is interesting. Translated to this project it means that the community could pay only 29.032 GHS per year, or the same, 0,80 GHS (0,59 USD) per household per day and the investor would still get his money back in five years. In this case the electricity cost would suppose 2,65 GHS (1,92 USD)[25], which is still too high, but it represents the lower threshold for the electricity cost.

Accordingly, if local conditions allow the community to use firewood for free with low collection time and efforts, no savings in expenditure on cooking fuels can be considered. This scenario is realistic in Asukro, where money is spend only for lighting. In this case the total benefits of the project would be narrowed down to the savings in lighting source expenditure, thus to 36.500 GHS (27.268 USD), nevertheless not threatening the financial viability of the project since the benefits are still higher than the threshold.

Alternative Scenarii

Having observed the feasibility from an investor's point of view one could proceed in adding the costs of the fridges, LEDs and stoves to the investment. The project would probably still be feasible in five years and would not depend on financial contribution of a third partner.

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[24] Electricity Cost = $\frac{\frac{36.500\,GHS}{year}}{\frac{31\,kWh}{day} * \frac{365\,days}{year}} = 3{,}18\,\frac{GHS}{kWh}$

[25] Electricity Cost = $\frac{\frac{29.007\,GHS}{year}}{\frac{31\,kWh}{day} * \frac{365\,days}{year}} = 2{,}65\,\frac{GHS}{kWh}$

If there is no possibility of obtaining the devices for all the households, one could start with putting a few fridges into the community center to be shared among everybody or providing a few households with fridges, but not 100.

These cases are interesting to study. Having arrived to these results at the end of my research, time did not allow me to re-calculate everything for these other cases. The CBA as well as all the other calculations are available in Microsoft Excel 2007 format.

4 Conclusions and Recommendations

Niche Analysis

While biogas systems are still a niche in Ghana that fights against other renewable energy systems and the subsidized fossil fuels for entry into the energy regime through governmental funding, the deployment of floating weeds for biogas production is yet a niche in that niche. For successfully becoming part of the already existing biogas network, biogas by floating weeds requires protection and subsidies from the government or external financial contribution and needs to be backed up with technological knowledge by biogas technology and weed research institutions hand in hand as well as with general awareness creation by these two actors.

Learning and network creation

Although the flow of information between research institutions is sometimes hindered, the rapid appraisal of the biogas network in Ghana indicates that knowledge is already being shared with decision makers through pilot plants at research institutions and at selected schools, prisons and hospitals that benefit from the dissemination of waste water problems solving biogas technology. Little until no knowledge is shared, though, with rural communities. Efforts on energy provision for rural communities have to go hand in hand with other efforts with the goal of improved living conditions, such as health, sanitation and education.

Expectations

While remote rural communities have generally low confidence in being considered by governmental agencies for their needs and their expectations of being included to the grid are nearly zero, they don't see any other actor that could take them into consideration since the Ghanaian population is historically used to be provided by the government with money, subsidized fuels and education after independence 53 years ago. Since these governmental actions were good willing, but not sustainable, now the expenditures decrease gradually. The expectations on being provided with everything, though, are still there. Rural communities prefer electricity provision to new sources of cooking fuel or lighting due to the possibility of additional income by conserving the fishes.

Technical viability

Both literatures on experiments and field work observations have shown that *E. crassipes* can be used properly alone and preferably in co digestion with animal manure for biogas production in spite of the weed's high lignin content. Since *E. crassipes* is rather found in a plant mix than alone and its biogas yield is locally specific, the viability of an implementation in a community has to be proven by a pilot project, where it has to be considered to maintain labour costs and effort low since these represent the highest barriers for the project's success. Due to its high consumption biogas lamps should not be considered, but LEDs, if electricity is projected to be produced.

Financial viability

Obtaining funding does not seem to be a problem as with a simple biogas system with a grinder and a biogas generator for electricity they can be repaid rapidly by the savings made in expenditure on cooking fuel and lighting. Since, in spite of the proven economic feasibility of a community scale project, the cost of electricity is still high, other renewable energy sources than

E. crassipes might be in a better position for governmental protection. Nevertheless, the policies on renewable don't work properly and it is still to study if achieving governmental funding is really accessible.

Since the remote communities live under extreme poverty and in infrahuman health conditions, the enhancement of their living conditions is urgent and the idea of a community scaled biogas project on floating weeds run by the community itself could provide a way towards energy access on behalf of their own.

Recommendations for further research

A study on the renewable energy regime and other local renewable energy systems like PV would reveal if they are more feasible technically and financially or not.

The Appraisal of local demand on energy has to be done in every specific case.

The energy outcome as function of working effort might be higher with other feed stocks.

The feasibility of deploying *E. crassipes* on large scale has to be studied, considering the local activities on controlling the plant's growth.

For the enhancement of site selection an *E. crassipes* infestation layer with a geographic information system (GIS) should be elaborated.

It is to study whether the deployment of *E. crassipes* as fertilizers would generate more income than the deployment for biogas.

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Appendix I Tables, Figures & Documents

In this first part of the Appendix you can find tables and figures of gas yields, *E. crassipes* growth, dry matter content after drying, electricity rates in Ghana and cutter consumption as well as a news note about weeds, a plant certificate (to be considered if leaving Ghana with plants), a price list of the machines produced and sold at Songhaï, technical data on the digesters used there and a figure of visited places.

Biogas production		**Residence time (days)**	**Methane (%)**	**Substrate**
(l/g DM)	(l/g VS)			
0.291	0.348	300	60	W (fresh)
0.245	0.292	300	60	W (dry)
–	0.19	–	–	W
–	0.4	–	–	W
–	0.24	–	–	W
–	0.20–0.28	15–60	63–67	W
0.190	0.293	8	62–66	W
0.143	0.286	8	–	W
0.19	0.4	8	65	WC

Table 3: Summary of reported gas yields with E. crassipes as a main substrate (Gunnarsson, 2005)

TABLE 1. Floating biomass and productivity of waterhyacinth growing in fresh water system reported for different parts of the world

Location	Maximum stand (t d.w. ha^{-1})	Productivity (t d.w. ha^{-1} yr^{-1})	Reference
Florida, USA	24	37	Knipling *et al.*, 1970
Parana River, Argentina	22	14	Lallana, 1981
Louisiana, USA	15	30	Penfound and Earle, 1948
Gorakhpur, India	7.2	2.6	Sahai and Sinka, 1970

Table 3: reported Growth of E. crassipes (Woomer, 1997)

