Valorization of water hyacinth as a renewable source of animal feed and biogas: a business case for Lake Victoria, Kenya

25/01/2015 V.A. Valk

In collaboration with Wageningen University for a double degree

Delft University of Technology

Challenge the future

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Abstract

This thesis is conducted for Royal IHC and Witteveen+Bos. Royal IHC is a Dutch ship builder and Witteveen+Bos an engineering consultant. Both companies have encountered the problems of water hyacinth.

Water hyacinth, *Eichhorni Crasippus*, is an aquatic weed which is widespread throughout the tropics and subtropics. It is an invasive species in most parts of the world and has a large impact on the local ecology, economy, livelihood and safety of people. Water hyacinth can be controlled by mechanical harvesting. Once the plant is harvested the biomass can be used as a resource. The aim of this research is to assess the potential value of the water hyacinth as a renewable resource and determine if it is economically feasible to process water hyacinth on an industrial scale, more than one hectare harvest a day. In order to assess the economic feasibility of water hyacinth usage, a literature study was conducted to evaluate the characteristics of the plant and define the processing options. Secondly a canvas business model and a cost-benefit analysis were made to assess the value chain and the theoretical feasibility of an investment in a large scale water hyacinth processing project. The final and third step was a business case based on a field trip to Kenya, to validate the theoretical business model and cost benefit analysis.

Water hyacinth is a very fast growing plant which reproduces both sexually and vegetativly. The plant is so successful because it can adapt easily to its environment. The plant thrives in eutrophicated and polluted water bodies. In these water bodies heavy metals are taken up by the plant and these have to be taken into account for usage of the biomass. The biomass of water hyacinth can be used for three purposes 1) energy 2) agriculture and 3) industry. The biomass is least valuable when it is used for its minerals, for biogas and energy production. Based on the literature review it was found that water hyacinth can best be used for the production of 1) animal feed 2) biogas and 3) fertilizer. The business models for these three products were assessed because of the high value of the end products and the feasibility of production in developing countries. For the processing of water hyacinth into animal feed, the leaves and the roots should be separated as animal feed can only be produced from the leaves. The roots and shoots can be separated during harvest by specialized equipment.

A business canvas was used to describe a business model for a company processing water hyacinth. The business models can vary because the location and water bodies where the weed grows are different. It was found that large scale processing is mostly feasible in big lake structures because of the availability of biomass. To evaluate if an investment in water hyacinth processing facilities is feasible the Net Present Value (NPV) was calculated. From the theoretical cost benefit analysis it could be concluded that water hyacinth processing is feasible for the production of animal feed, biogas and fertilizer. The production of electricity and compost is not economically feasible because of low prices and low efficiency.

To validate the assumptions made for the theoretical business model a business case was conducted in Kisumu, Kenya. For the business case, market data was assessed on local markets and all main stakeholders were interviewed. The market prices found are variable. A Monte Carlo simulation was therefore conducted. It is concluded that a water hyacinth processing plant is economically feasible. The internal rate of return determined in the business case was higher than found in the theoretical model. This can be explained by high demand and prices for animal feed and cooking gas. There is a large milk deficit in the case study area and dairy projects are likely to be started. Animal feed is however a constraint in the area. Local governments are therefore interested in production of animal feed from the weed. The local authorities are also interested in removal of water hyacinth because of the negative impacts of the plant, in particular the blocking of waterways. There is however no budget for removal of the plant. Water hyacinth usage is not propagated by the national government because of concerns that the problem of water hyacinth will increase if a commercial use is found. The plant is not abundant throughout the year in Lake Victoria because it infests the lake in cycles.

It is concluded that it is economically feasible to process water hyacinth into animal feed, biogas and fertilizer. Using water hyacinth to produce agricultural products will stimulate agriculture development and use nutrients to the best potential. Year round availability of water hyacinth for processing is however a problem. Cultivation of water hyacinth and alternative biomass sources need to be assessed. The processing of water hyacinth into animal feed is particularly recommended because it is the most valuable product. There will also be opportunities in the future for animal feed because of expected scarcity of animal feed. More research is needed for adapting harvesting equipment. For a pilot project a partner has to be selected as water hyacinth processing is not the core business of IHC or Witteveen+Bos. Partnerships with corporates in the feed and dairy industry should be evaluated. The whole value chain can then be established by processing water hyacinth into animal feed.

Key words: Water hyacinth, Aquatic weed harvesting, Biomass processing, Biogas, Animal feed, Canvas Business model, Cost-benefit

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This thesis is the last hurdle for finishing my Master Programs. This thesis gave me the opportunity to challenge myself, go abroad and to meet a lot of new great people from different nationalities and disciplines. This thesis would not have been possible without the funding and guidance of Royal IHC and Witteveen+Bos. I would like to thank both companies for the guiding and opportunities they have given me.

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I could not have made this thesis without the support of many people in Wageningen, in Delft and in Kenya. I would like to thank a few people in particular. First of all my supervisor from Royal IHC, Bart Hogeweg, for giving my guidance and the facilities to conduct my research. Secondly, I would like to thank Serio Ooijens for his valuable input, good conversation and dedication to start using water hyacinth. I would also like to express my gratitude to Rob Dijcker from Witteveen+Bos for his support. Niels van Stralen thanks for helping me to get familiar in the world of biomass processing.

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List of abbreviations

BCF	Bio Concentration factor
BMU	Beach Management Unit
CAPEX	Capital Expenses
DM	Dry Matter
FW	Fresh Weight
FAO	Food and Agriculture Organization of the United Nations
IRR	Internal Rate of Return
LVEMP	Lake Victoria Environmental Management Program
MTI	MTI Holland
NPV`	Net Present Value
OPEX	Operational Expenses
TA	Translocation Ability
UNEP	United Nations Environmental Program
UN	United Nations
W+B	Witteveen + Bos
WASH	Water, Sanitation and Hygiene

1 Introduction

The water hyacinth, *Eichhornia Crassipes*, is a free floating aquatic weed originating from South America. It can be recognized by its large swollen leaves and violet flowers arranged in spikes (Gopal 1987). Mankind introduced water hyacinth all over the world because of its beautiful appearance. The water hyacinth could however not be controlled by man and spread all over the tropics and sub tropics due to its fast reproduction and lack of natural enemies (Luo *et al*. 2011). Because the water hyacinth can reproduce through vegetative and sexual means, the plant is very difficult to control (Gunnarsson and Petersen 2007) It is an invasive species in most parts of the world. It can have a large impact on the local ecology, economy, livelihood and safety of people (Villamagna and Murphy 2010). In figure 1 the problem of water hyacinths mats is shown in for pictures.

The water hyacinth is considered to be responsible for reduction of biodiversity. Once introduced, it takes over the whole environment blocking waterways, rivers, irrigation canals and lakes. Ships and boats used for fishing and transportation have severe problems with their navigation because of water hyacinth mats. Fishermen have problems reaching the fishing grounds resulting in loss of livelihood. Water hyacinth can also block irrigation canals reducing the water flow resulting in poor irrigation and floods. These blockages are also problematic for hydropower generation (Albright *et al*. 2004).

A B

C D

Figure 1. A. Water hyacinth harvesting in Lake Victoria; B Water hyacinth infestation in an hydropower dam, China; C Mechanical Water hyacinth Harvesting; D Water hyacinth mats block a harbour and shipping route.

Water hyacinth mats are a perfect breeding place for mosquitos and other vectors of several diseases such a malaria, bilharzia, dengue and river blindness (Abdelhamid and Gabr, 1991). For that reason, the control of water hyacinth contributes to the health and safety of the people.

There is a lot of investment in the control of water hyacinth. The costs of control in China alone are estimated to be around one billion dollars annually (Theur, 2013).Water hyacinth can be controlled by different methods: mechanical control, biological control, chemical control and integrated management.

According to Gunnarsson (2007), mechanical control has several advantages:

- Superfluous nutrients are removed by removal of water hyacinth biomass
- Immediate results and limited damage to the ecosystem
- The water body can be used more widely once the plant is removed
- Mechanical harvesting can be done both in open flows and closed water systems
- The harvested water hyacinth can be used for several purposes

There are several opportunities for exploitation of the biomass of the harvested water hyacinth. Water hyacinth biomass has been used as feed for free ranging cattle. The use as feed can contribute to solve parts of the nutritious problem in developing countries(Malik 2007). Water hyacinth grows very well in areas where eutrophication takes place (Wang *et al*. 2012). The nutrients which are taken up by the water hyacinth from the water can be used as fertilizer for small holder farmers. Another option is to use the biomass for energy production. The biomass can be carbonized to charcoal or densified fuel or fermented to biogas (Gopal 1987).

Mechanical control is done by several machines such as weed harvesters, crusher boats and destruction boats. The problem is however that mechanical control is expensive. It is estimated that mechanical control costs approximately US dollar 600-1200 per hectare (Theur 2013). Because there are several opportunities for the use of the biomass there might be a possibility to economically harvest water hyacinth mechanically

Royal IHC is a Dutch company which builds specialized ships and equipment for 'wet' mining, dredging and complex off shore activities. During its dredging and mining operations the problem of the water hyacinth is often recognized. Royal IHC is therefore interested in the control of water hyacinth. Royal IHC has been involved in water hyacinth harvesting projects in Ghana in the past. The focus of Royal IHC during this project was the harvesting of water hyacinth, not the utilization of the harvested biomass. For future projects Royal IHC wants to gain more knowledge in the use of water hyacinth biomass to be able to advise their customers.

From literature it was concluded that, depending on environment, the content of minerals and especially of heavy metals in water hyacinth can be highly variable. It is therefore important to understand the different characteristics of the water hyacinth. Depending on the chemical content, different options for utilization may be considered.

1.1 Motivation

Since the latter of half of the 20th century a lot of research (Gopal 1987) (Center and Spencer) on water hyacinth control has been conducted in several countries throughout the (sub-) tropics. There are however no successful solutions found to eradicate and control water hyacinth. As water hyacinth could not be eradicated the potential uses of biomass were investigated. From literature it can be concluded that water hyacinth can be processed into several products. There have been several small scale projects for the production of biogas from water hyacinth biomass (Pyöry, 2014) (Serigas, 2014).

In literature no large scale projects have been described. Furthermore, most projects have been focused on the production of biofuels, fertilizer and fibers. The extraction of proteins has only been described in literature but never executed. Small scale bio refineries for grass and other aquatic crops have been developed in the last years such as Grassa and ABCKroos. The extraction of specific proteins and other substances from water hyacinth might be very profitable in the near future. The aim of this thesis is to assess if large scale processing of water hyacinth is feasible and what conditions are required to make processing successful.

Based on this research specialized harvest equipment can be built by Royal IHC. The specialized equipment can contribute to the processing of the weed by some form of pre-treatment. During this research specific requirements for harvesting equipment can be defined.

1.2 Aim and Objectives

The goal of this thesis is to determine a sustainable and profitable method to harvest and utilize water hyacinth as an integrated part of solving the water hyacinth problem.

The three main objectives of this thesis are:

1) Deciding which products can best be developed from water hyacinth biomass. This decision will be based on the characteristics of the water hyacinth and the latest techniques in biomass processing. For each utilization option the different processes from harvest to final product will be identified. Based on this potential adaptations in the pre-treatment and processing can be identified.
2) Identify the economic feasibility and potential profit or losses for different processing options and capacities. To be able to identify the economic feasibility a business model including an economic model will be developed.
3) Map the different stakeholders in a local business case and list their support for the development of a water hyacinth processing project.

The local business case will also be used to validate the assumptions made in the economic model.

1.3 Research Questions

To be able to achieve these goals the following questions need to be answered:

Main research question: is it feasible to develop a large scale water hyacinth harvesting and processing project? Large scale is defined as on operation which requires at least daily harvest of one hectare.

To gain a deeper insight in the possibilities of processing of water hyacinth the properties of the plant and latest biomass processing techniques are of importance. Therefore the following sub questions were developed:

1. What are the general characteristics of the water hyacinth?
2. What is the current approach to control the water hyacinth?
3. What are the options and processes to utilize the biomass of water hyacinth?

In order to answer the main research question the economics of water hyacinth harvesting and processing have to be assessed.

4. What is the economic impact of the water hyacinth?
5. What is the possible value and map the value chain of water hyacinth biomass?

1.4 Hypotheses

As there are lots of uncertainties and new techniques, an investor for a project will be hard to find. With governmental support a project will however be feasible. The use of water hyacinth will be economically feasible. As there will be a lot of development in the near future in biomass refinement, water hyacinth utilization will most likely get more profitable when these techniques become available for use in developing countries.

1.5 Thesis Outline

In order to assess economic feasibility of water hyacinth usage a literature study is conducted to evaluate the characteristics of the plant and the processing options. A business model and cost benefit analysis are conducted to assess the value chain and the theoretical feasibility of an investment in a large scale water hyacinth processing project. The final and third step was a business case based on a field trip to Kenya to validate the theoretical business model and cost benefit analysis. Figure 2 shows the subjects described per chapter.

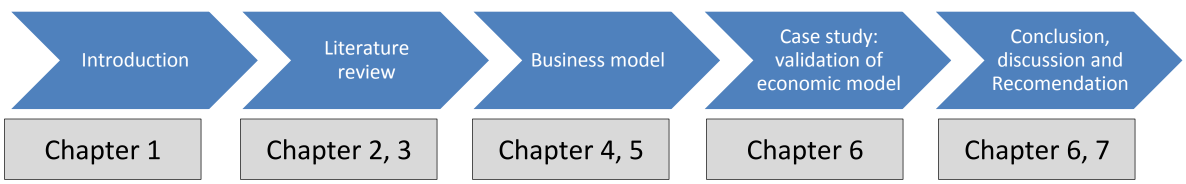


Figure 2. The subjects per chapter in the thesis

1.6 Research Scope and Limitations

The scope of this thesis is the harvesting processes of water hyacinth and the utilization of the biomass harvested. There is a lack of knowledge about the value chain and possible value streams of the water hyacinth. A business case is part of this study, to determine the value chain and value streams of water hyacinth harvesting and utilization. The technical design of harvesting equipment is however not be in scope. In figure 3 the scope of the project per section can be found.

Some of the topics that are out of scope are due to time limitations, eg the chemical content and growth of the plant at Lake Victoria. Other things that are out of scope are due to decisions made during this thesis because of technical and economical feasibility.

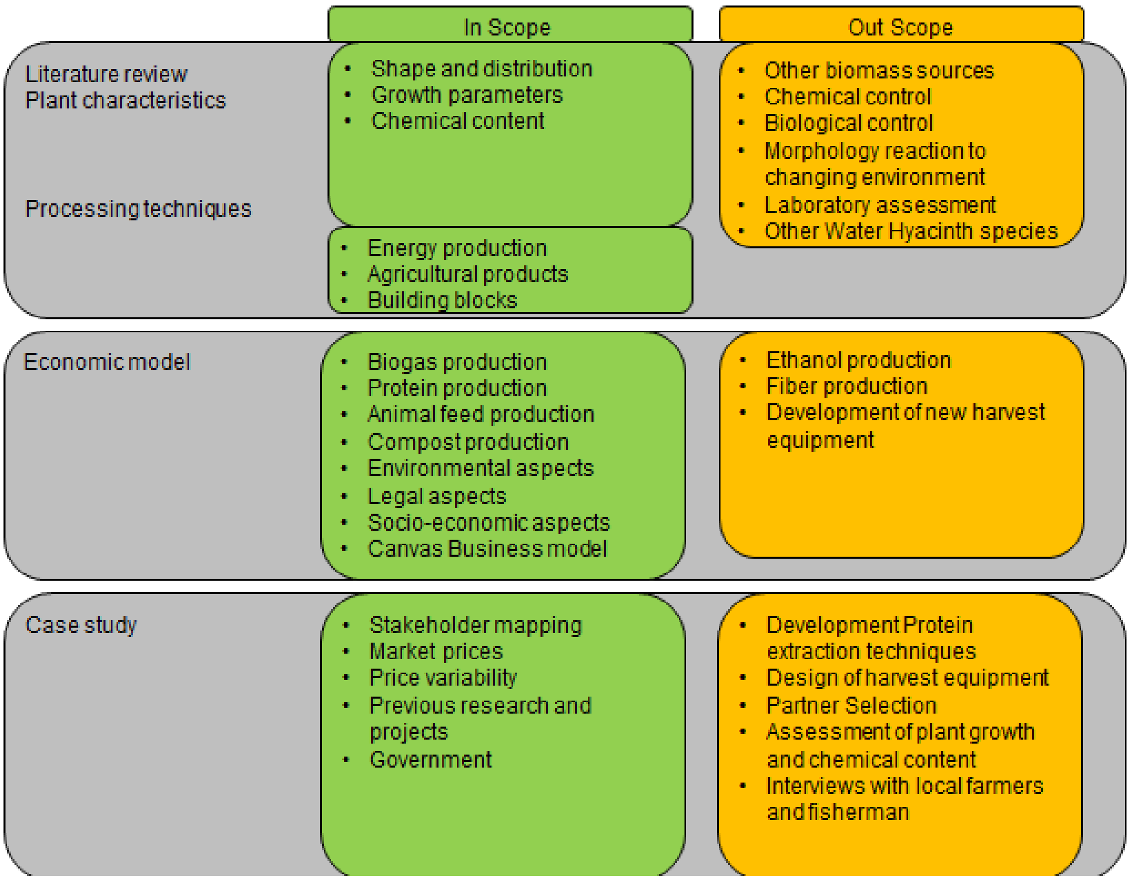


Figure 3. Scope of the thesis and limitations

1.7 Stakeholders and work division thesis

There were several stakeholders involved in this thesis project. This thesis was carried out for Royal IHC. From within Royal IHC there are several departments involved and interested in this thesis project.