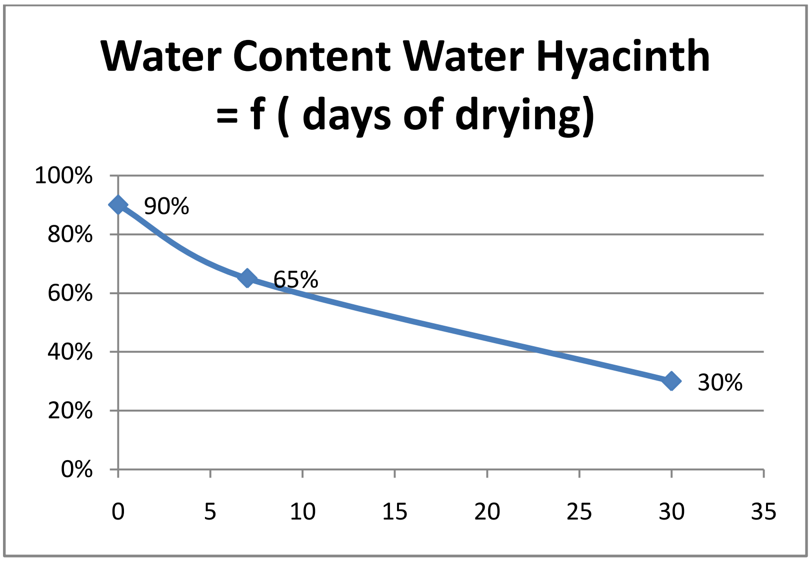


Figure 31: Days of Drying and Water Content of E. crassipes (Oosterkamp, 2002)

Hedge Cutter Consumption		
parametre	*unit*	value
machine starts	*#*	10
cutting time	*sec*	454
fuel consumed	*kg*	0,072
fuel density	*kg / L*	0,769
fuel consumed	*L*	0,094
fuel consumption	*L / h*	0,742

Table 4: Calculation of Hedge Cutter Consumption (own experiment, 2010)

Ghana Electricity Rates from April 2009		
0-300	0,140	GHS/kWh
300-600	0,170	GHS/kWh
600-99999	0,195	GHS/kWh
Service charge	2,5	GHS/bill
Nat elect. Levy	0,00017	GHS/kWh
Public Lighting Levy	0,00005	GHS/kWh
VAT	15%	

Table 6: Ghana Electricity Rates from April 2009

Invasion of alien plants

Story: Abdul Aziz

THE Council for Scientific and Industrial Research (CSIR), says 30 alien plants have found their way into the eco-system and are destroying the country's biodiversity.

The alien species, according to the CSIR were replacing indigenous plants that were useful to the ecosystem at a very fast rate.

The council, which is spearheading a four-year project to remove barriers hindering the management of exotic plants, has, therefore, appealed to the security agencies and personnel of the Ministry of Food and Agriculture (MoFA) at the country's borders to be vigilant by preventing travellers from bringing alien species into the country.

The Minister of Environment, Science and Technology Ms Sherry Ayittey, who launched four booklets on exotic plants, said the alien plants were causing devastation to crops and forest lands in areas such as the River Afram Headwaters Forest Reserves.

Ms Ayittey whose speech was read on her behalf said these alien plant species were also causing irreparable damage to socio-economic development and posed as health hazards to the people in the areas they were found.

She, therefore, urged agencies such as the CSIR to team up with the United Nations Environment Programme (UNEP) and the Global Environment Facility (GEF) to successfully implement the four year project to remove barriers for the management of the exotic plants.

Dr Abdulai Baba Salifu, Director-General of CSIR, who chaired the function, said some biological methods had been introduced by CSIR to control the weeds.

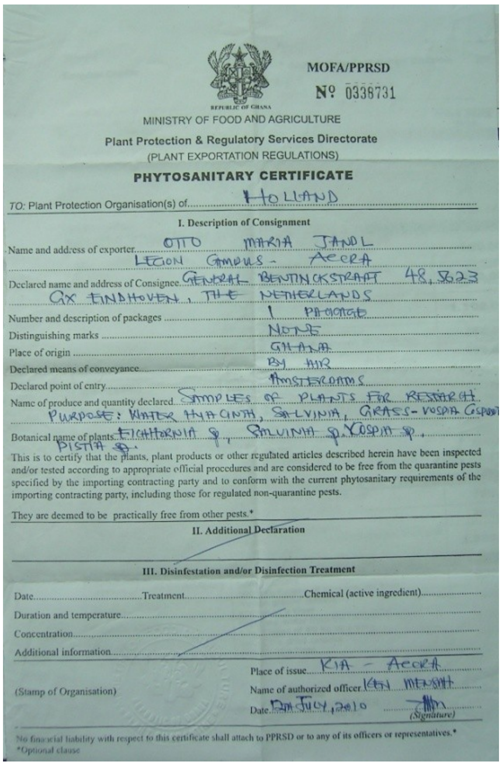
He said one of the methods was the introduction of some species of grasshoppers to feed on the leaves of the exotic plants.

He, however, said such biological control had its limits since the CSIR could not nurture a vast quantity of those grasshoppers to deal with the ever-spreading exotic weeds that were increasing in the country.

Dr Salifu appealed to the government to increase its component of funding the project to eliminate the alien plant species before they took over the ecosystem and destroyed the agricultural sector.

Some of the alien plants included Jatropha curcas (Adadze), Lantana camara (Ananse dokuno), Striga (Wumlim) Cecropia peltata (French Adwuma) Siam Weed (Acheapong).

Figure 32: News note on invasion of alien plants (Ghana Newspaper "Daily Graphic", June 2010)



MOFA/PPRSD

Nº 0338731

REPUBLIC OF GHANA

MINISTRY OF FOOD AND AGRICULTURE

Plant Protection & Regulatory Services Directorate

(PLANT EXPORTATION REGULATIONS)

PHYTOSANITARY CERTIFICATE

TO: Plant Protection Organisation(s) of HOLLAND

I. Description of Consignment

Name and address of exporter OTTO MARIA JANDL LEGON CAMPUS - ACCRA

Declared name and address of Consignee GENERAL BENTINCKSTRAAT 48, 5623 GX EINDHOVEN, THE NETHERLANDS

Number and description of packages 1 PACKAGE

Distinguishing marks NONE

Place of origin GHANA

Declared means of conveyance BY AIR

Declared point of entry AMSTERDAMS

Name of produce and quantity declared SAMPLES OF PLANTS FOR RESEARCH PURPOSE: WATER HYACINTH, SALVINIA, GRASS-VOSPIA CUSPID

Botanical name of plants EICHHORNIA sp., SALVINIA sp. VOSPIA sp. PISTIA sp.

This is to certify that the plants, plant products or other regulated articles described herein have been inspected and/or tested according to appropriate official procedures and are considered to be free from the quarantine pests specified by the importing contracting party and to conform with the current phytosanitary requirements of the importing contracting party, including those for regulated non-quarantine pests.

They are deemed to be practically free from other pests.*

II. Additional Declaration

III. Disinfestation and/or Disinfection Treatment

Date .... Treatment .... Chemical (active ingredient) ....

Duration and temperature ....

Concentration ....

Additional information ....

(Stamp of Organisation)

Place of issue KIA - ACCRA

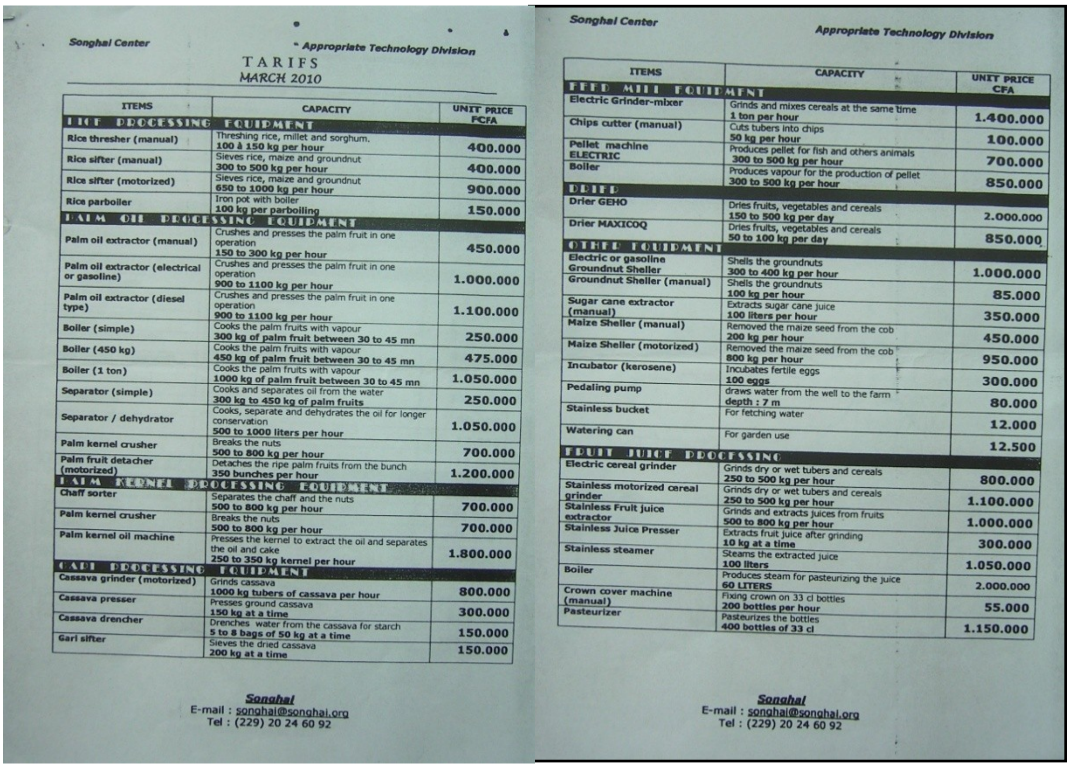
Name of authorized officer KEN MENSAH

Date 12th JULY, 2010 .... (Signature)

No financial liability with respect to this certificate shall attach to PPRSD or to any of its officers or representatives.*

*Optional clause

Figure 33: certificate to leave Ghana with plants, by Plant Protection (Ministry of Food and Agriculture, Ghana) (July 2010)



Songhai Center — Appropriate Technology Division

TARIFS
MARCH 2010

ITEMS	CAPACITY	UNIT PRICE FCFA
RICE PROCESSING EQUIPMENT		
Rice thresher (manual)	Threshing rice, millet and sorghum. **100 à 150 kg per hour**	400.000
Rice sifter (manual)	Sieves rice, maize and groundnut **300 to 500 kg per hour**	400.000
Rice sifter (motorized)	Sieves rice, maize and groundnut **650 to 1000 kg per hour**	900.000
Rice parboiler	Iron pot with boiler **100 kg per parboiling**	150.000
PALM OIL PROCESSING EQUIPMENT		
Palm oil extractor (manual)	Crushes and presses the palm fruit in one operation **150 to 300 kg per hour**	450.000
Palm oil extractor (electrical or gasoline)	Crushes and presses the palm fruit in one operation **900 to 1100 kg per hour**	1.000.000
Palm oil extractor (diesel type)	Crushes and presses the palm fruit in one operation **900 to 1100 kg per hour**	1.100.000
Boiler (simple)	Cooks the palm fruits with vapour **300 kg of palm fruit between 30 to 45 mn**	250.000
Boiler (450 kg)	Cooks the palm fruits with vapour **450 kg of palm fruit between 30 to 45 mn**	475.000
Boiler (1 ton)	Cooks the palm fruits with vapour **1000 kg of palm fruit between 30 to 45 mn**	1.050.000
Separator (simple)	Cooks and separates oil from the water **300 kg to 450 kg of palm fruits**	250.000
Separator / dehydrator	Cooks, separate and dehydrates the oil for longer conservation **500 to 1000 liters per hour**	1.050.000
Palm kernel crusher	Breaks the nuts **500 to 800 kg per hour**	700.000
Palm fruit detacher (motorized)	Detaches the ripe palm fruits from the bunch **350 bunches per hour**	1.200.000
PALM KERNEL PROCESSING EQUIPMENT		
Chaff sorter	Separates the chaff and the nuts **500 to 800 kg per hour**	700.000
Palm kernel crusher	Breaks the nuts **500 to 800 kg per hour**	700.000
Palm kernel oil machine	Presses the kernel to extract the oil and separates the oil and cake **250 to 350 kg kernel per hour**	1.800.000
GARI PROCESSING EQUIPMENT		
Cassava grinder (motorized)	Grinds cassava **1000 kg tubers of cassava per hour**	800.000
Cassava presser	Presses ground cassava **150 kg at a time**	300.000
Cassava drencher	Drenches water from the cassava for starch **5 to 8 bags of 50 kg at a time**	150.000
Gari sifter	Sieves the dried cassava **200 kg at a time**	150.000