Within Royal IHC, the thesis was written for the Mineral Technological Institute (MTI) and in particular mining advisory services. MTI is the R&D department of Royal IHC. The project supervisor from within the company was Bart Hogeweg, a consultant of mining advisory services.

Sergio Ooijens works for Royal IHCs dredging department as manager business development. Sergio's goal is to give an economic value to waste products of the dredging process. Currently water hyacinth is one of these waste products. He is therefore very keen in finding a solution for harvesting of water hyacinth. Sergio has been involved in water hyacinth harvesting projects in the past.

From a Sustainability perspective this thesis project is also interesting. Aleyda Ortega project leader R&D sustainability will be involved in this project. This sustainability team did however not have a lot of influence in this project. From within IHC there are already several stakeholders and it was decided that sustainability is not a deciding stakeholder.

The Business case is conducted in Africa. The Area Manager Africa, Praveen Badloo, of IHC was involved in the business case. Water hyacinth is a problem in most parts of Africa. It is therefore an interesting project for the area Africa manager.

IHC Merwede cooperates with Witteveen+Bos a Dutch engineering consultant. Witteveen+Bos gives advice in issues related to environment, water, energy and infrastructure. Witteveen+Bos has encountered the water hyacinth in several projects in Africa and Asia and have performed a pre-feasibility study for water hyacinth digestion in Rwanda. Rob Dijcker (consultant in waste management) represented Witteveen+Bos in this project. Furthermore, also Mark van der Werf (biogas expert) and Anna Veldhoen (biorefinery expert) from W+B were consulted on their specific expertise.

The international council for research in Agroforestry (ICRAF) is currently also working with water hyacinth harvesting related projects. Henry Neufeldt is the contact person from within ICRAF regarding water hyacinth harvesting.

Conver is a Dutch company which builds machines and ships for the removal of water plants. Their harvest boats compete with boats which may be designed as a result of this thesis.

As this thesis will be part of a double degree both Wageningen University and Technical University Delft were involved. The thesis has to meet the requirements of both universities. During the thesis project there have been several contact moments with both universities.

All the stakeholders identified and described above are shown in the power-interest grid in figure 4.

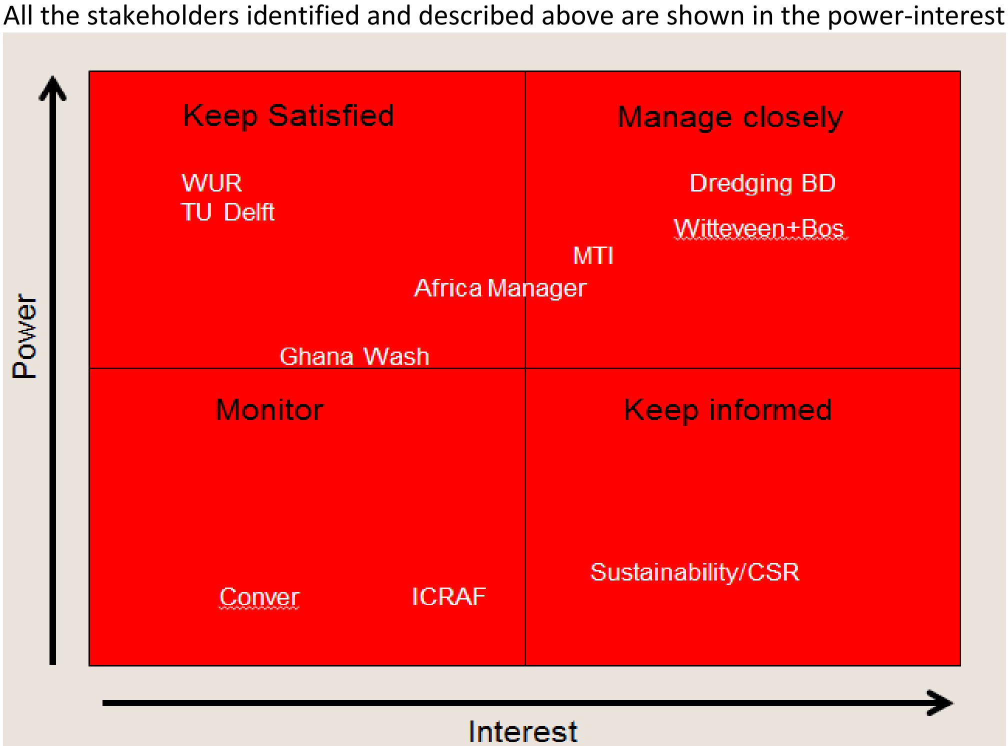


Figure 4. Power-Interest grid for internal stakeholder for this thesis

2 The water hyacinth

The control of water hyacinth is expensive, in China for example the costs are annually estimated to be 1 billion dollars per year (Theur 2013). The control is either done by chemical, biological or mechanical means. Mechanical control has the advantage that the biomass harvested can be used for several purposes. In order to get an understanding on how to control and use water hyacinth biomass the general characteristics of the plant should be assessed. To estimate the annual harvested biomass it is required to know the growth rate and distribution of water hyacinth. To be able to establish a plan for the best utilization option, it is important to be familiar with the chemical constitution.
The general understanding of the plant can therefore be divided in the following topics:

- General characteristics
- Growth parameters
- Chemical content

2.1 Water Hyacinth Characteristics

The German botanist and explorer C.F.P. Martius, first described the water hyacinth as a distinct species in 1824 (Gopal 1987). The water Hyacinth is part of the family Pontederiaceae and the genus Eichhornia. All species within the genus Eichhornia are aquatic.

Species known within the genus Eichornia arre (Ndimele and Jimoh 2011):

Eichhornia crassipes	: Common water hyacinth
Eichhornia azurea	: Anchored water hyacinth
Eichhornia diversifolia	: Variable leaf water hyacinth
Eichhornia paniculata	: Brazilian water Hyacinth

This study focuses on the common water hyacinth. The water hyacinth originates from South America in the Amazon basin. They have been distributed by man all over the tropics and subtropics(Gopal 1987). The current distribution of water hyacinth can be found in figure 5.

The water hyacinth is a floating perennial herbaceous hydrophyte. The plant can differ a lot in shape, number of leaves and flowers depending on the distribution, age and growing conditions (Fornasari 2002). The water hyacinth grows in fresh water with an optimum pH between six and eight. The plant does not grow in salty water. Salinity above 6-8 % is lethal. Water hyacinth can grow in temperatures between 1 and 40 °C (Malik 2007). They are however killed at temperatures below 0 °C. In Japan, where it can freeze in winter, water hyacinth behaves as a seasonal crop (Gopal 1987). Apart from this the water hyacinth grows in practically all environments. It can grow in eutrophic waters and in water contaminated with heavy metal. The plant can therefore also act as a remediation agent.

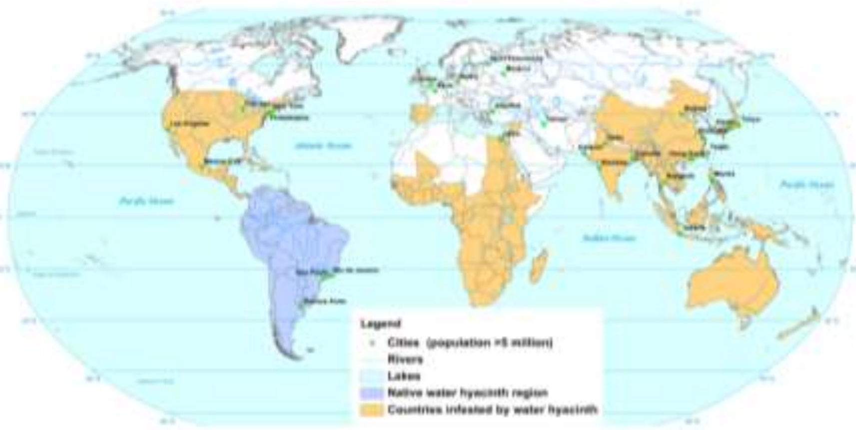


Figure 5. Global Water Hyacinth distribution (Theur 2013)

The plant is normally free-floating but can also be rooted in mud if stranded in shallow parts of the water. The float leaves and petioles of the plant have a spongy structure. This results in low density of the leaves and petioles. If the plant is free floating it keeps upright either by the high density of the roots and the low density of the leaves and petioles or by the interconnections of mats (Center and Spencer 1981). Water hyacinth can easily be moved by current or wind. This is beneficial for the spread of the water hyacinth and is an important reason why the water hyacinth distributes so easily over large areas (Fornasari 2002). For harvesting of biomass the movement of the plants can cause problems as the aquatic weed can move over large distances. The transportation of the harvested biomass to the processing facilities can in this case become problematic. A sketch of a water hyacinth is shown in figure 6.

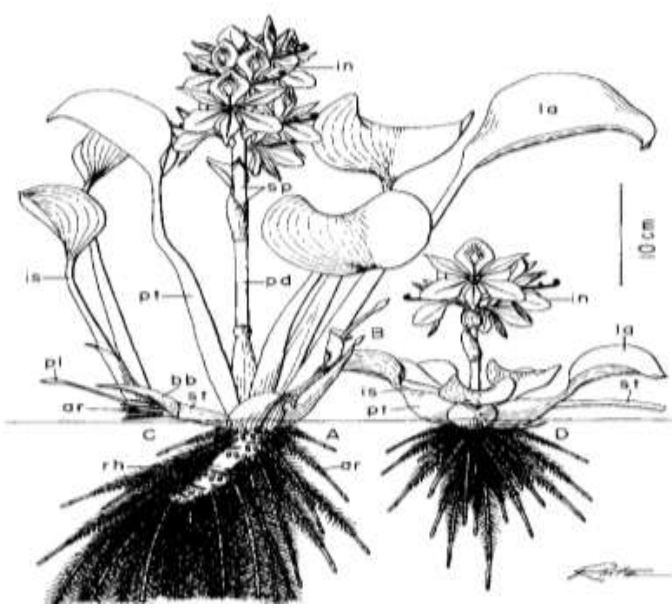


Figure 6. A generalized sketch of water hyacinth plants showing the growth form which occurs in dense mats (A) with an opening axillary bud (B) and an older ramet (C) as compared to the growth form which occurs in more open situations (D). the inflated petiole.

The crop can directly take up minerals from the water or from the soil where it is anchored (Greenfield *et al*. 2007). The water Hyacinth has low nutrient requirements but grows best in nutrient rich water. Growth, nitrogen and phosphorous content are positively related to the levels of nitrogen and phosphorous content of the water (Xie and Yu 2003). That the water hyacinth changes under varying conditions can also be seen in the morphology of the plant. According to Xie, (Xie and Yu) morphological plasticity occurs in both the leaves and the roots of the plant. If there is a high density of water hyacinth the plant will start growing vertical and develops longer petioles. If there is a high density the biggest variation in leaf length and diversity occurs (Center and Spencer 1981).

Water hyacinth is very successful due to their ability to reproduce both sexually and vegetatively. Vegetative reproduction happens through the production of stolons (Gopal 1987). The way of reproduction depends on the environment. The formation of stolons was found to be completely suppressed in plants grown in distilled water. In distilled water flowering occurred well while hardly any flowering was observed in a nutrient-rich environment (Gopal 1987). Flowering can occur throughout the year but is dependent on climatic factors. The number of flowers per flowering-event and the time for all of the flowers to open varies from 3 to 5 days. The plant also has the possibility of self-pollination, if there is no option of cross pollination (Gopal 1987).

According to (Gopal 1987) there is huge variation in the production of fruits and seeds. In particular the number of seeds per fruit is very variable. Water Hyacinth seeds require warm shallow water and high light intensities for germination (Center and Spencer 1981) The seeds of water hyacinth can stay dormant for a long time, up to 15-20 years has been recorded. This in combination with the ability of water hyacinth to regenerate from fragments of stems makes it very difficult to totally eradicate water hyacinth from a water body (Gunnarsson and Petersen 2007).

The seeds of water hyacinth were found growing on decaying peat floating on the surface (Gopal 1987). This was also something that IHC has observed in previous projects with water hyacinth. The ability of the seeds to germinate on floating sediment can also be problematic for dredging activities. During dredging the sediments are stirred and seeds can rise to the surface with sediments starting another water hyacinth infestation.

2.2 Growth parameters

The vegetative growth contributes to the fast growth of the water hyacinth. Water hyacinth stands out among all other macrophytes in similar growing conditions. Because the growing conditions differ a lot, it is difficult to derive a consistent set of growth parameters for water hyacinth (Gopal 1987). The growth parameters of water hyacinth have therefore been compiled from several literature sources as can be found in table 1.

The growth of the water hyacinth can be expressed as (Reddy and DeBusk 1984):

- Percentage increase per day (% d^{-1})
- Increase in biomass yield expressed in fresh weight (FW) or dry matter (DM) ($g\ m^{-2}\ d^{-1}$)
- Increase in surface area covered ($m^{-2}\ d^{-1}$)
- Intrinsic growth rate ($g\ g^{-1}\ d^{-1}$)

In some literature the growth was expressed in the doubling time, the time required to double the total amount. This characteristic can be derived from the percentage increase and from the intrinsic growth rate. In the table 1 the growth parameters from several literature sources are presented.

The percentage daily increase of the water hyacinth differs depending on the plant density due to intraspecific competition. Seasonal changes can influence the growth rate. In summer, the increase in percentage per day was between four and five times higher than in winter (Gutierrez *et al*. 2001). Nutrients in water are known to have an effect on the growth of water hyacinth. Most growth is found under nutrient and especially nitrogen rich environments. This is also why water hyacinth grows so well in eutrophic environments. The best growth of water hyacinths is in shallow water with roots anchored in mud (Gunnarsson and Petersen 2007) (Malik 2007).

Table 1. Growth Parameters of Water Hyacinth

	Gunnarson and Peterson 2007	**T. D. Spencer, 1981**	**Malik, 2006**	**Gutierrez, 2001**	**Gopal, 1987**	**Greenfield *et al*., 2007**
yield (t DM /ha/y)	140	-	-	-	2,6-95	-
% growht rate	-	1,5	-	1,07-9,34	1,7-12	-
Intrinsic growth rate (1/d)	-	-	-	0,016-0,072	-	-
Doubling time (d)	7	-	6-18	-	5,9	-
density (plants/ m^2)	60-90	110-186	-	-	60-90	-
Carrying capacity (kg/m^2)	-	50 FW	60 FW	33,5-49,6 FW 1,88-2,79 FW	-	1,8-4,3 DM

In several research projects the growth of water hyacinth has been modeled (Wilson *et al*. 2005). These calculations can be used to estimate the amount of biomass that needs to be harvested or can be harvested on an annual base.

(Wilson *et al*. 2005) used the following basic logistic growth model to calculate the growth rate of the water hyacinth, dM/dt (kg $m^{-2}d^{-1}$):

$$\frac{dM}{dt} = rM\left(1 - \frac{M}{K}\right) \quad \text{Formula 1}$$

In this equation r is the intrinsic growth rate (units per day, d^{-1}) and K the carrying capacity (kg m^{-2}). The equation is used to calculate the increase in fresh weight of the plant in relation of the actual amount (M). As the water content is rather stable and always around 94 %, the same calculations can be expressed in dry weight ((Wilson *et al*. 2005)). The Carrying capacity can be derived from literature. In table 1 the carrying capacity from several authors can be found.

2.3 Chemical content

To be able to develop processes and methods for the utilization of water hyacinth it is important to understand the chemical content of the water hyacinth. Table 4 (Gunnarsson and Petersen) includes some additional data from other literature sources. It can be seen that there are differences in chemical content between the different studies. The water hyacinth can easily adapt to the environment it grows not only morphologically but also in chemical content.

Table 2. Heavy metal content of water hyacinth according to different literature sources

	Lokeshwari and Chandrappa 2006 [µg/g DM]	**N. Kumar 2008 [ppm]**	**Ndimele , 2011 [ppm]**	**Singh, 2012 [g/kg DM]**	**Greenfield *et al*. 2007 [mg/kg]**	
					root	*shoot*
Iron	44-495		4,9-8,1	16925		
Cadmium	BDL-0,25	0,79		57		
Zinc	13-69	709,07	1,73-4,63	175,5		
Lead	BDL-33	9,81	0,3	1259		
Copper	2-12,0	44,5		73		
Chromium	BDL-15			301,3		
Nickel	BDL-8	28,83		194,5		
Cobalt		25,75				
Mercury					1,31	1,25-4,44

As can be seen in table 2 there are large differences in the concentrations of heavy metals in water hyacinth. The Bio Concentration Factor (BCF) can be used to estimate of the concentration of heavy metals in water hyacinth depending on its environment. The Bioconcentration factor (BCF) is the ratio of the trace element in the plant tissue at harvest to the concentration of the trace element in the external environment, i.e. water or sediment. If the concentrations of minerals in water are known the content of these minerals can be estimated by using the BCF.

$$\text{BCF} = \frac{Trace\ element\ concentration\ in\ plant\ tissue\ [mg/kg]\ at\ harvest}{Initial\ concentration\ of\ the\ element\ in\ the\ external\ nutrient\ solution [mg/L]}$$

From literature different BCF-values were found which are presented in table 3. For the utilization of the biomass of water hyacinth high heavy metal concentrations can be a constraint. The heavy metal content of the plant can vary depending on the location where it is found. If the crop grows close to an industrial waste water outlet there will, according to the BCF value, be high concentrations of heavy metals in the plant. Whereas if the crop is growing in an environment with few heavy metals, there will be a low heavy metal concentration in the biomass of the plant.