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Songhai Center — Appropriate Technology Division

ITEMS	CAPACITY	UNIT PRICE CFA
FEED MILL EQUIPMENT		
Electric Grinder-mixer	Grinds and mixes cereals at the same time **1 ton per hour**	1.400.000
Chips cutter (manual)	Cuts tubers into chips **50 kg per hour**	100.000
Pellet machine ELECTRIC	Produces pellet for fish and others animals **300 to 500 kg per hour**	700.000
Boiler	Produces vapour for the production of pellet **300 to 500 kg per hour**	850.000
DRIER		
Drier GEHO	Dries fruits, vegetables and cereals **150 to 500 kg per day**	2.000.000
Drier MAXICOQ	Dries fruits, vegetables and cereals **50 to 100 kg per day**	850.000
OTHER EQUIPMENT		
Electric or gasoline Groundnut Sheller	Shells the groundnuts **300 to 400 kg per hour**	1.000.000
Groundnut Sheller (manual)	Shells the groundnuts **100 kg per hour**	85.000
Sugar cane extractor (manual)	Extracts sugar cane juice **100 liters per hour**	350.000
Maize Sheller (manual)	Removed the maize seed from the cob **200 kg per hour**	450.000
Maize Sheller (motorized)	Removed the maize seed from the cob **800 kg per hour**	950.000
Incubator (kerosene)	Incubates fertile eggs **100 eggs**	300.000
Pedaling pump	draws water from the well to the farm **depth : 7 m**	80.000
Stainless bucket	For fetching water	12.000
Watering can	For garden use	12.500
FRUIT JUICE PROCESSING		
Electric cereal grinder	Grinds dry or wet tubers and cereals **250 to 500 kg per hour**	800.000
Stainless motorized cereal grinder	Grinds dry or wet tubers and cereals **250 to 500 kg per hour**	1.100.000
Stainless Fruit juice extractor	Grinds and extracts juices from fruits **500 to 800 kg per hour**	1.000.000
Stainless Juice Presser	Extracts fruit juice after grinding **10 kg at a time**	300.000
Stainless steamer	Steams the extracted juice **100 liters**	1.050.000
Boiler	Produces steam for pasteurizing the juice **60 LITERS**	2.000.000
Crown cover machine (manual)	Fixing crown on 33 cl bottles **200 bottles per hour**	55.000
Pasteurizer	Pasteurizes the bottles **400 bottles of 33 cl**	1.150.000

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Figure 34: Prices of locally produced machines for agriculture, Songhaï Centre, Porto Novo, Bénin (July 2010)

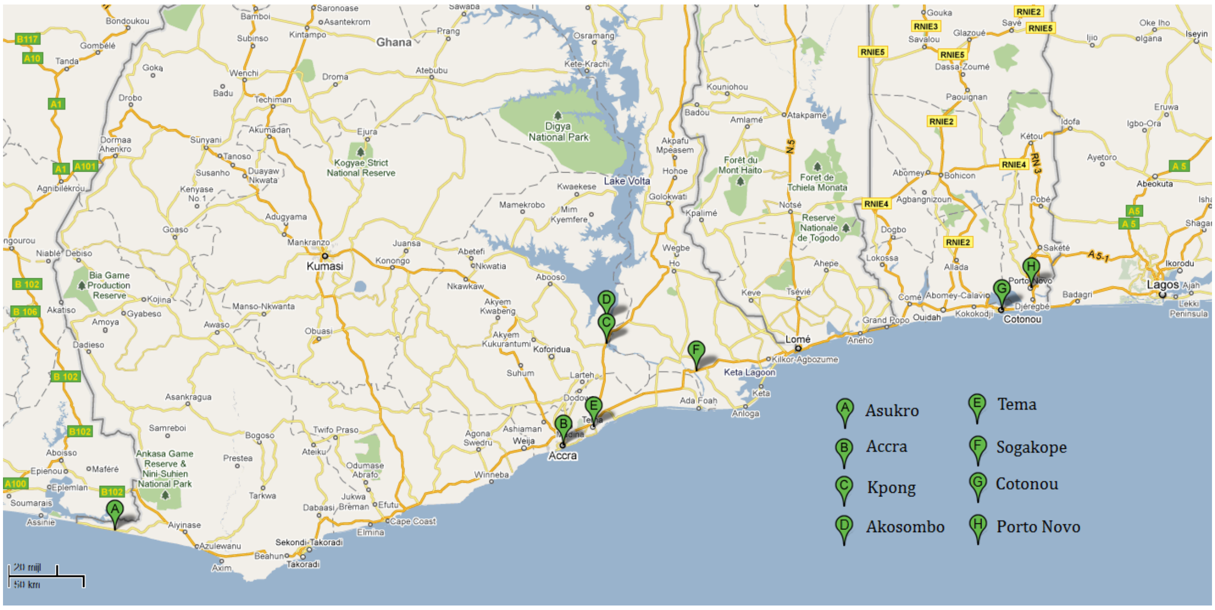

Figure 35: Locations of the visited places in Ghana and Bénin

Dimensions biogas digester Songhaï Centre	
Size digester:	20 m^3
Feedstock (per day):	
chicken and pig manure:	77 kg
E. crassipes and a bit chinese weed	2*77=154 kg

H_2O	2*(77+154)=462 L
Temperature Digester:	50-55°C
Pressure of biogas:	0,23 bar

Table 7: feedstock and technical values of biogas digester, Songhaï Centre, Porto Novo

Appendix II Calculations

All calculations made with Microsoft Excel 2007. In case of interest in the files please contact me via ottomaria@jandl.de.

Calculations for Technical Data:

Calculation BG requirement for cooking		
heat capacity H2O	*kJ / kgK*	4,187
cooking starting T	*°C*	25
heat requirement	*kJ / kg*	314,025
	kJ / L	314,025
	MJ / L	0,314025
H2O requirement / (person * day)	*L / (person*day)*	1
persons / household	*#*	6
energy requirement / household	*MJ / day*	1,88415
Lower Heating Value biogas	*MJ / m³*	22
efficiency cooking BG	*%*	15%
usable energy / m³ BG	*MJ / m³*	3,3
BG requirement / (household * day)	*m³ / day*	0,57
BG requirement / (person * day)	*m³ / day*	0,10

The calculation of the biogas requirement for cooking for one person per day is done assuming that one person needs to cook one liter of water per day and a starting water temperature of 25°C. The lower heating value of biogas refers to a methane content of 65%, while the efficiency of cooking can vary by the way of cooking. The table, furthermore, gives the daily biogas requirement for cooking per household. This result is taken into account in the calculations of the total daily biogas requirement (for cooking, lighting and electricity), which itself determines the required amount of biomass to meet the needs.

Calculations for CBA:

Calculations BG plant Songhaï		
Parameter	*unit*	value
size	*m³*	20
input	*TFM / day*	0,693
	m³ / day	0,693
retention time	*days*	29

To find a comparative retention time for the projected system the one of the Songhaï Centre has to be taken account. Knowing the size of the digester and the daily feed stock input, the retention time turns out to be 29 days, which are used to calculate the digester size.

Calculation digester dimensions		
	unit	value
Harvested amount of *E. crassipes*	*TFM / day*	10,7
Dry Matter Content (day of harvesting)	*%*	5%
Dry Matter Content (after 1 day of drying)	*%*	10%
Amount of *E. crassipes* (after 1 day of drying)	*TFM / day*	5,4

Rentention time	*days*	29
Size of biogas digestor fluid	*m³*	155
ratio space for biogas / space for fluid	*m³*	0,50
Size of biogas digestor biogas	*m³*	77
Digester Size	*m³*	232
chosen size		
digester size	*m³*	200
number of digesters	*#*	2
Digester dimensions		
assumption ratio digester length/diametre	*ratio*	6
bag diametre	*m*	3,49
bag length	*m*	20,93
Bag surface	*m²*	248,46

The 10,7 tons of fresh matter with a 5% of dry matter content harvested daily weigh half of it after one day of drying, doubling the dry matter content, now 10%. (derived from Oosterkamp, 2002) The calculation arrives at 155m^3 size for the fluid, assuming that it supposes 2/3 of the whole size, being 1/3 the size for the produced gas. Having estimated the required digester size at 232m^3, the chosen digester size for the community size is 400m^3, in case this size will be necessary on the longer term. As digester type a bag digester has been chosen due to its low price compared to other systems. Since, estimating a ratio length/diametre of 6, one digester would be too long and thick, two of 200m^3 each have been chosen. The surface of the digesters is used later for the calculation of its price (see „Calculations of Costs and Benefits“).

Calculation LPG requirement for cooking

parametre	unit	value
H2O requirement / (person * day)	*L / (person*day)*	1
efficiency cooking LPG	*%*	50%
cooking starting T	*°C*	25
heat capacity H2O	*kJ/kgK*	4,187
heat requirement	*kJ/kg*	314,025
	kJ/L	314,025
	MJ/L	0,314025
energy requirement for cooking / (household * day)	*MJ / day*	1,88
density LPG	*kg / m³*	553
Lower Heating Value LPG	*MJ / kg*	46,61
specific energy LPG	*MJ / kg*	23,30
LPG requirement / (household * day)	*kg / day*	0,08
mass cilindre LPG	*kg / cilindre*	14
duration cilindre LPG	*days / cilindre*	173

Based on a comment of one of the stakeholders of the harvesting group in Kpong, this calculation determines the lifetime of a LPG cilindre of 14kg, assuming again one liter of water to be cooked per person per day and 25°C starting water temperature. Also here the result depends on the efficiency of cooking (the better the stove, the higher the efficiency). Further use of this calculation is made in the calculations of savings on cooking fuel expenditure.

Calculation Fuel Consumption Grinder

parametre	unit	value
energy content Diesel	*MJ / L*	37,3
power grinder (30m³/h)	*kW*	3
daily grinder working time	*h / day*	6

grinder load rate	%	70%
efficiency mechanical conversion	%	20%
power grinder (2m³/h)	kW	1,5
energy content Diesel	kWh / L	10,4
net energy content Diesel	kWh / L	2,1
daily energy requirement for grinder	kWh / day	6,3
daily Diesel consumption	L / day	3,04
annual Diesel consumption	L / year	793

Scaling down the known power of a Diesel grinder with a grinding capacity of 30 m^3 / h to another one with 2 m^3 / h, that fits the projects requirement of 10,9 TFM / day = 1,82 TFM / h (1 TFM occupies approximately 1 m^3) it is determined how much fuel is consumed annually, which will be taken into account in the CBA as expenditure. Here the variables are the grinder's load rate and it's conversion efficiency.

Calculations of required Labour Force:

characteristics 3m*3m piece of plants		
parametre	unit	value
surface	m²	9
weight	kg FM	450

characteristics 0,4m*0,4m pieces of plants		
parametre	unit	value
surface	m²	0,16
weight	kg FM	8

distances		
parametre	unit	value
average distance plants to shore	m	50
distance shore - grinder	m	10
distance grinder - drying place	m	50
distance drying place - digester	m	50

In Kpong, Ghana, the harvesting group collects bigger 'pieces' (3m*3m) of floating weeds from where they are to find and bring them to the shore, where they are cut down to smaller 'pieces' of 0,4m*0,4m. Since this harvesting activity has been the only observed one the calculations of required labour are based on their 'business as usual'. Given values are the surfaces of the bigger and smaller 'pieces' of *E. crassipes* and its fresh matter weight. Input variables are the distances between the working spots. In function of those the required work force changes (the greater the distance the more workers are needed). The distances are also assumed based on field observations.

Working variables		
parametre	unit	value
working time	h / day	6
walking speed with full wheelbarrow	km / h	2
walking speed with empty wheelbarrow	km / h	4
capacity wheelbarrow	L	80
percentage work / working time	%	70%
cutting speed / person max	m / (min * person)	3

cutting speed / person min	*m / (min * person)*	1,5
cutting speed / person average	*m / (min * person)*	2,25

The calculations, furthermore, are done assuming the values of the 'Working variables' table. The 6h of daily working time is a result from field observations as well as the assumption of percentage working time. The calculations are highly sensitive to this percentage. Thus, it has to be studied more detailed which value meets reality the best. The cutting speed is an observational result based on own experiments both in the Netherlands and in Kpong, Ghana.

The required labour force for each step is calculated in terms of one person's daily capacity of cutting/grinding/transporting/… equivalent to m² water surface. It is to say, if one person, e.g., is able to transport 450 kg of fresh matter daily, this results in an equivalent water surface of 9 m² (see first table "characteristics 3m*3m piece of plants").