The order of the following metals, Zn>Cu>Pb>Ni>Co>Cd ,shows the regulation capacity of the water hyacinth to accumulate trace elements independent of the concentration in the external environment (Kumar *et al*. 2008). This means that Zn is more easily accumulated by the plant than Cu. There is also a difference in allocation between the roots and the shoots resulting in differences between BCFs for root and shoot. Smolyakov, (Smolyakov 2012) found the following order of BCP for heavy metals of roots and shoots, respectively: Cu>Zn>Ni>Pb>Cd and Cu>Zn>Ni>Pb>Cd. He also found different BCP values and order if the pH of the medium was changed.

The stem and leaves of the water hyacinth have lower concentrations of heavy metals than the roots (Kumar *et al*. 2008). The difference in concentration of the root and the shoot of the plant can be explained by the translocation ability (TA) or allocation ratio. The TA shows the ability of the plant to allocate heavy minerals from the root to the shoot. Based on different literature sources, the Translocation ability has been determined and is shown for Cn, Pb, Cd, Ni, Zn in table3.

The different mineral content in leaves, stem and shoot should be kept in mind for the processing of the crop. In some cases, the leaves might be interesting for utilization while the roots are not suitable for utilization. Some countries have set a maximum to the addition of heavy metals to the soil (Mortvedt 1995). Depending on the country where the water hyacinth grows and the amount of heavy metals in the plant it has to be decided if the plant can be used as fertilizer. If the heavy metal concentration in the harvested biomass is below admissible limits of national regulations for fertilizer, water hyacinth can be used as organic fertilizer for agriculture.

Table 1. Bio Concentration Factor and Translocation Ability of Water Hyacinth

	Pb	**Zn**	**Cu**	**Ni**	**Cd**
Bio Concentration factor (BCF)					
Smalyakov, 2012	2500-3200	1200-2100	2950-3800		800-2900
Hasan 2007		626-725			352-756
Translocation ability (TA)					
Liao, 2004	8,56+/-3,17	3,37+/-1,27	14,77+/-4-56	5,44+/-3,05	5,84+/-2,27
Smalyakov 2012	10,5-12,4	3-4	18-24,8		4,2-4,8

Table 2. chemical content of water hyacinth from Gunnarson (2007)

	Adhelhamid and Gabr, 1991	**Bolenz *et al*. 1990**	**Chanakya *et al*. 1993**	**Patel *et al*. 1993**	**Poddar *et al*. 1991**	**Polprasert *et al*. 1980**	**Gunnarsson and Matsson, 1997**		**Luo 2011**	**Y. Gao 2013**	**Goswami 1994**
							Fresh	Dried			
Dry Matter (% on wb)	9,5	6,2	9,4	-	-	-	-	-	-	-	-
Organic matter	74,3	-	83,65	-	83,61	-	-	-	-	-	-
Fat	-	-	-	-	-	-	-	-	8,3	-	-
crude protein	20	-	-	11,9	16,25	-	-	-	18	-	-
ether extract	3,47	-	-	-	1,61	-	-	-	-	-	-
Fiber	-	-	-	-	-	-	-	-	59,2	-	-
crude fibre	18,9	-	-	-	16,34	-	-	-	-	-	-
Nitrogen free extract	31,9	-	-	-	49,41	-	-	-	-	-	-
ash	25,7	15	-	20,2	16,39	-	35,6	52,07	12,3	38,11	18,4
C/N ration	-	-	-	-	-	15,8	23,5	25,1	-	-	-
Neutral detergent fibre	62,3	-	-	-	56,14	-	-	-	-	-	-
Acid detergent fibre	29	-	-	-	37,72	-	-	-	-		-
Holocellulose	-	-	-	-	-	-	-	-	-	-	54,8
Hemicellulose	33,4	22	33,97	43,4	18,42	-	-	-	26,8	18,9	21
Cellulose	19,5	31	18	17,8	25,61	-	-	-	26,1	16,5	-
Lignin	9,27	7	26,36	7,8	9,93	-	-	-	6,3	11,6	6,7
Water soluble	-	-	21,68	-	-	-	-	-	-	-	-
Phosphorus	0,53	-	-	-	0,53	0,5	0,26	0,32	-	-	-
Carbon	-	-	-	-	-	-	27,6	18,54	-	-	-
Nitrogen	-	-	-	-	2,76	2,9	1,18	0,74	-	2,03	-
Magenesium	0,17	-	-	-	-	-	-	-	-	-	-
Calcium	0,58	-	-	-	2,29	-	-	-	-	-	-
Potassium	-	-	-	-	2,44	-	4,53	2,27	-	-	-

3 Options for Utilization

The tree in figure 7 shows the options for the use of the wet biomass of water hyacinth. Based on this tree and the plant characteristics the processes and requirements for the utilization options have been mapped.

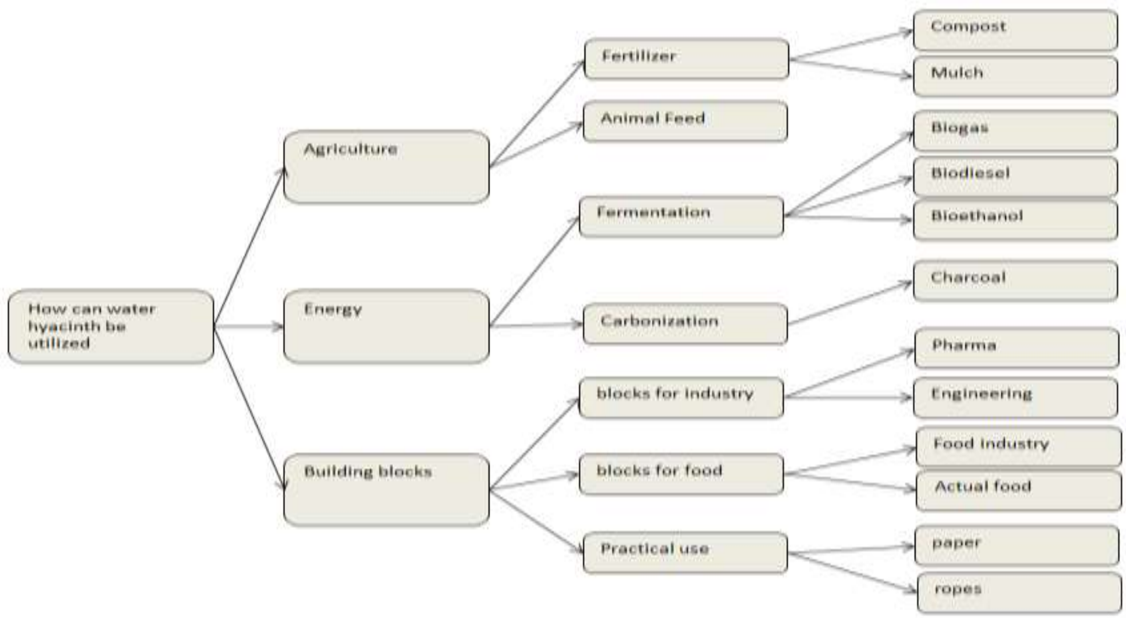


Figure 7. Map of possibilities for water hyacinth use

The Water hyacinth can be utilized for three options:

1. Agriculture
2. Energy
3. Building blocks

It is important to keep in mind that the biomass is wet biomass, containing around 94 % water. The transport of biomass of the water hyacinth can therefore be problematic and energy inefficient. Drying might be part of the process to utilize water hyacinth. This however consumes energy or requires space for sun drying.

In a developing country, the simplest option is to use the biomass as an organic fertilizer. The water hyacinth will contribute to the required minerals in the soil (N,P,K), to the carbon content and structure of the soil. The water hyacinth might also be a good feed source for livestock. In the past this has been done in less developed and poor parts of China. However, since the development of China, the plant is only rarely used as duck feed in some cases (Jianqing *et al*. 2001). There might be potential to use the water hyacinth as animal feed after processing of the biomass. If the water hyacinth grows in an environment with heavy metals it is however not feasible to use water hyacinth for agricultural purposes.

Water hyacinth can also be used to generate energy. There are several fermentation processes which can produce biogas, biodiesel or bioethanol.

The biomass can also be used for the development of building blocks for different industries. At the moment new techniques are developed to extract valuable substances and building blocks from waste biomass for engineering practices (Gallert and Winter 2002). Biomass of plants can also be used more easily by for instance absorbent of minerals. So the feasible options for the development of valuable building blocks for industry will also be mapped. Another option can be to use water hyacinth for day to day products such as paper and rope. This is however not assessed as this is not economically feasible on a large scale.

Water hyacinth can also be used as a source of food for humans. Proteins can be extracted from the biomass for the food industry or the plant itself might be used as food for humans (Bolenz *et al*. 1990) . The use of water hyacinth for food can be a good contribution to the foreseen food scarcity problem in the coming years.

In figure 8 a pyramid is shown representing the different options for biomass utilization. The value of the product decreases from the top of the pyramid whereas the availability is highest at the bottom of the pyramid. Based on an interview with Niels van Stralen, 2014, one of the founders of Chaincraft, The dotted line was set, which represents what is currently economically feasible with biomass and what is not. It is currently still very difficult to develop high valuable materials from wet waste biomass.

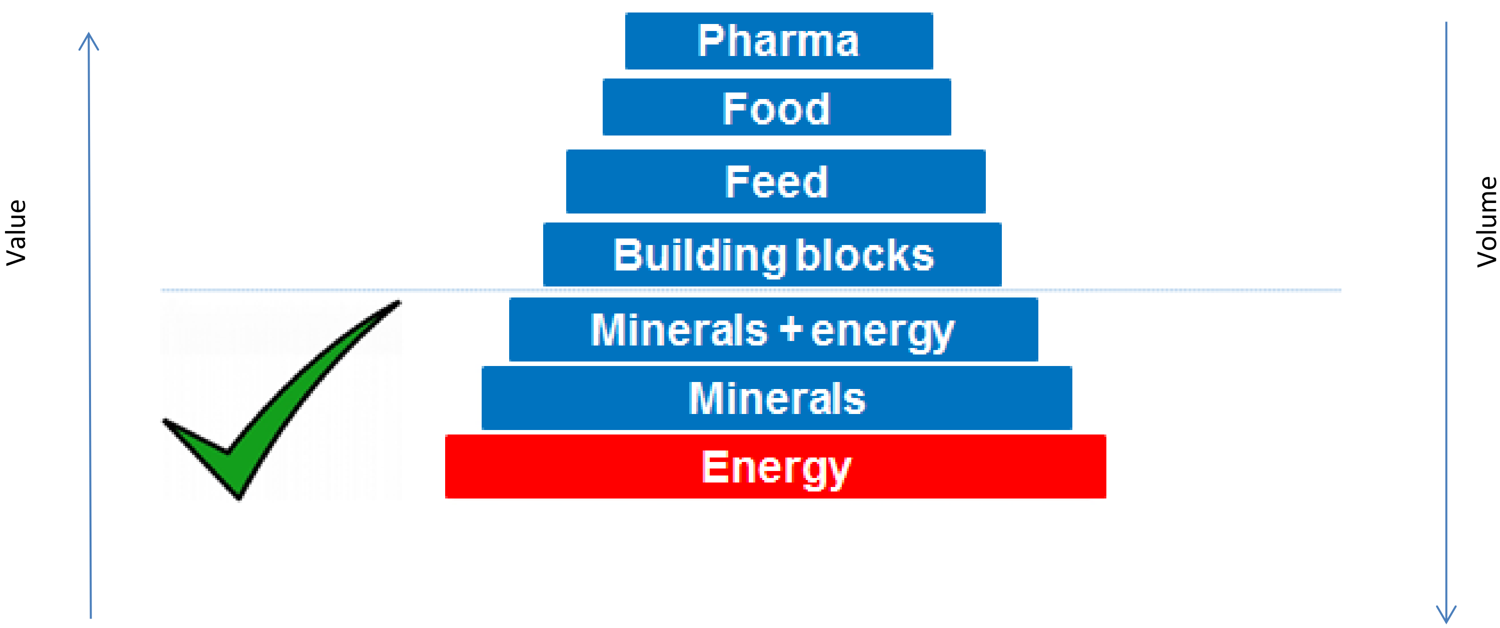


Figure 8. The biomass value pyramid. The techniques below the line are available for processing of water hyacinth. Source: Chaincraft, 2014

The required processes, requirements and pros and cons will be assessed for the most feasible and valuable utilization options.

3.1 Water Hyacinth as a potential resource for Agriculture

Half of the world population now lives in towns and cities, a figure expected to reach two-thirds by 2050 with an increase world population expected to reach 9,6 billion people in 2050 (Un-habitat 2010). With urbanization there is an increasing demand for food. Not only is the world population growing, in developing countries the demand for higher quality food is also increasing, i.e. meat and dairy products.

The growing food demand puts an increasing pressure on land availability, as there is more land required for crop cultivation, foraging grounds and high quality food production for livestock. Therefore there is more energy and water required for agriculture. All these resources, land, water and energy, will compete with other purposes generating higher economic returns than most agricultural purposes. This typically includes uses such as industry, urban use and nature.

The resources required for agriculture are predicted to deplete. Some projections show economically viable mineral reserves becoming depleted within a few decades. Phosphorus-induced food shortages are therefore a possibility (Childers *et al*. 2011). Phosphorous is an essential mineral for the production of crops. Therefore research is currently conducted to find a potential solution to capture phosphorous from water sources.

A potential solution to some of the problems occurring from competition of land and resources could be the utilization of water hyacinth. The growth of water hyacinth is not land based and does therefore not compete with any other way of land utilization. Besides this the plant is known to capture minerals from water since the harvested material can be used as a fertilizer for crops.

The utilization methods for water hyacinth are either:

1. Water hyacinth can be used for Livestock feed as i) ruminant feed, ii) fish feed in aquaculture and iii) poultry feed.
2. Water hyacinth can be applied as Fertilizer on agricultural field

3.1.1 Water Hyacinth biomass as livestock feed

According to Wu, 2011 water hyacinth is superior to soy bean in the production of proteins per hectare (Wu and Sun 2011). Feed for ruminants should at least contain 9% of crude protein on a dry matter basis (Gunnarsson and Petersen). Water hyacinth contains between 12-20% crude protein as can be found in table 4. Water hyacinth could therefore act as a cheap and easily attainable resource for feed production

Water hyacinth however has to be processed before it can be used as feed because of some negative characteristics, as described below. Water hyacinth has a lot of air filled intercellular space in its leaves. The air filled spaces soak up water. If livestock eats the water hyacinth and drinks, the water is soaked up in the intercellular spaces resulting in an animal not eating as much biomass as it would normally do (Bolenz *et al*. 1990). This results in a decrease in animal growth rate which is not desirable for livestock production. Water hyacinth also contains calcium oxalate. The needle like calcium oxalate crystals can cause damage to the intestinal track of animals feeding on it (Bolenz *et al*. 1990).

The plant mass also contains 18,7 mg/kg alkaloids. The maximum amount of alkaloids in dietary feed is 200 mg/ kg. The structure of alkaloids does however determine the toxicity of alkaloids. The structure has not been researched (Wu and Sun 2011). The biomass also contains 5,2 mg/kg phenols. The structure of the phenols also determine the toxicity. This has not been evaluated and further research is recommended (Wu and Sun 2011).

Because of these characteristics water hyacinth needs pre-treatment before it can be used as livestock feed. The water hyacinth leaves are only feasible for animal feed as these contain more proteins, fewer heavy metals and other characteristics which decrease animal growth. Water hyacinth can either be treated as described by S. Bolenz, (Bolenz *et al*. 1990) which is described below or should be processed to silage.

3.1.2 Water hyacinth treatment to get useful animal feed products

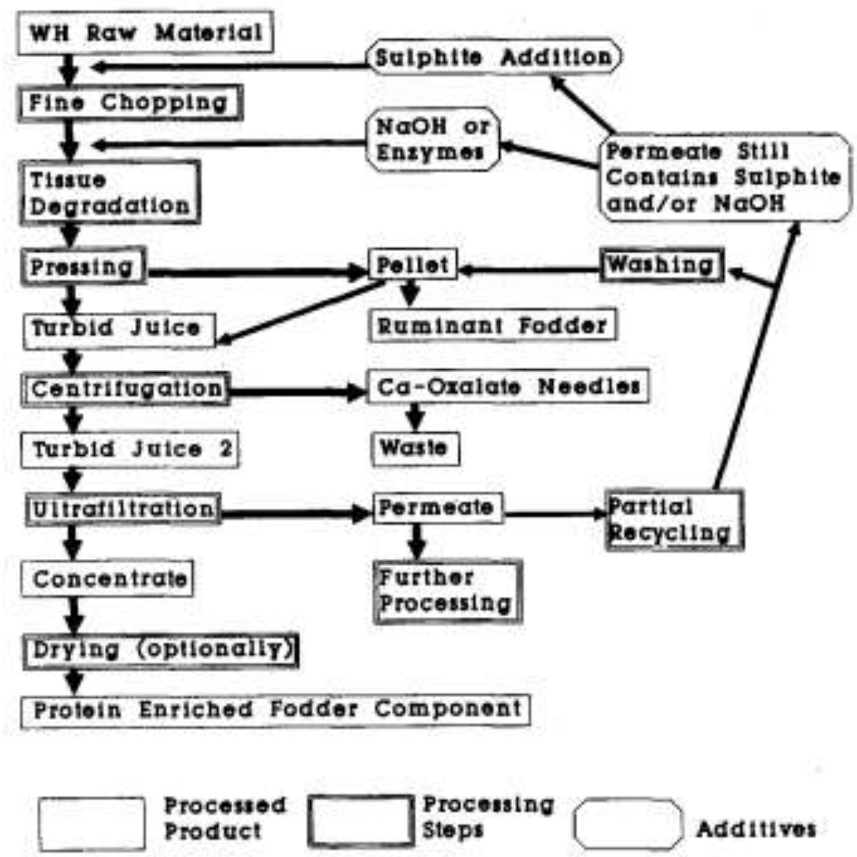
The purpose of the treatment suggested is to make water hyacinth digestible and remove toxic elements (Bolenz *et al*. 1990). Bolenz eliminates the risks of calcium oxalate and extracts nutrients from the plant material that can be used as animal feed.