1. Collect & Transport to Shore

parametre	unit	value
average distance plants to shore (d1)	*m*	50
t_{GO}[26]	*min*	0,5
t_{CUT}[27]	*min*	2
$t_{TRANSPORT}$[28]	*min*	2,5
$t_{GO,CUT\&RANSPORT}$	*min*	5
Collecting and transporting capacity[29]	*m² / min*	1,8
	m² / h	108
	m² / day	648

2. Cut into 0,4m*0,4m pieces

parametre	unit	value
average cutting speed	*m / min*	2,25
meters to be cut[30]	*m*	45
$t_{CUTSMALL}$	*min*	20
Cutting capacity	*m² / (min * person)*	0,5
	*m² / (h * person)*	27
	*m² / (day * person)*	162

3. Transport pieces to grinder & feed it

parametre	unit	value
distance Shore grinder	*m*	10
Capacity Wheelbarrow	*kgFM*	70[31]
$t_{FILLING}$[32]	*min*	0,5
t_{FULL}[33]	*min*	0,3
t_{EMPTY}[34]	*min*	0,3

26 $tGO = \frac{d1}{100}$, observation: 1 min per 100 m
27 observation
28 $tTRANSPORT = \frac{d1}{20}$, observation: 5 min per 100 m
29 $capacity = \frac{1\ piece\ 3x3}{tGO, CUT\ \&TRANSPORT} * \frac{surface\ \ 3x3}{1piece\ 3x3}$
30 Meters to be cut by cutting a 3m*3m piece into 0,4m*0,4m pieces
31 Estimation of plant mass in one wheelbarrow, about 6 0,4m*0,4m pieces
32 Time for filling one wheelbarrow = 0,5 min
33 Walking time with full wheelbarrow, including the filling of the wheelbarrow
34 Walking time with empty wheelbarrow

$t_{FEEDING}$ [35]	*min*	2,0
$t_{TRANSPORTTOGRINDER}$	*min*	3,1
Transporting&Grinding Capacity	*m² / (min * person)*	0,45
	*m² / (h * person)*	27
	*m² / (day * person)*	163

4. Transport pieces to drying place		
parametre	*unit*	value
distance grinder - drying place	*m*	50
Capacity Wheelbarrow	*kgFM*	70
$t_{FILLING}$ [36]	*min*	0,5
t_{FULL} [37]	*min*	1,5
$t_{EMPTYING}$ [38]	*min*	0,2
t_{EMPTY} [39]	*min*	0,8
$t_{TRANSPORT2}$	*min*	2,9
Transporting Capacity	*m² / (min * person)*	0,48
	*m² / (h * person)*	28,8
	*m² / (day * person)*	173

5. Transport pieces to digester & feed it		
parametre	*unit*	value
distance drying place - digester	*m*	50
Capacity Wheelbarrow	*kgFM*	70
$t_{FILLING}$	*min*	0,5
t_{FULL}	*min*	1,5
t_{EMPTY}	*min*	0,8
$t_{FEEDING}$ [40]	*min*	0,2
$t_{TRANSPORT3}$	*min*	2,4
transporting capacity	*m² / min*	0,3
	m² / h	17
	m² / day	104

The comparison of labour capacity per step leads to the following table:

Labour Force Requirement	
	m² / day optimum
to be harvested daily	
1. Cut & Transport to Shore	648
2. Cut into 0,4m*0,4m pieces	162
3. Transport pieces to grinder & feed it	163
4. Transport pieces to drying place	173
5. Transport pieces to digester & feed it	104

Assuming that a 70% (based on observations) of the 6h working time is actually used for the labour the following table gives an overview over the labour force needed per step and the amount of cutting machines, wheelbarrows and shovels needed.

[35] One person is assumed to be able to feed 3 pieces of 8kg in a minute to the grinder
[36] Time for filling one wheelbarrow = 0,5 min
[37] Walking time with full wheelbarrow
[38] Time of emptying the wheelbarrow = 10 s
[39] Walking time with empty wheelbarrow
[40] Time of emptying the wheelbarrow into the inlet tank of the digester = 10 s

Labour Force Requirement	*m² / day optimum*	*m² / day real*	*% of daily need*	*requirement*	*required workers*	bottleneck?
to be harvested daily		217				
Cut & Transport to Shore	648	454	209%	1	3	108,74%
Cut into 0,4m*0,4m pieces	162	113	52%	2	2	4,37%
Transport pieces to Grinder & feed it	163	114	52%	2	2	4,75%
Transport pieces to drying place	173	121	56%	2	2	11,33%
Transport pieces to digester & feed it	104	73	34%	3	3	0,77%
				total required workers:	12	

Equipment Requirement	*required cutting machines*	*required wheelbarrows*	*required shovels*
Cut & Transport to Shore	1		
Cut into 0,4m*0,4m pieces	2		
Transport pieces to Grinder & feed it			2
Transport pieces to drying place		2	2
Transport pieces to digester & feed it		3	3
	3	5	7

The capacity of the first step's workers overcomes the biomass to be harvested daily. Therefore two men for driving the boats and one cutter are enough. One worker of the second, third or third step would not be able to meet the requirement, hence two workers are needed at each step. For the last step even three workers are necessary, what makes a total of 12 workers. Nevertheless, it should be thought about contracting one more worker for each of the cuttings at the shore, the transportation and feeding to the grinder and the transporting and feeding to the digester as the calculated labour force overcomes just the daily threshold of 217m² in the mentioned steps (see 'Bottleneck?'). Furthermore, 3 cutting machines, 5 wheelbarrows and 7 shovels will be needed for the 12 workers.

Detailed Calculations of Costs and Benefits:

Currency Equivalents		
	EUR	1
Bénin[41]	*CFA*	655,957
Ghana[42]	*GHS*	1,7
USA	*USD*	1,27

The Cost Benefit Analysis takes into account prices of different parts of the project in different currencies. This table gives an overview over the current exchange rates.

INVESTMENT

41 The currency in Bénin, CFA, is directly linked to the EUR.
42 GHS to EUR and USD to EUR rates from June, 2010

Generator		
parametre	*unit*	value
price per 30kW generator[43]	*USD / 30kW*	14.768
price per kW	*USD / kW*	492
	GHS / kW	659
price Generator	*GHS*	16.473
Cost Electricity Grid[44]		
	USD / HH	100
	GHS / HH	134
	GHS / community	13.386
Digester		
parametre	*unit*	value
price surface digester	*€ / m²*	12
price digester WR	*USD / m³*	20
price digester Tecogas	*€ / m³*	30
price digester vdW (10m³)	*USD / m³*	50
price digester vdW (100m³)	*USD / m³*	105
price digester by surface	*GHS*	10.137
price digester thesis (price WR)	*GHS*	10.709
price digester thesis (price Tecogas)	*GHS*	9.449
price digester thesis (price vdW) (10m³)	*GHS*	26.772
price digester thesis (price vdW) (100m³)	*GHS*	56.220
chosen price		
price Digester[45]	*GHS*	10.709
pipes, pumps, other assecoires		
	GHS	5354
price pipes, pumps, other assecoires[46]	*GHS*	5.354
Grinder		
parametre	*unit*	value
price per grinder with 30m³/h capacity	*€*	15.000
price grinder / (m³/h capacity)	*€ / (m³/h)*	500
	GHS / (m³/h)	850
price Grinder	*GHS*	1.700
Hedge Cutters		
parametre	*unit*	value
Price / Hedgecutter[47]	*€*	180
	GHS	306
required Hedge Cutters	*#*	3
price Hedge Cutters	*GHS*	918
Wheelbarrows		
parametre	*unit*	value

43 The price for a 30kW generator by a Chinese Producer is taken as a reference (source: van der Wal)
44 The grid price is estimated as 100 USD / household, on the basis of a Fact report.
45 Different prices of bag digesters are compared (sources van der Wal, Rijssenbeek, Tecogas). For further calculations, in accordance with Fact, the price of 20USD / m^3 will be used.
46 The price of all the assecoires for the digester is estimated as half the digester cost.
47 Motomix Stihl, bought in the Netherlands in May, 2010

price per Wheelbarrow (80L)[48]	€	30
	GHS	51
required Wheelbarrows	#	5
price Wheelbarrows		255
Shovels		
parametre	unit	value
price per Shovel[49]	USD	7
	GHS	9,4
required Shovels	#	7
price Shovels	GHS	66
TOTAL INVESTMENT	GHS	48.861

The total investment cost is 48.861 GHS (36.502 USD), representing the generator with 16.473 GHS (12.306 USD), the Electricity Grid with 13.386 GHS (10.000 USD) and the digester with 10.709 GHS (8.000 USD) the highest costs.
Gas stoves for the houses, as well as LEDs and fridges are not included in the investment in order to keep the investment costs low and, consequently, make the project more attractive to investors.

OPERATIONAL COSTS

Labour Costs[50]					
parametre	working days[51]	required workers	days to be paid	Labour Costs	
unit	days / week	#	days / year	GHS / day	GHS / year
Cut & Transport to Shore	5	3	780		
Cut into 0,4m*0,4m pieces	5	2	520		
Feed the Grinder	5	2	520		
Transport pieces to drying place	5	2	520		
Transport pieces to digester & feed	7	3	1092		
		total to be paid per year	3.432	4	13.728

Gasoline Cost Hedge Cutter[52]		
parametre	unit	value
Fuel Price	GHS / L	1
Fuel Consumption[53]	L / h	0,742
cutting time	h / day	8,9
Fuel Consumption	L / day	6,6
Gasoline Cost Hedge Cutter	GHS / day	6,6
	GHS / year	1.713

Diesel Cost Grinder		
parametre	unit	value

[48] Source: ebay.de
[49] Source: nextag.com
[50] The labour costs derive from a salary of 4 GHS per worker for a 6h working day.
[51] The feeding of the digesters has to be done daily, the rest of the workers work 5 days a week.
[52] The cutters work 5 days per week (=5/7*365 days)
[53] Own experimentation, calculations to be found in the Appendix

annual Diesel consumption[54]	*L / year*	793
Diesel Price	*GHS / L*	1
Diesel Cost Grinder	*GHS / year*	793
Maintenance		
parametre	*unit*	value
Maintenance	*GHS / year*	2.443
TOTAL OPERATIONAL COSTS	*GHS / year*	18.651

The total annual operational costs are 18.651 GHS (13.933 USD), being the labour costs with 13.728 GHS (10256 USD) the most important contributor by far.
The losses in fishing income (or any other loss in income) as well as time costs are not included.

SAVINGS		
savings in cooking		
parametre	*unit*	value
Cost of Firewood	*GHS / (day * household)*	1
% of users	*%*	45%
Annual Savings in Firewood / Community	*GHS / year*	16.425
Cost of Charcoal	*GHS / (2 weeks * household)*	7
% of users	*%*	50%
Annual Savings in Charcoal / Community	*GHS / year*	9.100
Cost of LPG	*GHS / 14kg Cilindre*	22
% of users	*%*	5%
Annual Savings in LPG / Communtiy	*GHS / year*	232
savings in cooking	*GHS / year*	25.757
savings in lighting		
parametre	*unit*	value
Cost of Kerosene	*GHS / gallon*	5
Kerosene Requirement	*gallons / (household * month)*	1
	*gallons / (community * month)*	100
Annual Savings in Kerosene / Community	*GHS / year*	36.500
Cost of Batteries[55]	*GHS / battery*	1
Battery requirement	*batteries / (household * month)*	0
	*batteries / (community * year)*	0
Annual Savings in Batteries / Community	*GHS / year*	0
savings in lighting	*GHS / year*	36.500
electricity[56]		
electricity price	*GHS / kWh*	0,195
VAT	*%*	15%
Annual Savings in Electricity	*GHS / year*	2.575
TOTAL SAVINGS	*GHS / year*	62.257

54 The grinder works 5 days per week
55 Unknown price, no use of batteries in Asukro
56 Savings in electricity are virtual since the communities do not have electricity

The total annual savings by using biogas for cooking and lighting are 62.257 GHS (46.509 USD), being the savings in expenditure on cooking 25.757 GHS (19242 USD) and the savings in expenditure on lighting 36.500 GHS (27.268 USD) per year.

The savings in cooking are estimated on an observational basis, assuming that one household uses only one cooking fuel. In Kpong most of the people cook on charcoal, the poorest have to cook on firewood (1GHS), because they can't afford the 7GHS investment for a charcoal bag. LPG is used by very few, although the cheapest option.