To avoid soaking up of water by the intercellular spaces the water hyacinth biomass should be chopped. It is necessary to separate the shoots from the roots as the roots may contain more heavy metals as has been elaborated before. The roots contain also more ash and lignin compared the shoots of the plants (Cheng *et al*. 2010). For the production of livestock especially the hemicellulose and the cellulose are interesting.

The biomass should be pressed and centrifuged to separate the dissolved proteins from the solid matter. The remaining solid biomass can be used as animal fodder after being washed with acid. The acids dissolve the calcium oxalate. Before the biomass is chopped it should be blanched or sulfite should be added to prevent poly phenol oxidases to react with the protein resulting in indigestible proteins and hindering extraction. The addition of small amounts of sulfite is the most effective method.

Bolenz, (Bolenz *et al*. 1990) added different additives to improve the amount of proteins extracted from the biomass. The addition of NaOH showed most protein yield compared to the other methods. The proteins can be extracted from the juice by ultrafiltration. The product of the filtration was a concentrate of protein which can be used for feed. After the filtration, some of the NaOH could be recycled.

The process suggested by Bolenz (1990) has two outputs that can be used; the pressed solid biomass and the extracted proteins. The solid biomass can be used as fodder straight away whereas the extracted proteins are a more valuable product which might be of interest for the feed industry.



F*igure 9. A process flow for the production of proteins from water hyacinth biomass as described by Bolenz, (Bolenz et al. 1990)*

Grassa a Dutch startup which builds refineries for the extraction of proteins from grass using a similar technique as described by Bolenz (Bolenz *et al*. 1990). Figure 10 shows the Grassa pilot plant and the fiber output.

Figure 10. (left) Grassa pilot plant (right) fibre output from the Grassa plant

Hence the Grassa process can very likely be used to extract protein from water hyacinth biomass. The Grassa plant processes grass biomass into fibers, containing a substantial amount of protein, raw protein and liquids. The proteins are denaturized during the process. The fibers can be used as animal feed.

ABCKroos a Dutch start up is also able to extract proteins from biomass. Tests have been done on duck weed. In figure 11 the streams of biomass of the ABCKroos process can be found. The proteins are not denaturized during the ABC extraction. These proteins are still functional and can be used in several industries.

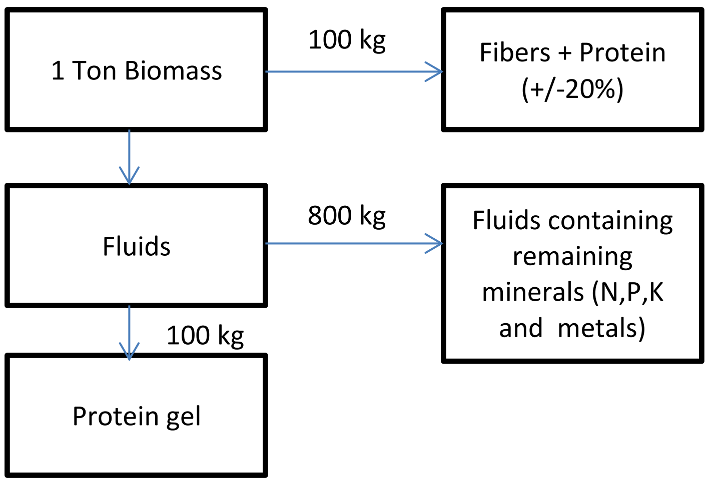


Figure 11. A flow chart of the protein extraction process from duckweed by ABCKroos

The other treatment method to produce animal feed is silage production. Silage is a feed source that is harvested while it is still green and conserved by fermentation of the sugars from the biomass. Lactic acid is produced when sugars are converted by the fermentation process. These acids ensure the conservation of the feed. Silage can be stored up to 5 years (USAid). The production of silage can contribute to a continuous supply of feed. Drying of water hyacinth into hay is not an option because fermentation or processing is required. Complete drying of water hyacinth into hay will also be difficult due to the humid climate in the tropics and sub-tropics (Tham and Udén 2013).

The water hyacinth should be chopped to destroy the intercellular spaces containing air. These can otherwise lead to aerobic molds during the fermentation process. These molds can also be prevented by the addition of acid to the silage (Gunnarsson and Petersen 2007). High moisture content is a bad characteristic for the production of feed from biomass (Woomer *et al*. 2000). Treatment before ensiling is required because water hyacinth has a moisture content of 94 %.This can either be done by drying or by milling of the biomass. Because drying of biomass requires surface, milling is favored above drying.

In literature (Woomer *et al*. 2000) it is described that water hyacinth biomass should be mixed with other biomass sources to obtain optimal characteristics for the fermentation process. Ensilage and fermentation of water hyacinth alone results in silage with a pH of 7,3 which is too high for the conservation of the feed. Therefore other carbohydrate additives are required for the fermentation process (Woomer *et al*. 2000).

Molasses and maize or rice bran are used as additives for water hyacinth silage. Another additive that can be used to obtain the best characteristics for the fermentation process is sugar Bolenz, (Bolenz *et al*.1990) suggested adding 0,4 % sugars to the water hyacinth biomass to start the fermentation process running. Bacteria can also be added to the biomass.

Water adsorption is also a good characteristic for an additive resulting in a lower amount of seepage. Maize bran is a good additive for fermentation as it adsorbs water well and also contains the sugars (Woomer *et al*. 2000) required for the fermentation of water hyacinth. The combination of low quality components, in this case water hyacinth, and more qualitative components results in the most economic attractive silage (USAid).

To ensure anaerobic production, the biomass is often sealed from air by plastic. This can be done either by heaping and covering or bagging smaller quantities of biomass, the last is often done in the field. Because additives are required to get the best silage, it is suggested to heap the biomass and then cover it. Most likely the water hyacinth will be collected at a central place on shore where it can be heaped and covered for silage production. If the water hyacinth is collected in smaller quantities, bagging can be a better solution for ensiling.

3.1.4 Water Hyacinth as fish feed

For the production of herbivorous fish local, availability of feed is often a problem (El-Sayed 2003). Because water hyacinth is a fast growing crop which is abundant in the tropics and sub-tropics this might be a good resource for the production of fish for human food. Water hyacinth feed can be fermented or freshly fed to the fish. The are several fish that are cultivated in aquaculture systems that can be used for the control of water hyacinth (Jafari 2010). Water hyacinth can therefore also be used as a feed source for these fish.

The high fiber content of water hyacinth is however difficult for the fish to digest. The digestion of lignin can be a problem (El-Sayed 2003). During composting the lignin and cellulose is degraded and can therefore be a better feed source than fresh water hyacinth.

The growth rate of Tilapia was found to be lower when water hyacinth feedstock was used both for fresh and fermented water hyacinth. There was however not a loss in growth rate if water hyacinth comprised 10 % or less of the feed for the fish. There was no difference in growth rate of the fish between fresh water or fermented water hyacinth if it contained 10 % or less of the feed (El-Sayed 2003)
Water hyacinth has also been used for enrichment of nursery ponds for larval rearing of Indian major carp. The compost of water hyacinth biomass was added to the ponds for larval rearing. The ponds with compost performed better than ponds with organic fertilizer or control ponds (Sahu *et al*. 2002).

Some of the fish feed can be substituted by water hyacinth without an effect on the growth of fish. If there is a large aquaculture operation there might therefore be an opportunity to use water hyacinth as part of the feed for fish.

3.1.5 Water Hyacinth as poultry feed

In some of the poorer parts of China, Water Hyacinth is still used as poultry feed because it is a freely available and feed source for chicken and ducks. Lu , (Lu *et al*. 2008) assessed the effects of fresh water hyacinth as part of duck feed.

The roots of the water hyacinth were removed and then added to the normal diet of the ducks. Lu, (Lu *et al*. 2008) A higher feed intake was found if ducks were fed a combination of normal feed and water hyacinth. The amount of eggs produced by the ducks was higher. The weight per egg was also bigger with the combination with water hyacinth feed. The conversion of feed to egg production was however lower if water hyacinth was part of the feed (Lu *et al*. 2008). If fresh water hyacinth is added to the feed it is a cheap resource with a bigger egg yield. Therefore it can be questioned if it is a problem that there is a lower conversion rate.

More research needs to be done to assess if it is feasible to substitute part of the feed of poultry by water hyacinth. The research of Lu, (2008) has promising results for the use of the plant for poultry feed.

3.1.6 Water hyacinth as fertilizer

Most of the countries where water hyacinth grows are developing countries. Nearly one-third of the human population lives on small farms (Wright *et al*. 2012). Often chemical fertilizer is not available or too expensive for the local small farmers. Using water hyacinth as mulch, green manure or compost a high amount of nutrients, crude protein and organic carbon is applied onto the field (Gunnarsson and Petersen 2007). The nutrient content of the harvested water hyacinth biomass can therefore be a source of fertilization of agricultural fields for small and even large scale farmers. The use of water hyacinth as fertilizer recycles the material and disposes the water hyacinth at the same time (Jiwan Singh and Ajay S Kalamdhad 2012). In Sri Lanka for instance a mix of water hyacinth, other organic biomass waste, ash and soil was composted and sold to local farmers (Jafari 2010).

The decision to use crop residues as mulch, green manure or compost can be based on the table below from Palm (Palm *et al*. 2001). As can be read from table 4 is the nitrogen content of the plant above 2,5% and the lignin content below 15% The content of phenol in in water hyacinth according to(Wu and Sun 2011) contains 5,2 mg/kg. It can be concluded that water hyacinth can be used mixed with other fertilizers.

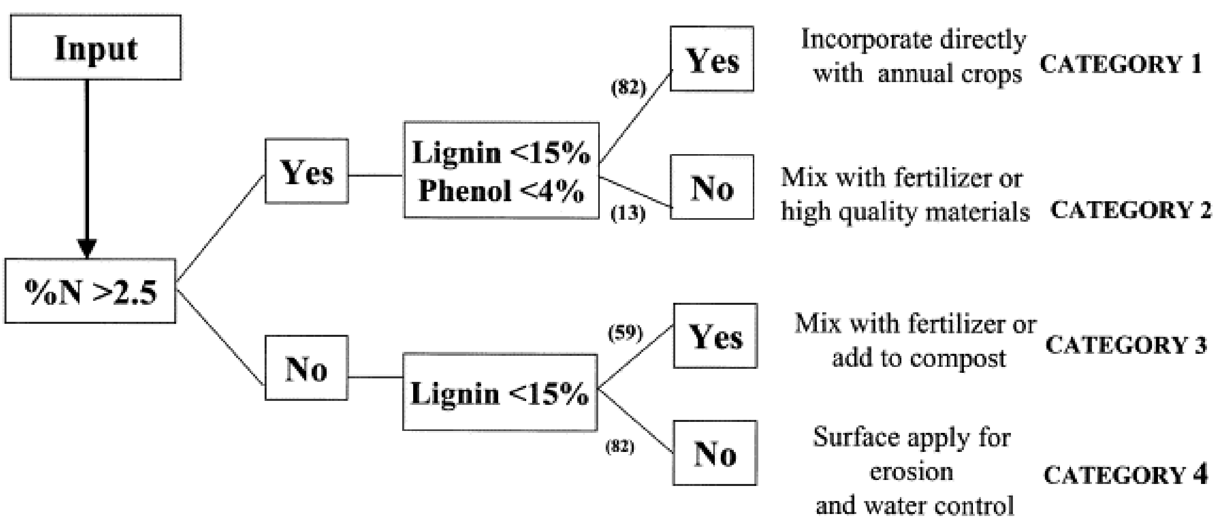


Figure 12. Decision tree for plant biomass as a resource for agriculture (Palm et al. 2001)

The nutrients that are washed from agricultural fields are taken up by the water hyacinth. These minerals can be released back into the fields if water hyacinths are applied as mulch or compost. Nutrient ratios in water hyacinth and in the water bodies in which the plants grow, are similar to the nutrient ratio depleted from arable land by crops (Woomer *et al*. 2000). The mulch or compost not only contains the main nutrients, nitrogen, phosphorous and potassium as a chemical fertilizer but it also contains micronutrients. These micronutrients contribute to the growth of agricultural crops.

Mulch and compost both assist in water retention of the soil and can help to suppress weeds in the early stage of production. Apart from this it also contributes to the inhibition of pathogens and soil born plant diseases. The application of mulch onto the fields is a good way to recycle the carbon from the plants which increases the organic matter (SOM) of the soil (Balasubramanian *et al*. 2013).

In plots where water hyacinth was applied a lower pH was detected, resulting in mineralization of organic materials resulting in increased N, P, K availability (Balasubramanian *et al*. 2013). The nutrient availability increases due to a low C: N ratio of water hyacinth as can be found in table 4. If the C: N ration is high the application of biomass can immobilize nitrogen from the soil for mineralization of the organic material (Muhammad *et al*. 2011).

Water hyacinth should be covered by soil if used as mulch to prevent loss of nutrients. The plants should be disintegrated before usage to prevent growth of water hyacinth in the field and further distribution of water hyacinth (Gunnarsson and Petersen 2007). For the use of water hyacinth as compost drying can be done to minimize risk for bilharzia for the persons handling the water hyacinth biomass. Furthermore drying decreases transportation costs. Drying however might lead to loss of biomass and nutrients (Gunnarsson and Petersen 2007).

There are several methods to compost waste organic matter as described below. (Gajalakshmi *et al*. 2002) composted water hyacinth in 50 L wooden boxes. A mixture of water hyacinth biomass and digested cattle manure was heaped in a 10 cm thick layer and covered with 1 cm of garden soil. The heap was watered to a moisture content of 50% and covered. The product after five weeks of composting is sludge like compost with a C/N ratio of 20,8. (Singh and Kalamdhad 2013) used a rotary drum of 550 liter. The drum had a length of 1,22 m and a diameter of 0,76 m. The drum was filled with 150 kg of wastes and manually rotated. The drum contained two adjacent holes for excess water. After 20 days the compost could be harvested. According to (Jiwan Singh and Ajay S. Kalamdhad 2012), water hyacinth can be heaped in a mixture with other organic waste in trapezoidal heaps. These heaps were manually turned. After 30 days the compost could be harvested. Another method of composting is vermicomposting. For vermicomposting earthworms are added to the organic waste. (Gajalakshmi *et al*. 2002)) used 4 liter circular plastic containers which were filled sawdust, river sand, soil and water hyacinth in layers of 1 cm, 2 cm, 3,8 cm and 2 cm respectively. Earthworm populations were added to the containers. After 10 days the compost could be harvested and the earthworms recovered. All of these methods were described on small scale. For water hyacinth composting bigger set ups will be required.

Water Hyacinth biomass can be mixed with other materials to optimize characteristics of the compost. Singh, (Singh and Kalamdhad) found the best mixture of compost with the ratio 90 kg water hyacinth, 45 kg cow manure and 15 kg sawdust. Other mixtures for composting can be selected, depending on the availability of organic residues.

Chopping of the crop is required for well-functioning compost In order to enhance bacterial decomposition. The water hyacinth should be shredded in 5 cm long pieces (Gunnarsson and Petersen 2007). The water hyacinth should be chopped to a maximum of 1 cm in order to provide better aeration and moisture control (Singh and Kalamdhad 2013). The moisture content of water hyacinth is too high for a good composting. Due to high evaporation in tropical climates the high moisture content of water hyacinth is not problematic for composting (Gunnarsson and Petersen 2007). If the water content of water hyacinth is too high the biomass can be milled or dried.

Water hyacinth has relatively high lignin content if compared to other organic waste used for composting. Therefore additives can be added to the biomass to enhance the composting process. A mixture of fungi, actinomycetes and bacteria added to the compost increases the degradation of lignin and cellulose (Adhikary *et al*. 1992).

Application of water hyacinth should only be done on fields close to water where the water hyacinth is harvested because there is a risk of propagation of the water hyacinth to adjacent water bodies (Woomer *et al*. 2000). The water hyacinth can also be pre-treated to prevent it from spreading if used as mulch. A problem of using water hyacinth as mulch is that it can only be disposed of on the agricultural fields before the start of the growing season. If the water hyacinth is harvested when it can't be applied on agricultural fields it has to be disposed.

3.2 Water Hyacinth as a potential resource for Energy Production

Society is dependent on a steady reliable supply of energy. Most of world's energy supply comes from fossil and nuclear sources. At the moment there is no shortage of fossil fuels but problems with recovery of fuels is expected (Dresselhaus and Thomas 2001). Fossil fuel sources are depleted while consumption is expected to increase.

Apart from being finite, fossil fuels are a main contributor to global warming due to emissions of carbon dioxide during combustion. With the Kyoto Protocol (Protocol 1997) most countries in the world agreed to reduce the emission of greenhouse gasses by 2020. Currently a shift is taking place from energy generation by fossil fuels to renewable energies.

Agricultural crops are a possible alternative resource for energy production. Agricultural products are not finite and do not contribute to the increase of greenhouse gasses in the atmosphere. Crops have been used to produce bioethanol, biogas and biodiesel. The use of land for biofuel production has the problem of competing with land for crop production and nature. With the ongoing increase of the world population a major transition from food crops to cellulosic crops for energy production is required which is a threat for many areas that have already been fragmented and degraded, rich in biodiversity and provide habitat for many endangered endemic species (Beringer *et al*. 2011). Water hyacinth can be a potential resource to produce biogas and bioethanol (Wang and Calderon 2012). Water hyacinth can therefore be a good alternative for the production of energy.

More than 80% of urban households in sub-Saharan Africa use charcoal as their main source of cooking energy (Zulu and Richardson 2013). Ernst and Young (2014) predict an increase of natural gas consumption in Africa of 2,0% per year. Water hyacinth might be used as a resource for carbonization. If the production of biogas is a more feasible solution cooking using gas can be promoted. The water hyacinth biomass can be digested in the following resources:

- Biogas
- Bioethanol
- Charcoal

3.2.1 Water hyacinth as a resource for the production of biogas

New sources of energy are being explored by governments, research institutes and companies. One of these sources of energy is the digestion of biomass into biogas. Gas has been produced from several agricultural products and household wastes. The costs of the production of biogas from agricultural crops have been evaluated by Chynoweth, (Chynoweth *et al*. 2011). It was found that 26,1% of the costs of the production of biogas come from crop production for biomass for digestion. Water Hyacinth can be a good alternative to agricultural crops because there are no production costs for water hyacinth biomass. Gas derived from water hyacinth biomass should therefore in theory be a good and cheap source of biomass for the production of biogas. The biomass only needs pre-treatment for optimal biogas production.

Biogas is produced by several bacteria which convert carbohydrates and sugars into methane, hydrogen and carbon dioxide by anaerobe fermentation. For the fermentation of biomass it is important to break down complex components of the plant. This can be done mechanically, chemically and by biological fermentation.

For the biological break down of biomass there are four important processes for the digestion of biomass for the production of methane:

1. Hydrolysis
2. Acedogenasis
3. Acetogenesis
4. Methanogenis

The temperature of biogas digestion depends on the bacteria used for digestion. These can either be mesophyll or thermophile bacteria. For the production of biogas from water hyacinth in the tropics and sub-tropics Van der Werf (2014), from W+B recommends the use of mesophyllic bacteria. Mesophillyic bacteria are less sensitive to changes and therefor easier to maintain.

Pretreatment of water hyacinth is required to ensure optimum production of biogas. The moisture content of water hyacinth is too high with 94%. A mixture of different sources of biogas can also be used for biogas production. Another way to decrease the moisture content is by shredding and milling of the biomass. Shredding of water hyacinth biomass also enhances the access of microbes (Larsen *et al*. 1991) For water hyacinth fermentation the optimum particle size was evaluated, Moorhead, (1993) concluded that a particle size of 6,4 mm favored the methane production better than a size of 1,6 mm and 12,4 mm. However Verma (Verma *et al*. 2007) concluded that the optimum particle size for production is 5 mm.

The chemical content of the feedstock is also important for the optimization of biogas production. Too high nitrogen content can for instance kill bacteria. The optimum C:N ratio for microbial activity lies between 25/32:1 (Kivaisi and Mtila 1997), 20/30:1 (Chynoweth *et al*. 2001).Water hyacinth as can be seen in table 4 has a C:N ratio varying from 25,1/15,8:1 which can be favorable for the production of biogas from the biomass. If water hyacinth contains too many heavy metals the production of gas decreases. If the concentration of heavy metals is not too high they increase the production of gas because they acts as micronutrients for the bacteria digesting the biomass into gas (Verma *et al*. 2007).In several literature sources (Gunnarsson and Petersen 2007) Water hyacinth was mixed with other wastes to optimize the characteristics of the feedstock. It was found that the combination of water hyacinth and cattle manure yields the highest amount of gas (Ofoefule *et al*. 2009). Apart from the highest yield of biogas cow manure does contain enough microorganism which can serve as inoculum (Gunnarsson and Petersen 2007). There addition of other chemicals can also contribute to a higher biogas yield. The addition of NaOH based on 3 wt% for instance, will increase the production of methane and hydrogen from water hyacinth biomass (Cheng *et al*. 2010).

Water hyacinth can be fermented in different kind of digesters. Van der Werf, (2014) recommended based on experience with fermentation of wastes, a single stage digester as the best choice for the fermentation of water hyacinth biogas in the sub-tropics. Other biogas digesters are more difficult to maintain as the processes have to be controlled very accurately. As for developing countries the decision of a digester that is easy in control and maintenance is most likely. The Digestion of water hyacinth can be done either by a continuous or a batch process. Water hyacinth will most probably be delivered continuously or stockpiled near the fermentation facilities. It is therefore most argumentative to use a continuous digestion process. It is also easier to maintain and automate a continuous process than a batch process. The retention time of the biomass depends on the biomass and the digestion environment. The retention time varies between 30-50 days In hot areas digestion can have a retention time can only be 14 days whereas in a colder environment it can take 100 days (Yadvika *et al*. 2004). The digestion time depends on the bacteria used for digestion. A shorter retention time is desired as a longer retention time requires a large volume digester, which can increase the capital costs. The production per ton biomass is lower with a lower retention time. The optimal retention time for water hyacinth was estimated by M. van der Werf, 2014 to be around 30 days.

Apart from biogas also sludge is produced during anaerobic digestion. The sludge might be used in agriculture as an organic fertilizer. The fermentation sludge contains minerals water hyacinth contains. Application of sludge on agricultural lands adds nutrients to the soil but also improves the soil structure and the water capacity of the soil (Larsen *et al*. 1991). The heavy metals the plant contains also remain in the fermentation sludge. If the heavy metals in the sludge do not exceed the legal threshold levels the sludge can be used as a fertilizer in agriculture. If the sludge however does contain too much heavy metals disposal of the sludge can be a problem. The handling of the waste sludge can therefor differ per area.

3.2.2 Water hyacinth as a resource for bioethanol production

Agricultural products are currently used for the production of bioethanol. In the Americas maize is often used as a source for the production of bioethanol. The production costs of maize are high and also require energy. The net yield of bioenergy from maize is therefore low. The use of agricultural crops for energy competes with the production of food crops. The prices of maize increased since maize was used for the production of bioethanol (Babcock 2012). To prevent competition of agricultural product for food and energy wastes should be used for energy production. Water hyacinth should therefore be considered as a possible source for the production of bioethanol.

For the production of bioethanol from wastes lignocellulose is fermented to alcohol. Lignocellulose consists of lignin, cellulose and hemicellulos. The lignocelluloses have to be broken down into smaller components to produce alcohol. For the production of alcohol from water hyacinth the biomass required pre-treatment, hydrolysis and finally fermentation of reducing sugars (Sarkar *et al*. 2012).

The aim of pre-treatment of the biomass is make the lignocellulose biomass susceptible to quick hydrolysis to monomeric sugars (Sarkar *et al*. 2012). Pre-treatment solubilizes and separates each of the components from the lignocellulose. Pre-treatment can be done by 1) physical treatment 2) psychochemical treatment 3) chemical treatment or 4) biological treatment.

Of these 4 options mechanical pre-treatment or steam explosion is most often used to break down the lignocellulose matrix. Another easy method to break down the complex is addition of acids or alkaline substances. Similar to anaerobic digestion sodium hydroxide can be used to enhance the production of ethanol. Biological pretreatment is a relatively slow method to break down the lignocellulose complex (Sarkar *et al*. 2012) it is therefore not recommended to use biological pretreatment.

Saccharification is a critical step in the production of bioethanol. Saccharification is the hydrolysis of complex carbohydrates into simple monomers, glucose and xylose (Sarkar *et al*. 2012). After this hydrolysis the monomers are fermented by yeast into alcohol. The output of the fermentation process is distilled to produce pure alcohol. The process of saccharification and fermentation can be done simultaneously (SSF) or the fermentation can be separated from the hydrolysis (SFH) (Ganguly *et al*. 2012). SSF is found to be more productive and yield more ethanol (Mishima *et al*. 2008).

3.3 Water Hyacinth as a potential resource for building blocks in industry

For the production of chemicals or other substances for industrial purposes fossil fuels or raw sugars are used as an input. Some of these chemicals can currently be produced using biomass. According to Van Stralen (2014) the production of these chemicals is nowadays mainly done by fermentation sugars or carbohydrates from agricultural crops. Biotechnical engineering has made bacteria that are able to convert organic wastes into organic chemicals useful for the industry. The purchasing of agricultural products which are also used for food crops are fairly expensive whereas waste is for free. The Dutch government even pays companies to accept organic waste to digest into biogas according to Van Stralen (2014). Production for industries from wastes such as water hyacinth can compete with products obtained from fossil fuels and agricultural crops according to Van Stralen (2014).

The production of chemicals which can be used in industry from wastes is fairly new. There are at least two (Chaincraft, 2014) start-ups that are able to produce chemicals which are useful for the industry from waste but currently this is all still laboratory scale. There might be a transition to waste conversion into valuable chemicals in the future. The following two products which are interesting for industries which can be produced from water hyacinth biomass have been identified:

- Water hyacinth biomass as biosorbent
- Lactic acid production from water hyacinth biomass

3.3.1 Water Hyacinth roots as a biosorbent

Adsorption is an important process for water purification and separation of chemicals. There are several chemicals that can be used as an adsorbing agent. Studies show that biomass and especially roots can be used as a cheap resource to adsorb substances from solutions (Low *et al*. 1995). Water hyacinth roots can also be used as a bioadsorbent.

Biosorbents are an effective and clean adsorbing agent. Other adsorbents have some negative characteristics compared to biosorbents (Low *et al*. 1995):

- High energy requirements
- Toxic residual sludge
- Reagent requirements
- Incomplete metal removal

Recent studies have investigated the potential of dried water hyacinth roots to be used as a biosorbent. The dried roots of water hyacinth have a high sorption capacity for the removal of metal ions (Zheng 2010). The roots of the plant are a waste product if water hyacinth is used for agriculture. The use of the roots as biosorbent can be a good alternative for the use of the biomass. Water hyacinth roots are cheap and easily available compared to other adsorption techniques. The roots are also effective for the removal of heavy metal ions from solutions. The dried roots furthermore have no other nutrient requirements for effective adsorption (Mahamadi 2011).The roots can also be used as biosorbent to remove pollutions like dyes from water (Low *et al*. 1995).

A minimal amount of sludge is produced if water hyacinth roots are used for adsorption. There seems to be potential to also recover valuable metals with the water hyacinth roots. The roots can be re-used and the metals are extracted. (Mahamadi 2011). From research it can be concluded that water hyacinth roots can certainly be used as a biosorbent. More research is however required to investigate to the potential of recovery of the metals adsorbed.

3.3.2 Lactic acid production from water hyacinth biomass

Organic chemicals are of great importance for the chemical industry. Lactic acid is widely used in cosmetics, as mordant and in the food industry. Lactic acids are currently mostly produced by the fermentation of sugar. Because major steps have been made during the last couple of years in the processing of wastes, more complex structures can also be used for the production of lactic acid. Water hyacinth biomass can be an alternative source for the production of lactic acid, gluconic acid, itaconic acid, citric acid. These chemicals are the basic ingredients for laundry detergents, glues, preservatives and polylactides (Gallert and Winter 2002).

By Saccharization of water hyacinth biomass glucose and xylose can be produced which can be fermented to lactic acid and other chemicals. During the production of silage from water hyacinth lactic acids are produced. For the production of silage either sugars or other sources of carbohydrates need to be added, ie molasses or maize bran. For the production of organic chemicals from biomass it is likely that similar additives are required. More research is however required to get a better understanding of how to optimize production of organic chemicals from water hyacinth biomass on a large scale.

3.4 Current Water Hyacinth Utilization projects

Humans have tried to eradicate water hyacinth from water bodies since the middle of the 20th century. Total eradication of water hyacinth has not been successful. The use of the water hyacinth biomass has been considered during the last ten years. To assess the possibilities of processing water hyacinth biomass it is important to know what is currently done to control the plant and also if there have been any initiatives in processing the water hyacinth biomass.

It was found that research has been done to select natural enemies of water hyacinth to control water hyacinth biologically. Seven arthropod species have been introduced in several countries to contribute to the control of water hyacinth(De Groote *et al*. 2003). Weevils have however not been very successful in managing the plant since it is still years after introduction. Often a combination of mechanical and biolgocial control, Integrated control, is used. Chemicals are also sometimes used . Water Hyacinth is susceptible to herbicides such as 2,4-dichlorophenoxyacetic acid (2,4-D), diquat, paraquat, and glyphosate (Malik 2007). The use of chemicals only results in short term removal of water hyacinth. Chemical control is used in hydropower dams, in Ghana for instance, as water hyacinth clogs the system and evaporates more water (FAO, 1998). In other countries of chemicals have not been used because it is prohibited. The use of chemicals is nowadays more controversial as there is more awareness on the effect of chemicals on the environment.

Harvesting of the weed is probably the best option to keep water hyacinth infestation at controllable levels. Harvesting will have a limited effect on the environment compared to chemical control while it yields quicker response than biological control. The biomass of the harvested water hyacinth is used in several places in the world. Several water hyacinth utilization projects have been identified at different spots all over the world. In literature (Cheng *et al*. 2010)/(Gunnarsson and Petersen 2007) several small scale tests have been conducted for the use of water hyacinth biomass for biogas, animal feed and fertilizer. Local farmers have also applied water hyacinth on their field as fertilizer on small scale. Only a few large scale projects to use water hyacinth have been identified.

The ongoing projects identified can be classified into three different categories:

1. Biogas
2. Fertilizer
3. Other/Weaving

3.4.1 Biogas

The most promising projects using water hyacinth biomass for biogas production are the Serigas projects in India. Serigas (2014) produces biogas from water hyacinth waste. Serigas proclaims to have much higher methane content in biogas than conventional digestion. The Serigas process can produce between 120 m^3 and 200 m^3 bio methane per ton biomass. Van der Werf, (2014) mentioned that these proclaimed outputs are higher than conventional anaerobic processes. Not only Serigas has been looking at the potential of water hyacinth for gas production. Pyöry (2014), an international consulting and engineering firm started a pilot project in Guatemala to convert water hyacinth biomass into biogas. Apart from this the water hyacinth has been used as feed for ruminants by the local population. All stakeholders in this project are currently working on funding for a large scale water hyacinth biogas project.

Deltares (One World, 2014) (SustainableMotion, 2014) participated in the student contest "business challenge Ghana". A group of Dutch students has been working in Ghana together with local students on a solution for the water hyacinth problem. The students proposed a boat which harvests and onboard processes water hyacinth into biogas. The boat will deliver gas once every two weeks to several villages. The follow up on this project has not been communicated.

3.4.2 Fertilizer

In the Philippines water hyacinth is used to make compost. Grassroots Integral Development Initiative (GIDI) coordinates the production and selling of water hyacinth fertilizer (Minda News, 2010). The water hyacinth plants are collected by local people and sold to the composting facilities. The water hyacinth is composted and can be sold for 250 Philippine Peso (equals ,.50 euro, 1 Euro=55,6 PHP, 15-12-14) per bag. GIDI is able to produce 10000 bags of organic fertilizer per month.

3.4.3 Other/Weaving

There are also several projects supported by NGO's or western governments to support small scale project that can contribute to the livelihood of local population.

In Kenya there are several initiatives to produce baskets, bags and paper from the fibers of water hyacinth. Local woman collect the water hyacinth and produce bags and baskets to sell to local markets. Water Hyacinth can contribute to the livelihood of the families who collect and use the water hyacinth.

The Kottapurum Integrated Development Society (KIDS) together with India Canada Environmental Facility (ICEF) stimulate the use of water hyacinth in India by (The Hindu, 2006):

- Use of fibers by local woman for baskets, bags
- Biogas
- Fertilizer

4 Business Model

4.1 Business model

To assess the feasibility of processing water hyacinth and selling the products obtained from the weed it is important to develop a business model. To formulate a business plan, the following should be defined, the business model, value chain and economic model. A business model describes to whom a company sells and how it generates a profit (Fritscher and Pigneur 2010). It also identifies to position of a company within the supply chain. The business model will give an insight in the cost structure of the value proposition and in how profit is generated. Understanding how a company functions is required to make the cost & benefit analysis and the subsequent investment analysis. To assess the feasibility of water hyacinth processing it is required to know the role of the different stakeholders throughout the supply and value chain.

For the development of the business model for water hyacinth processing it was decided to narrow the scope. Based on feasibility of the several utilization options described in chapter3 .It was decided to define a business model for the following options:

- Biogas
- Fertilizer
- Animal feed

To develop the business model an understanding is required of the impact of processing of water hyacinth and sales of the products made from the plant on internal and external stakeholders. An understanding of the legal status of the processing and sales of water hyacinth made products is also required. For the businesses model it is therefore needed to assess the following aspects:

1. Environmental impact. The environmental impact of harvesting and processing of water hyacinth is generally positive because the weed is major environmental hazard as described in 4.1.1
2. Legal status. The legal status of harvesting and processing of water hyacinth is unclear because it is such a widespread problem as described in 4.1.2
3. Socio- Economic impact. The socio-economic impact of water hyacinth is removal and processing is generally positive as described in 4.1.3.