INCOME		
Income by selling sludge as fertilizer		
parametre	*unit*	value
Average Nutrient Prices on the Ghanaian market[57]		
parametre	*unit*	value
price N	*€ / kg*	0,39
price P	*€ / kg*	1,44
price K	*€ / kg*	1,06
price N	*GHS / kg*	0,66
price P	*GHS / kg*	2,45
price K	*GHS / kg*	1,80
World market prices		
parametre	*unit*	value
price N	*USD / t*	338
price P	*USD / t*	1.245
price K	*USD / t*	917
price N	*GHS / kg*	0,45
price P	*GHS / kg*	1,67
price K	*GHS / kg*	1,23
Nutrient Content of *E. crassipes*[58]		
N Content	*%*	3,80%
P Content	*%*	1,10%
K Content	*%*	5%
Fertilizer Market Value	*GHS / kgDM*	0,08
Fertilizer Market Value	*GHS / TDM*	83,66
Benefits of Selling Fertilizer	*GHS / year*	10.579
TOTAL INCOME	*GHS / year*	10.579

The potential annual income, without selling biogas or electricity, rises to 10.579 GHS (7.903 USD).

57 Source: Drewko, 2010
58 Source: John, 1984

CBA Overview in USD (Ghanaian Investor)

COSTS BIOGAS PROJECT

parametre	unit	value
Investment		
biogas generator	USD	12.307
electricity grid	USD	10.000
biogas digester	USD	8.000
pipes, other assecoires	USD	4.000
grinder	USD	1.270
hedge cutters	USD	686
wheelbarrows	USD	191
shovels	USD	49
TOTAL INVESTMENT		36.502
Operational Costs		
labour costs	USD / year	10.256
Gasoline Cost for Cutters	USD / year	1.279
Diesel Cost for Grinder	USD / year	592
maintenance	USD / year	1.825
TOTAL COSTS	USD / year	13.952

ECONOMIC & FINANCIAL VALUES

parametre	unit	value
project duration	years	5
inflation rate (p)	%	19,6%
nominal interest rate (i)	%	25%
real interest rate ®	%	4,52%
population growth	%	2,50%

BENEFITS BIOGAS PROJECT

parametre	unit	value
Savings		
cooking	USD / year	19.242
lighting	USD / year	27.268
TOTAL SAVINGS	USD	46.510
Income		
fertilizer	USD / day	0
gas	USD	0
electricity	USD	0
TOTAL INCOME		0
TOTAL BENEFITS	USD / year	46.510

NON FINANCIAL Cash Flow *Constant Prices*

year	Costs	Benefits	Net Cash Flow	Discount factor	non-fin CF	cum. non-fin CF
	USD	USD	USD		USD	USD
0	36.502		-36.502	1,00	-36.502	-36.502
1	14.301	47.672	33.371	0,96	31.930	-4.572
2	14.659	48.864	34.205	0,92	31.314	26.742
3	15.025	50.086	35.061	0,88	30.710	57.452
4	15.401	51.338	35.937	0,84	30.118	87.570
5	15.786	52.621	36.836	0,80	29.537	117.107

FINANCIAL Cash Flow *Current Prices*

year	Loan	Repayment	Interest on loan	Discount Factor	financial CF	cum. Financial CF
		USD	USD		USD	USD
0	48.669			1,00	48.669	48.669
1		-9.734	-12.167	0,80	-17.521	31.148
2		-9.734	-9.734	0,64	-12.459	18.689
3		-9.734	-7.300	0,51	-8.722	9.967
4		-9.734	-4.867	0,41	-5.980	3.987
5		-9.734	-2.433	0,33	-3.987	0

TOTAL Cash Flows *Current Prices*

year	CF	cum. CF
	USD	USD
0	12.167	12.167
1	14.409	26.576
2	18.855	45.431
3	21.989	67.419
4	24.138	91.557
5	25.550	117.107

Investment Values

parametre	unit	value
IRR	%	89,71%
Pay Back Period	years	2
NPV	USD	117.107

CBA Overview in USD (Dutch investor)

COSTS BIOGAS PROJECT		
parametre	*unit*	value
Investment		
biogas generator	*USD*	12.307
electricity grid	*USD*	10.000
biogas digester	*USD*	8.000
pipes, other assecoires	*USD*	4.000
grinder	*USD*	1.270
hedge cutters	*USD*	686
wheelbarrows	*USD*	191
shovels	*USD*	49
TOTAL INVESTMENT		36.502
Operational Costs		
labour costs	*USD / year*	10.256
Gasoline Cost for Cutters	*USD / year*	1.279
Diesel Cost for Grinder	*USD / year*	592
maintenance	*USD / year*	1.825
TOTAL COSTS	*USD / year*	13.952

ECONOMIC & FINANCIAL VALUES		
parametre	*unit*	value
project duration	*years*	5
inflation rate (p)	*%*	1,2%
nominal interest rate (i)	*%*	2,56%
real interest rate ®	*%*	1,34%
population growth	*%*	2,50%

BENEFITS BIOGAS PROJECT		
parametre	*unit*	value
Savings		
cooking	*USD / year*	19.242
lighting	*USD / year*	27.268
TOTAL SAVINGS	*USD*	46.510
Income		
fertilizer	*USD / day*	0
gas	*USD*	0
electricity	*USD*	0
TOTAL INCOME		0
TOTAL BENEFITS	*USD / year*	46.510

NON FINANCIAL Cash Flow *Constant Prices*

year	Costs	Benefits	Net Cash Flow	Discount factor	non-fin CF	cum. non-fin CF
	USD	*USD*	*USD*		*USD*	*USD*
0	36.502		-36.502	1,00	-36.502	-36.502
1	14.301	47.672	33.371	0,99	32.929	-3.573
2	14.659	48.864	34.205	0,97	33.304	29.731
3	15.025	50.086	35.061	0,96	33.684	63.415
4	15.401	51.338	35.937	0,95	34.069	97.484
5	15.786	52.621	36.836	0,94	34.457	131.941

FINANCIAL Cash Flow *Current Prices*

year	Loan	Repayment	Interest on loan	Discount Factor	financial CF	cum. Financial CF
		USD	*USD*		*USD*	*USD*
0	37.461			1,00	37.461	37.461
1		-7.492	-959	0,98	-8.240	29.221
2		-7.492	-767	0,95	-7.852	21.369
3		-7.492	-575	0,93	-7.478	13.890
4		-7.492	-384	0,90	-7.118	6.772
5		-7.492	-192	0,88	-6.772	0

TOTAL Cash Flows *Current Prices*

year	CF	cum. CF
	USD	*USD*
0	959	959
1	24.688	25.647
2	25.452	51.100
3	26.206	77.305
4	26.950	104.256
5	27.686	131.941

Investment Values		
parametre	*unit*	value
IRR	*%*	89,71%
Pay Back Period	*years*	2
NPV	*USD*	131.941

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