4.1.1 Environmental impact is a driver for water hyacinth use

The overall environmental impact of the removal and utilization will contribute to a more sustainable environment. Water Hyacinth is a worldwide problem with a tremendous environmental impact on the ecosystem the weed invades. Water hyacinth can colonize areas and suppress local species. The weed has a negative impact on the water quality, variety of species and the whole ecosystem.

If gasses produced from water hyacinth are not stored in a safe and responsible way methane can escape into the atmosphere. Methane has a much higher greenhouse gas potential than carbon dioxide. The emission of methane from the processing plant but also from the local household consuming the biogas should be prevented and controlled. Also other gasses such as carbon dioxide will be produced during the production of biogas. These gasses have to be extracted from the gas before sales of the product. If biogas is used for the generation of electricity the waste fumes should be managed. If the water hyacinth is composted preventive measures should also be taken to prevent leaching of nutrients and heavy metals.

4.1.2 Legal status can become a problem if water hyacinth becomes an asset

Because the problem of water hyacinth is found throughout the world in different countries it is not possible to define a precise legal status as this might differ per location. It is however possible to point out potential legal issues that can occur for harvesting and processing the weed.

The ownership of the water hyacinth can be unclear. Water bodies are often used as a border between countries, provinces and municipalities. Lake Victoria for instance, a lake where water hyacinths flourishes is part of Kenya, Tanzania and Uganda. At the moment ownership of the water hyacinth is not desired. Currently water hyacinths are associated with costs because they need to be managed. If there is a market for products obtained from water hyacinth a discussion on the ownership of the biomass might arise. Clear arrangements with the country government to prevent problems with ownership of the plant should be made before investment. For the processing facilities some land has to be acquired. Land can governmentally owned, leased for an certain amount of time or privately owned. It needs to be assessed how this influences the investment risk and how this can be mitigated.

4.1.3 Livelihoods can benefit from water hyacinth products

Water hyacinth is the cause of several complications causing harm to different socio-economic aspects. As described in Chapter 1 water hyacinth blocks fishing grounds, irrigation systems and hydropower systems. On a household level, there is a large impact if fisherman can't fish due to blockage of fishing grounds. The same applies to farmers whose crops fail due to lack of water when their irrigation system is not working due to clogging. As water hyacinth can also clog big hydropower systems there can also be a much larger economic effect. The removal of water hyacinth will therefore have a positive socio-economic impact. The socio-economic impact of cultivation of water hyacinth in a controlled manner can also have a positive impact as it prevents over fishing in areas of the lake. The perception and acceptance of cultivation of local inhabitants might however differ on this matter, because water hyacinth is seen as a big threat by fisherman.

The sales of products obtained from water hyacinth especially fertilizer and animal feed will contribute to the local development of agriculture. Agriculture is often the most important source of income in rural areas in the developing world. A boost in agricultural production due to application of fertilizer or feeding protein which enhance livestock growth will therefore have a positive socio-economic impact.

4.2 Scenarios

The problem of water hyacinth is widespread and found in water bodies all over the tropics and sub tropics varying from irrigation systems, to great lakes. It is difficult to make a general assessment for water hyacinth harvesting and processing. The production of biomass, the accessibility and the investment risk differ tremendously per area but also for different sized and shaped water bodies. There are also different approaches for the management of the water hyacinth 1) total eradication and 2) management of the weed. In large water bodies it is deemed impossible to eradicate the plant whereas it is feasible to eradicate the weed in smaller water systems such as irrigation systems. Total eradication of water hyacinth will also not be beneficial if a large investment is made in harvesting equipment and processing facilities.

In some cases products which can be obtained from water hyacinth are of interest for the local market. Specific proteins may for instance not be as valuable in a very remote location as in a city. It is therefore important to determine if there is a market for the processed water hyacinth biomass. The investment costs differ per processing option. The investment in equipment and facilities are much higher for a protein extraction plant than if compost is produced. The decision for investment and processing facilities also depends on the size of the infestation. Large scale processing of water hyacinth is only feasible in big water surfaces like lakes. To make the different circumstances more tangible it was decided to describe the processing and harvesting solutions for the following scenarios:

1. Great lakes
2. Rivers
3. Irrigation systems/small streams/small ponds

4.2.1 Great Lakes

In several big lakes including Lake Victoria and Lake Volta, water hyacinth has a tremendous impact on the environment and the local economy (Villamagna and Murphy 2010). If water hyacinth is abundant in large mats it is feasible to harvest and process the biomass. For the scenario of a big lake the example of Lake Victoria is used, because several studies have been done on the impact and distribution of water hyacinth. In the past, water hyacinth has covered at least 17500 hectares in Lake Victoria. The area covered by the weed was probably even bigger. After intensive control and removal of water hyacinth the infested area decreased significantly. It was also recognized that the cloudy and wet weather of EL Nino, 1997-1998 could have been a major contributory factor to the poor growth of water hyacinth leading to the reduction during the end of the last century (Williams *et al*. 2005).

For this scenario water hyacinth coverage of 12000 hectares and a shoreline infestation of 80% was assumed as was the case in the lake in 1995 (Albright *et al*. 2004). Such coverage indicates an average water hyacinth infestation of 43 m of water hyacinth from the shore into the lake. The water hyacinth is found in mats of several hectares on the lake. Thus, the infestation is much higher in areas where these mats are abundant. Villages and cities are often near the bays resulting in higher nutrient and contamination levels in the bay. The water hyacinth thrives in these nutrient rich conditions. It is therefore considered to develop a processing plant in one of these bays. If the water hyacinth reaches 43 m into the lake a distance of 229 m along the shoreline has to be harvested to harvest 1 hectare of water hyacinth.

If water hyacinth is going to be harvested from a Great Lake it is optimal to design an area in which water hyacinth will be cultivated. By designing such an area continuous feed is secured and transport distance to the processing facilities will be standardized and optimized. In such a case, the major transport routes should first be cleared of water hyacinth and then controlled by an appropriate harvesting scheme. Water Hyacinth is easily transported over great distances by wind. If water hyacinth is cultivated and controlled for the production of proteins and biogas floating objects should be installed to prevent the spreading of water hyacinth. Within the setting of a lake, water hyacinth will be blown to the production facilities a number of days a year. The size of such a harvesting area will therefor differ per area for similar capacities

The areas used for cultivation should be chosen in consultation and agreement with the local governments and inhabitants. Harbors for instance need to be cleared from water hyacinth to ensure water transport and fishing is possible. At other places which are less densely populated, water hyacinth growth is not very problematic. Most problems that occur due to water hyacinth are near densely populated areas. Thus, a market for the products obtained from water hyacinth is close by.

4.2.2 Rivers

Water hyacinth also the causes of a lot of problems in different sized rivers. Rivers are often an important medium for transportation. When a river is infested with water hyacinth and clogged the weed has to be removed. Biomass processing facilities will most likely be situated on a fixed location. It can be questioned if the transportation distances of water hyacinth obtained from a river are too high for a profitable harvesting and processing operation. Some of the equipment for processing such as the protein extractor can be transported, in such case a river can be an interesting medium for water hyacinth utilization.

The Nseleni River in South Africa is used as an example for a river infested by water hyacinth. This river was infested for 17,1 km and clogged the river over its whole width in some areas (Jones and Cilliers 2001). An average shoreline infestation of 70 % was assumed and the water hyacinth coverage of 50 % of the river. This results in coverage of 140 hectares. This is more than the required area for water hyacinth processing. The transport distance of an infested river will be higher than a lake infested by water hyacinth. There may be a variation in the amount of infestation per river because of size differences but also due to difference in infestation persistence. An investment in expensive processing facilities is therefore not recommended. The biomass could be used for compost, silage and small scale biogas digesters.

4.2.3 Irrigation Systems

In an irrigation system it is not desired to have any growth of the water hyacinth as it increases evaporation up to 48% compared to free water evaporation (Van Der Weert and Kamerling 1974) and can clog the canals resulting in non-performance of the irrigation system. In an irrigation system, total eradication of water hyacinth is desired. In such case a large investment in a processing plant on a fixed location is not recommended. Irrigation systems vary in size and shape, within an irrigation system there are huge differences between the canals. To make it more tangible the assumed irrigation system as described below is used as example.

An irrigation system with a total length of 20 kilometers was assumed to be an average sized irrigation system. The canal size in such a system varies enormously; an average canal width of 2,5 m is used. If an irrigation system with such a size is heavily infested by water hyacinth, i.e. 70%, 3,5 ha are covered. The area covered is too small to feed a large scale processing facility. In such case the water hyacinth biomass can be used as compost. There will be several farmers who use the irrigation system for water and can collect to weeds to use as compost. The institution or corporation running the irrigation system also can produce the fertilizer and sell it to the local farmers.

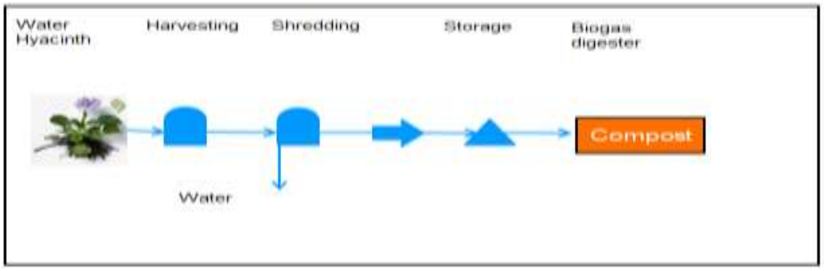
4.3 Process flow

To get an understanding of the processing of the biomass for the different options, 1) fertilizer 2) feed and 3) biogas as defined in section 4.1 it is required to describe the different steps. This can be done by defining the process flow. In the case of water hyacinth the process flow depends on the desired product. The first steps of the process flow are however similar for all three options. The process flows of fertilizer, animal feed and biogas production and a combination of biogas and animal feed production are described in this chapter. There are no ongoing projects using water hyacinth biomass to produce feed, fertilizer and gas. The process flow described is there for hypothetical.

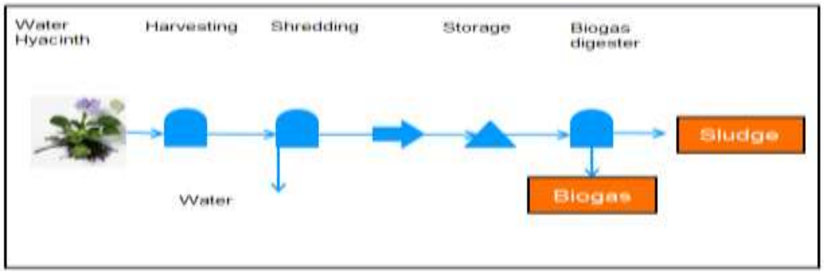
For each final product it is required to harvest and shred water hyacinth biomass. It is recommended to integrate harvesting and shredding. The weed has a very low primary density because it contains a large amount of air filled spaces. After shredding the density will be much higher. Transport of the shredded plant material is also easier because the shredded product can be pumped. After harvest and shredding the biomass is transported by barges to shore where it can be stored. After harvest the shredded biomass can in all cases be processed without any other pre-treatment. At the processing facility the biomass can be moved by conveyer belts. At the operating facility a group of six personal is able to maintain and operate the refinery, digester or composting facilities.

For the production of compost the process is straight forward. The biomass has to be left to compost and mixed twice a week. The production of biogas, as shown figure 13, is undertaken by feeding the biomass to a digester to be left in there for a certain retention time. For the production of proteins from water hyacinth the roots and leaves should be separated. A boat which is able to separate these during harvest has to be designed. This boat will be operated by minimal two personal. In Appendix V the initial design of such a boat can be found. The leaves will be harvested by a similar mower as used for grass harvest in agricultural practices. The roots then remain in the water to be harvested by a conveyer belt similar to boats that are currently used for harvesting water hyacinth. The roots and leaves will both be shredded separately on the boat. As the volume of the required feedstock for the bio digester will likely exceed one barge, two barges are used. One of the barges will transport the leaves and the other barge the roots. If only one barge is required the barge should have two separate compartments for the leaves and roots.

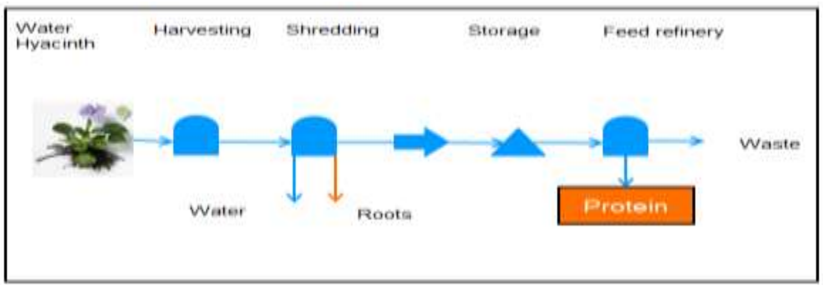
Figure 13 shows the integrated approach of feed and biogas production. It is most likely that such processing facilities will be build. This process flow is a mixture of the separate flows for feed and biogas production. In this figure, the weight of water hyacinth per hectare is added and it shown what fraction is used for each purpose. It is assumed there is 48900 kg of water hyacinth biomass available per hectare as will be explained in chapter 5. Due to the efficiency rate of the boat not all of the water hyacinth is harvested. There will be a continuous demand for biogas and animal feed, thus a continuous supply of water hyacinth is required. Fertilizer can only be applied during specific times during the growing season. The fertilizer produced from water hyacinth should be available during these times of year and storing facilities are required and need to be built.



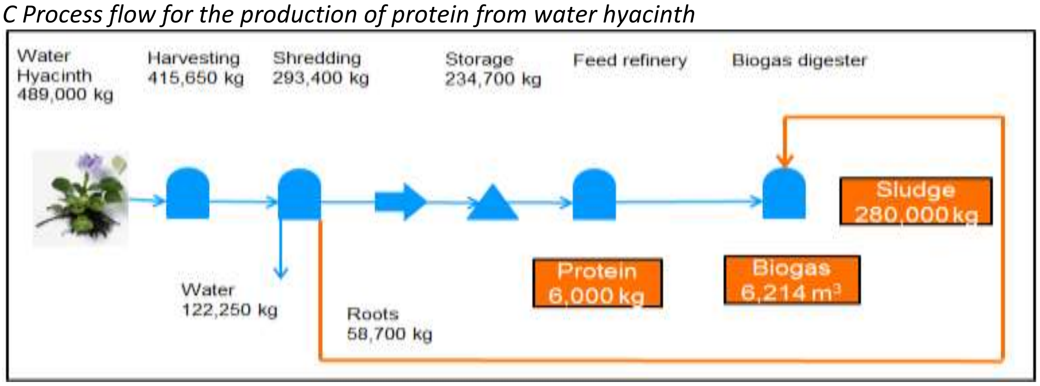
A Process flow for the production of compost from water hyacinth



B Process flow for the production of biogas from water hyacinth



C Process flow for the production of protein from water hyacinth



D Process flow for the integrated production of animal feed and biogas from water hyacinth

Figure 13. Process flow to obtain compost(A), gas(B) and feed(C) and a combination of fertilizer, feed and gas (D)

4.4 Canvas Business Model

For the design of the business model, a Canvas was used. The Business Model Canvas is a strategic management and entrepreneurial tool. It allows the user to describe, challenge and invent a business model (Osterwalder, 2010) The Canvas business model consists of nine building blocks as can be seen in figure 14. These building blocks were derived from a literature review of a large number of previous conceptualizations of business models (Fritscher and Pigneur 2010). In the center of the business model the value proposition can be found. The value proposition describes the business advantage of the business model. The customers, the way how the customers are reached and the desired customer relation are also assessed. On the other side of the model it is shown how the value proposition is delivered by the resources, key activities and the partner network. The financial information of the business model is found in the cost structure which are aligned with the core ideas of the business model and the revenue streams which shows the value customers are willing to pay and how they desire to pay (Fritscher and Pigneur 2010). In figure 14 the relations between the different building blocks can be found.

The canvas business model is used in this research as it has the ability to describe the business logic of a company in one page (Fritscher and Pigneur 2010). The business canvas is a structured way to assess what activities are required to deliver the value proposition, how the customer is reached but also the financial information of the value proposition and the relationships.

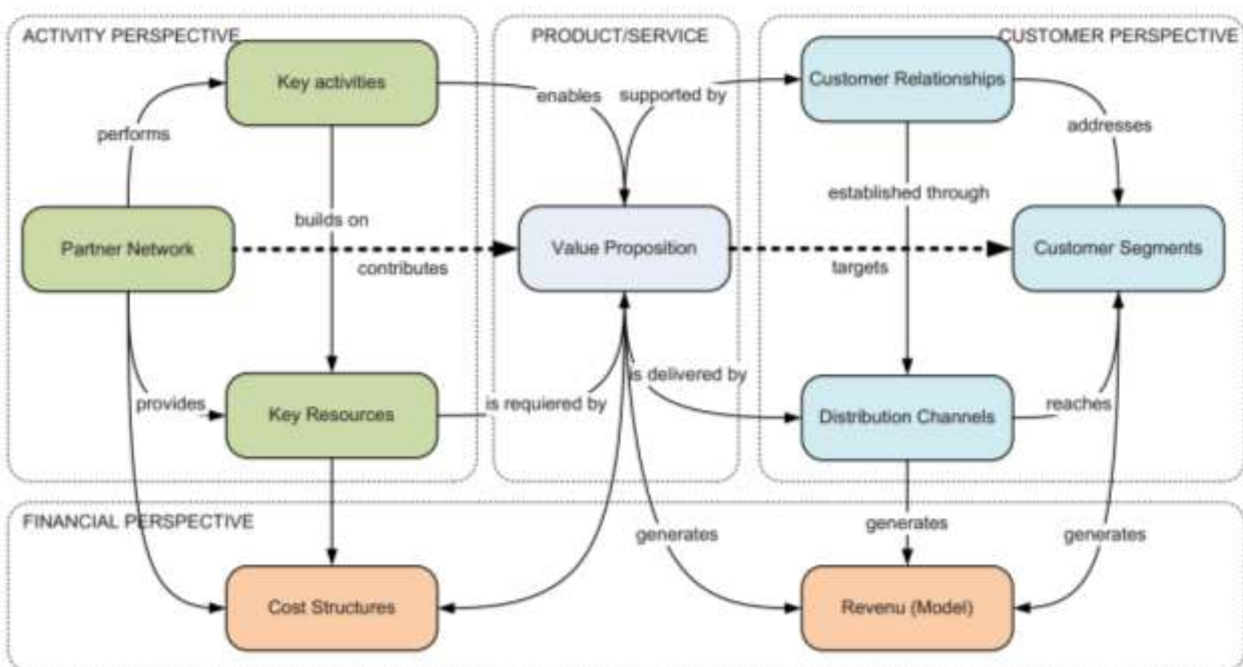
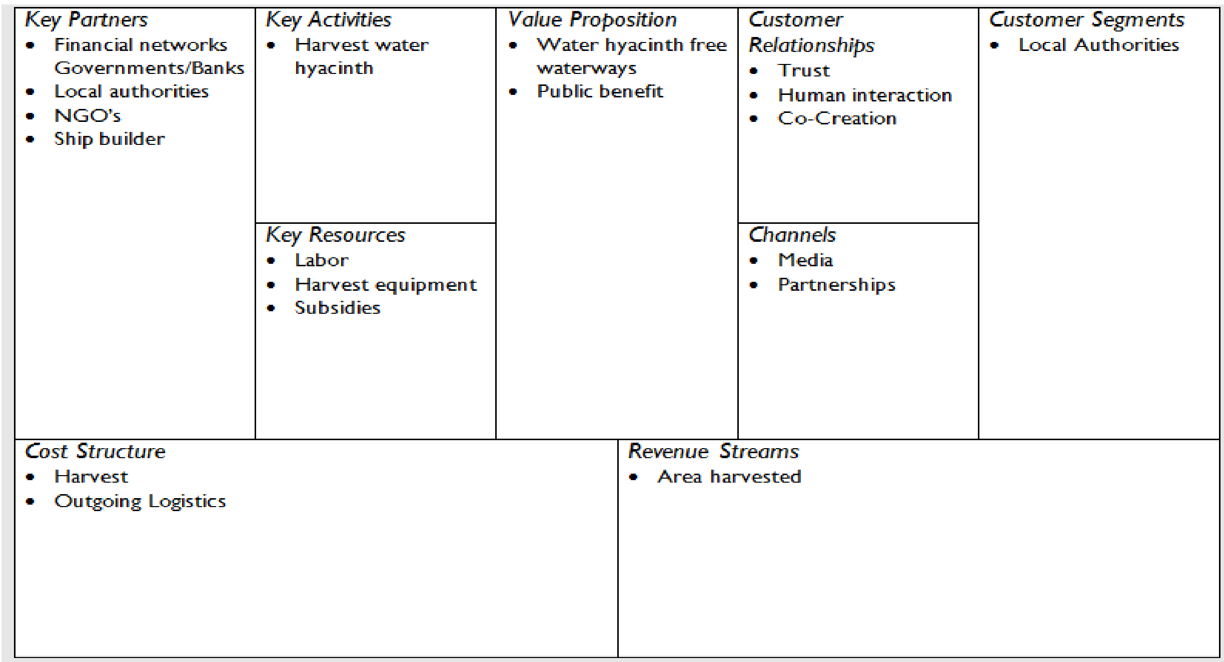
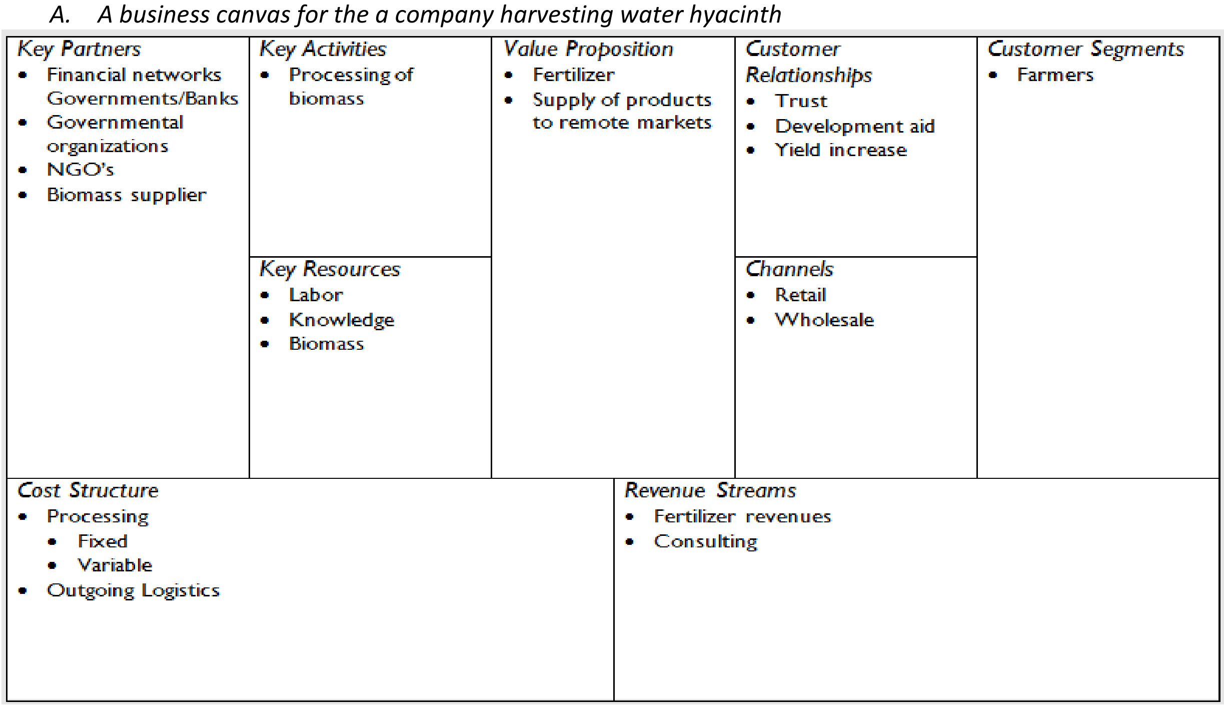


Figure 14. Canvas business model building blocks and relations (Fritscher and Pigneur 2010)

In figure 15 A-F several canvasses can be found for the different value propositions from water hyacinth. In these figures a canvas can be found for the different revenue streams of water hyacinth processing. In figure 15 F the envisioned business model can be found. In the envisioned business model proteins will be extracted from the biomass through refinery, the waste products from this process will be used as feedstock for bio digestion. There are several different figures because the canvas of the envisioned model in unbundled. Osterwalder (2010) describes that companies exist of three fundamentally different businesses. In this case the corporate companies exist of 1) customer relationship businesses 2) product innovation business and 3) infrastructure businesses. It is explained that these three types of businesses can co-exist within one company but that they preferably should be unbundled (Osterwald 2010). For water hyacinth processing there are also different businesses, i.e. production of animal feed and harvesting of water hyacinth. To get a better understanding of the business model of water hyacinth harvest and processing the business are first unbundled in figure 15 A-E and then rebundled in figure 15 F.



A. A business canvas for the a company harvesting water hyacinth



B. A business canvas for a company producing fertilizer from water hyacinth biomass

Key Partners
- Financial networks Governments/Banks
- Animal feed companies
- NGO's
- Biomass supplier

Key Activities
- Processing of biomass
- Research

Key Resources
- Labor
- Biomass refinery
- Knowledge
- Biomass

Value Proposition
- Animal feed/ Proteins
- Supply of products to remote markets
- Alternative to conventional feed sources
- Sustainability

Customer Relationships
- Consistency
- Feed Quality
- Contracts
- Yield increase

Channels
- Retail
- Wholesale
- Media

Customer Segments
- Farmers
- Animal Industry

Cost Structure
- Processing
  - Fixed
  - Variable
- Outgoing Logistics

Revenue Streams
- Protein revenues
- Animal feed revenues
- Consulting

C. business canvas for a company producing animal feeds from water hyacinth biomass

Key Partners
- Financial networks Governments/Banks
- Governmental organizations
- NGO's
- Biomass supplier

Key Activities
- Processing of biomass
- Research

Key Resources
- Labor
- Biogas digester
- Knowledge
- Biomass

Value Proposition
- Biogas
  - Cooking gas
  - Electricity generation
- Supply of products to remote markets
- Sustainability

Customer Relationships
- Trust
- Human interaction

Channels
- Retail
- Energy network
- Media

Customer Segments
- Farmers
- Families
- Local industry

Cost Structure
- Processing
  - Fixed
  - Variable
- Outgoing Logistics

Revenue Streams
- Electricity revenues
- Gas cylinder revenues
- Fertilizer revenues

D. A business canvas for a company producing biogas from water hyacinth biomass

Key Partners
- Financial networks Governments/Banks
- Local authorities
- NGO's

Key Activities
- Processing of biomass

Key Resources
- Labor
- Biogas digester
- Knowledge

Value Proposition
- Carbon Credits

Customer Relationships
- Trust
- Sustainable Energy

Channels
- Media
- Climate conventions

Customer Segments
- Authorities
- Corporates

Cost Structure
- Energy Generation

Revenue Streams
- Carbon Credit Revenues

E. A business can for a company earning carbon credits by processing of water hyacinth biomass

Key Partners
- Financial networks Governments/Banks
- Local authorities
- NGO's
- Animal feed producers
- Ship builders

Key Activities
- Cleaning waterways
- Processing of biomass
- Research

Key Resources
- Harvest equipment
- Labor
- Biogas digester
- Knowledge
- Biomass refinery
- Subsidies

Value Proposition
- Water hyacinth clean water ways
- Fertilizer/compost
- Animal feed/proteins
- Biogas
- Carbon credits
- Supply of products to remote markets
- Public benefit
- Sustainability
- Alternative to conventional feed sources

Customer Relationships
- Trust
- Human interaction
- Co-creation
- Yield increase

Channels
- Retail
- Energy network
- Media
- Partnerships

Customer Segments
- Farmers
- Families
- Local industry
- Animal (feed) industry
- Local authorities

Cost Structure
- Harvest
- Processing
    - Fixed
    - Variable
- Outgoing Logistics

Revenue Streams
- Fertilizer revenues
- Electricity revenues
- Feed revenues
- Gas cylinder revenues
- Carbon credits
- Revenues for harvest of water hyacinth
- Consulting

F. A business canvas for a company producing animal feed and biogas from harvested water hyacinth biomass

Figure 15. Business canvas models for harvesting and processing of water hyacinth into several products (A-F). The figure A-E are unbundled business from the suggested overall business model which is shown in figure F.

4.4.1 Key Partners

- Local authorities, for instance the water authorities. If the local authorities are involved a strategy in line with local governance for the removal of water hyacinth can be developed.
- Water hyacinth processing is not the core business of Royal IHC or W+B. They will both not be running a project. A partner who will run the project needs to be selected. It can be an NGO, government, western corporate or animal feed producer.
- For the funding of this project a partner should be selected this will either be a bank or a (western) government investing in development aid. Success has not been proven on a large scale water hyacinth project. To ensure a project will be started subsidies are most likely required.
- Another key partner for the utilization of biomass is the ship builder of the harvesting equipment. The design of the ship can be changed depending on the desired products.

4.4.2 The Key Activities

- The control of water hyacinth
- Processing of biomass into compost, animal feed and fertilizer
- Research to obtain more valuable products. Some specific proteins can be very valuable. Technologies to extract them are often still in a developmental phase. Continuous research to extract these proteins is therefore recommended.

4.4.3 The Key Resources

- Harvest equipment
- Bio digester
- Biomass refinery
- Local skilled and unskilled labor
- Subsidies
- Knowledge on how to control, process and use water hyacinth biomass. The water hyacinth should be harvested in a way to ensure sufficient production of biomass for the processing facilities but also to ensure minimized social, environmental and economic impact of the weed.
- Biomass

4.4.4 The Value Proposition

- Cleaning of waterways to limit the negative impact of water hyacinth
- Production of proteins, biogas, fertilizer, carbon credits
- The products obtained from water hyacinth processing will be available for local farmers often located in remote places. These farmers normally don't have access to these products. A water hyacinth project can therefore contribute to the development of such remote areas.
- Specialized equipment to harvest water hyacinth suitable for processing into animal feed, biogas and fertilizer
- Water Hyacinth has the potential to produce more proteins per hectare than Soya as mentioned in chapter 3. It can therefore be a good alternative source of animal feed production.

4.4.5 The Customers

- Local farmers; Animal feed and fertilizer are scarce in most parts of Africa. A water hyacinth project may allow farmers to buy relatively cheap feed and fertilizer.

- Local Households and industry; The Energy produced from biogas can be used by local households and by industrial companies. If the gas produced is sold as cooking gas this will mainly be bought by rural and urban households.
- The animal industry can be a customer of high quality animal feed which otherwise needs to be transported from other areas.
- Local authorities can buy the services to control water hyacinth.

4.4.6 The Customer Relation

- Trust is the basis of this business model. The products obtained from water hyacinth will help to increase yields of crops and livestock.
- Human interaction
- Co-creation; Together with authorities a harvesting/mining schedule will be made to ensure sufficient production while solving the problems of water hyacinth.

4.4.7 Channels

- Electricity grid, if electricity is produced from water hyacinth biomass this can be delivered to the local electricity grid, if available.
- Retail and wholesale can be used to distribute consumer goods, like gas cylinders throughout an area.
- Media; In Kenya water hyacinth project are often mentioned by the media. If the media propagates the use of water hyacinth products this can reach potential customers.

4.4.8 The Cost Structure

- Capital investment and operational costs of equipment for both harvesting and processing of the water hyacinth biomass.
- Outbound logistics

4.4.9 The Revenue Streams

- Sales of animal feed, biogas and fertilizer, and cleaning of waterways
- This project will contribute to a more sustainable environment and reduction of carbon dioxide emissions and might thus generate carbon credits.

4.5 Value chain analysis

The value chain of water hyacinth biomass has to be defined to assess the feasibility of the use of water hyacinth biomass as a resource. It is required to understand which companies can make a profit by harvesting and using water hyacinth biomass and at which position in the value chain they make this margin. It also identifies the position of IHC and W+B within the value chain and which other parties should be involved in the startup of a processing project. Identifying the value chain can also identify the added value of the processing of water hyacinth as described in this thesis compared to other initiatives. Processing of biomass is not the core business of either royal IHC or W+B. The processing should be executed by a different partner. Thus, a key question for this research is who will actually run processing facilities. The value chain analysis also helps in identifying potential partners who can perform the operation.

For the assessment of the value chain Porters value chain analysis is used. In figure 16 the value chain can be found. Porter's value chain disaggregates a company into strategy relevant activities to understand the cost structure (del Carmen Díaz-Peña
. 2013). It is needed to create a general understanding of the cost structure to understand if processing is feasible and under what circumstances. If harvesting is paid for the return of processing might for instance be higher

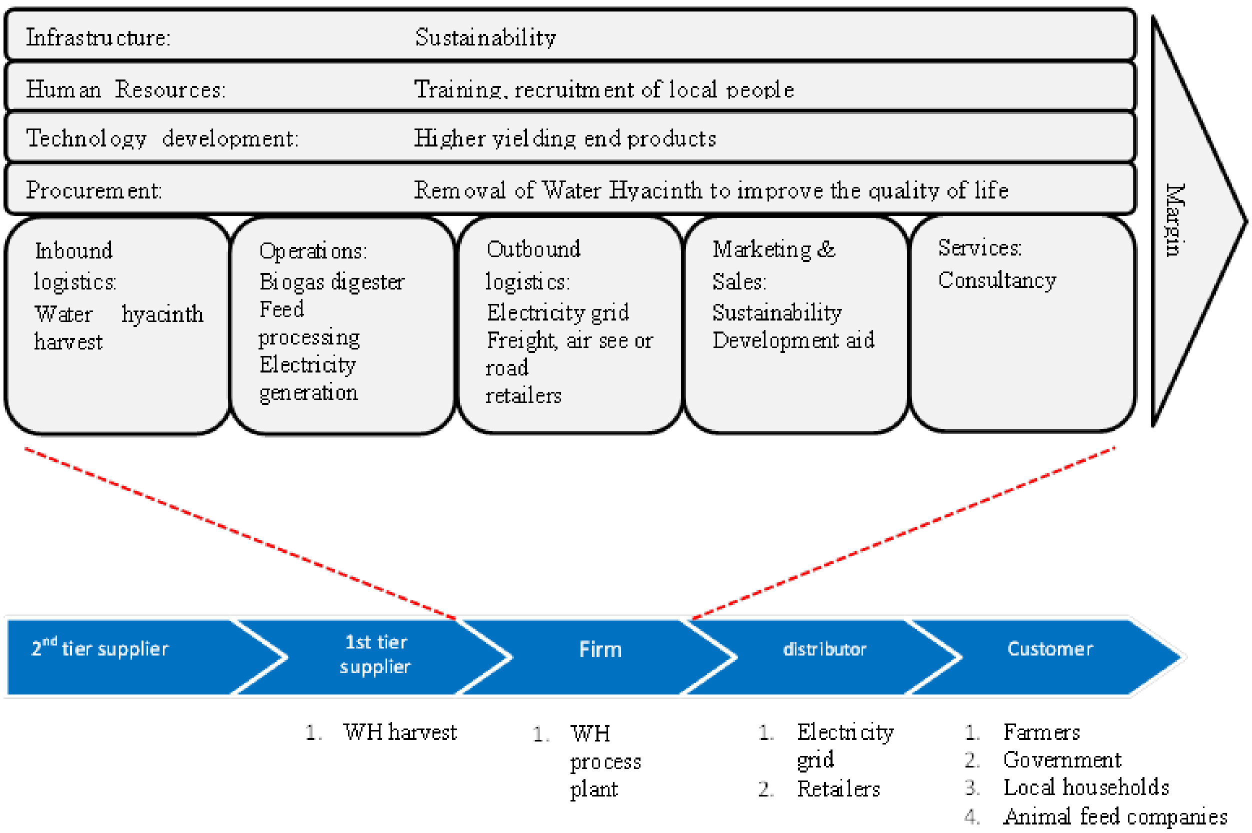


Figure 16. Porters Value chain for processing of water hyacinth into animal feed, and biogas

4.5.1 Inbound logistics

For each utilization option harvested water hyacinth biomass is required. In some cases the water hyacinth is removed by the government or private companies. They can supply the processing plant with the harvested biomass. Another option is that the processing company itself harvests the biomass. It might gain income by the removal of water hyacinth. The company needs to buy equipment in order to harvest the water hyacinth, such as specialized boats. The equipment can be adapted to ensure that the harvest product is pre-processed. If the leaves are for instance the only product of economic value, only the leaf should be supplied to the processing plant. Consultancy and training from the equipment builder or other companies can also be part of the inbound logistics

4.5.2 Operations

The processing costs of the biomass depend on products. Based on the cost benefit analysis it was decided to produce a combination of animal feed, biogas and fertilizer from water hyacinth biomass.

4.5.3 Outbound Logistics

The total costs of outbound logistics will depend on the location of production.

The electricity can be distributed by the electricity network in the country. In some countries the electricity grid is privately owned whereas in other countries this is a governmental owned infrastructure. It might be the case that payments are required for the use of the electricity grid. Furthermore there will be losses of electricity over distance between the power generation plant and the final customers. The cooking gas and compost will most likely be sold to local markets. Therefore local wholesalers and retailers are targeted to sell the compost and cooking gas to the local farmers and households. The wholesalers and retailers are able to pick up the cooking gas and compost from the processing facility. If water hyacinth is processed to concentrate feed it can be shipped over large distances as this feed can compete with other animal feed sources.

4.5.4 Marketing & Sales

The social and economic impacts of water hyacinth are important reasons for the harvesting of water hyacinth. Because water hyacinth biomass is considered waste, the final products might be cheaper than other competing products.

4.5.5 Service

There arise no costs from services. The people contributing to the sales will give advice on how to use the products. This will however not increase the costs of product sold.

5 Economic Model

The main objective of this research is to determine whether it is economically feasible to build a large scale processing plant to obtain valuable products from water hyacinth. To answer this, an economic model was built. This model will help to assess the effects of the capacity of processing facilities and the effect of market prices on the feasibility of water hyacinth harvesting and processing. This chapter describes how the economic model has been built and the economic results for several processing options. Two important findings of the economic model are that it is economically feasible to process water hyacinth at large scale and that there is a big difference in economic feasibility depending on the products made from water hyacinth.

To assess the economic and financial feasibility an economic model has been built. This model is based on several assumptions either derived from literature or based on prior knowledge. The assumptions for the economic model can be separated into two clusters:

1. Assumptions of water hyacinth characteristics
2. Investment and cost-benefit assumptions

5.1 Assumptions on plant characteristics

There are several assumptions made to calculate potential production of feed, fertilizer and biogas which are based on the plant characteristics. In Chapter 2.1 plant characteristics based on several literature sources were described. For the model the quantitative information from this chapter is used to calculate the potential outputs of water hyacinth products. The production amounts are required to calculate the potential income of the processing facilities. The main assumptions that were made to calculate the potential outputs are based on the following issues:

- Crop growth and yield
- Processing of water hyacinth into gas, feed and fertilizer

5.2 Crop growth and yield characteristics

To assess the amount of water hyacinth biomass that can be processed on a daily basis it is required to know the production of Dry Matter (DM) water hyacinth per hectare. Earlier it was reported that on average 48,9 kg/m^2 fresh water hyacinth biomass was found. To calculate the dry matter production a dry matter content of 6 % was used. The annual production of water hyacinth found in literature is very high up to 140 ton DM per year. To calculate the annual production of water hyacinth an average growth of 200 kg/ha/day was used which results in a yield of 73 t DM/ha/y. A yield of 73 t DM/ha/y is realistic and is also in line with the data found by (Gopal, 1978) as shown in table 1. This means that for production facilities with a capacity of 2 MW 500 hectares of water hyacinth are required.

Table 3. Average water hyacinth density per m^2 and hectare and biogas production per g DM as found in the literature study

	FW kg/m^2	Biogas production l/g DM
Average	48,9	0,212
Min	30	0,143
Max	71,6	0,291
Production per hectare	489000 kg	6214 m^3 biogas

It is not possible to retain all the biomass during harvest. The efficiency of harvesting is assumed to be 85% because some of the biomass will be lost during separation of the leaves and shredding. During the harvesting of water hyacinth the roots are separated from the shoots. To calculate the amount of root biomass a root weight fraction of 20% was used (Spencer 1981). For the transportation of water hyacinth biomass the density is significant. If the density of water hyacinth is higher, it is easier to transport as it requires less space. The density of fresh water hyacinth was found to be 167 kg/m^3 (Bagnall 1982). After shredding, the density increases significantly and it is assumed to be 900 kg/m3 as all the air filled spaces are shred and some of the moisture content is lost during shredding.

5.3 Biogas, feed and fertilizer production

In chapter 3 the production rates for fertilizer, biogas and feed from water hyacinth dry matter are described. The numbers described in this chapter will be used to calculate the potential production of biogas, feed and fertilizer.

The average gas production is based on the numbers found from different literature sources. In table 5 the average gas, minimum and maximum gas production per gram DM can be found. The size of the biogas digester depends on the desired energy capacity. To calculate the size of the biogas digester a specific energy of biogas, 23 MJ/m3, was used (BINAS, 2006). The size can now be calculated based on the gas/feed ratio of the digester, capacity and retention time. The volume of the biogas digester will consist of 66% feed and 34% gasses. Biogas will continuously be taken from the digester. The retention time of water hyacinth in a biogas digester is assumed to be 28 days based on the recommended retention time described in Chapter 2. It might be better to have a smaller retention time because the size of the digester can then be decreased. Depending on the capacity of the biogas digester the size will differ. The capacity has to be decided based on the outcomes of the model.

Biogas can either be sold as cooking gas or it can be used to generate electricity. If the gas is used for the generation of electricity a lot of the energy is lost because of low efficiencies. The overall efficiency of electricity generation from water hyacinth biomass was calculated to be 14,6 %. According to literature (McKendry 2002) the overall efficiency of the production of electricity from biomass varies between 10 and 16 %. The 14,6% was calculated based on the efficiency of electricity generation from biogas, which was found to be 20,8 % (Pipatmanomai *et al*. 2009). Furthermore the production of biogas was assumed to be 70 % from the potential conversion of biomass into biogas.

The numbers for production of proteins from water hyacinth are based on an interview with prof J. Sanders, 2014, professor at Wageningen University and one of the founders of Grassa, which follow the Grassa refinement process. From grass 15% of the wet biomass can be processed into protein enriched slurry. Because water hyacinth has a lower dry matter content it was estimated water hyacinth, after shredding, only produces 7,5% enriched slurry. Based on an input of 10 t of fresh biomass per hour and an operation time of 8 hours per day, 6 ton of protein enriched slurry is produced. The remaining biomass will be transported to the biogas digester for gas production. For the production of proteins only the leaves are suitable. The leaves and roots are collected separately during harvesting. The roots will immediately be processed to biogas.

Table 6 shows the amount of nutrients per hectare of water hyacinth. The amount of nutrients are calculated based on the average content from table 4. These nutrients can be applied on to agricultural fields as fertilizer.

Table 4. Average nutrient content on DM basis found in a literature study and the nutrients per hectare based on 29 t DM/ha

	DM %	kg/ha
Nitrogen	1,9	564
Phosphorous	0,4	126
Potassium	3,1	904

In the Netherlands it is allowed to apply 230 kg of Nitrogen per hectare (Compendium voor De Leefomgeving, 2014). These regulations differ however per location depending where water hyacinth grows. The Dutch regulations are therefore used as a benchmark for the application of compost/fertilizer. The biomass of one hectare of water hyacinth can be used to fertilize 2,5 hectares of agricultural fields. Depending on the area harvested the inland market for the sales of fertilizer can be determined. For the sales of compost and fertilizer sludge it is important to have a market close to the production facilities. The value of fertilizer is probably not very high. Transport cost should therefore be minimized.

5.4 Economic assumptions

To define the economic feasibility the investment costs, operational costs and income have to be defined. Estimating the costs and income of a project processing water hyacinth in general is not possible because locational factors will have a big effect on the costs and income. Costs of specialized equipment are not easily accessible. Equipment manufacturers are not willing to provide this information. Estimating the operation and capital costs can therefore be difficult. The operational expenses are therefore also based on assumptions.
In this section the assumptions are explained for the following topics:

- Capital Investment
- Operational costs
- Market Prices
- Net Present Value

5.5 Capital investment

The capital expenses (CAPEX) of facilities and equipment are mostly based on literature (Metso, 2014) and prices of comparable products in the Netherlands. The capital investment requirements for a project can be found in Appendix I. The capital expenses for bio digestion were based on the ADP calculator. This is a tool to calculate the economics of a bio digester in Western Europe. The increase in investment of equipment is not linear with the increase of capacity of equipment. Because one of the purposes of the economic model is to assess the optimal capacity assumptions have to be made to estimate the investment of equipment. From literature (Bruins and Sanders 2012) formula 2 was found to estimate the increase of investment costs compared to an increase in capacity. The R is estimated to be between 0,6-0,8 (Bruins and Sanders 2012). The R used for the cost benefit analysis was 0,7.

$$\frac{\text{Size2}}{\text{Size1}} = \left(\frac{\text{Cost2}}{\text{Cost1}}\right)^{R}$$ Formula 2

The size of the harvesting boat depends on the required capacity. The capacity of the boat is calculated by the width and speed during harvest of the boat. Based on discussions within IHC it is assumed that the speed of the harvesting boat during harvest will be around one m/s. If the harvesting equipment has a width of 4 meters, 4 m^2 per second is harvested. When the boat is operated 8 hours per day 11,5 hectares can be harvested daily. The decision is made that two barges with a large capacity will be used to transport the harvested water hyacinth. It was also assessed whether piping could be used for the transport of water hyacinth from the harvester to the processing facilities. If a boat is merely used for the harvesting of water hyacinth the capital investment of pipes will be too high. The barges will be transported back to the processing facility by the harvesting boat. At the harvesting facility the water hyacinth biomass can be stored.

5.6 Costs and benefits

The total revenues are calculated by the sum of the product revenues, royalties and residual value. For this project it is assumed the only revenues come from product revenues. The product revenues depend on the capacity of the processing plant and on the price of the products. The market prices of electricity, cooking gas and fertilizer have been estimated based on literature (Nonhebel and Kastner 2011) (Nuon, 2014) and data from W+B and Royal IHC.

The costs for this project consist of the operational costs, indirect costs, depreciation, amortization, interest, carried forward losses and taxes; these can also be found in Appendix II. The operational expenses (OPEX) consist of salaries, maintenance costs and cost of energy. It was assumed that the maintenance costs will yearly amount to five percent of the initial investment. The energy costs depend on the size of the equipment. In appendix A the amount and costs of the required energy and manpower can be found. The processing facilities require energy 24 hours per day. It is likely that processing plant will be built in an area with regular power cuts. A diesel generator is therefore used. Based on the calorific value of diesel it is assumed that 10 kWh is generated by one liter of diesel. In appendix I the energy requirements for all equipment can be found based on a daily harvest and processing of 3 hectares for a working week from Monday to Friday. It was assumed there are no indirect costs.

In appendix II a balance for the first twenty years of a running water hyacinth can be found. The annual net profit is calculated using a few steps. First the EBITDA (Earnings Before Tax, Amortization, Depreciation and Interest) is first calculated. The operational costs and indirect costs are subtracted from the revenues. The EBIT (Earnings Before Interest and Tax) is then calculated. The depreciation of this project was defined to be linear distributed over the lifetime, 20 years, of the project. There is no amortization because no intellectual property rights apply. The earnings before tax (EBT) are calculated by subtracting the interest and carried forward losses from the EBIT. The interest was set to 2% over the loan. The Interest rate is low, because it is assumed that some subsidies will contribute to the investments of this project. The net profit is calculated by subtracting the taxes from the EBT. It can be discussed if tax should be paid or not. In a lot of developing countries there are favorable tax rules for investors. Payment of tax will however contribute to the development of a country. Based on discussion with stakeholders from the companies involved, it was decided to include payment of taxes in the business model. Taxes will be different per country. For the business model a tax of 20 % is assumed.

5.7 Net Present Value (NPV)

The net present value is calculated to identify if the future earnings are profitable compared with today's value of the investment. To calculate the Net Present Value (NPV) of this project an investment analysis is done, which can be found in appendix II. For the investment analysis the net operation cash flow should be calculated. The net operational cash flow is calculated as the sum of the cash in and cash out during the projects lifetime. The cash in is calculated by the sum of the EBIT, depreciation and carried forward losses. The cash out is calculated by the sum of tax, investment and working capital.

The NPV is then calculated by discounting the net operational cash flow. For the calculation of the net present value the discount rate was set at 5 %. For normal mining project the discount rate is set at 10-15%. The discount rate may however be different as this depends on the risk profile. A low discount rate was chosen as projects dependent on subsidies and with the purpose of development aid should not be compared to projects of major investment banks. The sum of the discounted net operational cash flow is the NPV, the formula can be found as formula 3. If the NPV is positive the investment should be made because the cumulative discounted earnings are higher than the investment. If the NPV is equal to zero the investment can be done but there will not be a net profit. IF the NPV is negative no investment should be made. Another Indicator for investors is the Internal Rate of Return (IRR). The IRR is defined as the interest rate that equates the present worth of a series of cash flow to zero (Hartman and Schafrick 2004). Both the IRR and the NPV were calculated for the different investment options.

$$\text{NPV} = \sum_{t=1}^{t} \frac{Cash\ flow}{(1+i)^t} - \text{Initial investment} \qquad \text{Formula 3}$$

5.8 Results of the Economic Model

The economic feasibility of this project is measured by the NPV. The NPV indicates how attractive an investment is for financiers. The feasibility of this investment depends on the obtained products from the water hyacinth and the desired capacity. The NPV an IRR have therefore been assessed for different capacities and production options.

With the economic model as described in section 5.1 and 5.2 the different options for the processing facilities have been assessed. A range of capacities, products, mixture of products, market prices and investments have been measured. The purpose of these tests is to assess which capacity and product will be most profitable. The Internal Rate of Return (IRR) is an indicator which represents the feasibility of the project. A higher IRR means a better return on investment. In table 7 the IRR and minimum product price for a positive NPV value can be found for different capacities and products obtained from the water hyacinth. The prices used in this table are all estimates based on reference prices like soy or local electricity prices. In the graphs in figure 19 the NPV and the sensitivity of the OPEX, revenues and interest rate can be found for the production of biogas, proteins and silage.

Table 5. NPV and IRR for different water hyacinth products and capacities. The column products shows the price used for the calculation, the product minimum product price shows the minimum prices to ensure a positive NPV.

Products	Capacity	minimum product price NPV>0	IRR
Animal Feed, 300 €/t Biogas, 0,2 €/m^3 Sludge, 0,015 €/kg DM	2 MW	Feed Price > 235 €/t biogas price > 0,1 €/m^3	8,96%
Animal Feed, 300 €/t Biogas, 0,25 €/m^3 Sludge, 0,015 €/kg DM	1 MW	Feed Price> 295 €/t biogas price > 0,1 €/m^3	5,59%
Electricity, 0,12 €/kWh Sludge 0,015 €/kg DM	2 MW	Electricity > 0,27 €/kWh	NPV<0, The investment is not feasible
Silage, 10 €/t	1 ha/day	10 €/t	16,92%
Silage, 10 €/t	2 ha/day	10 €/t	10,03%
Compost			NPV<0, Not Feasible on large scale,

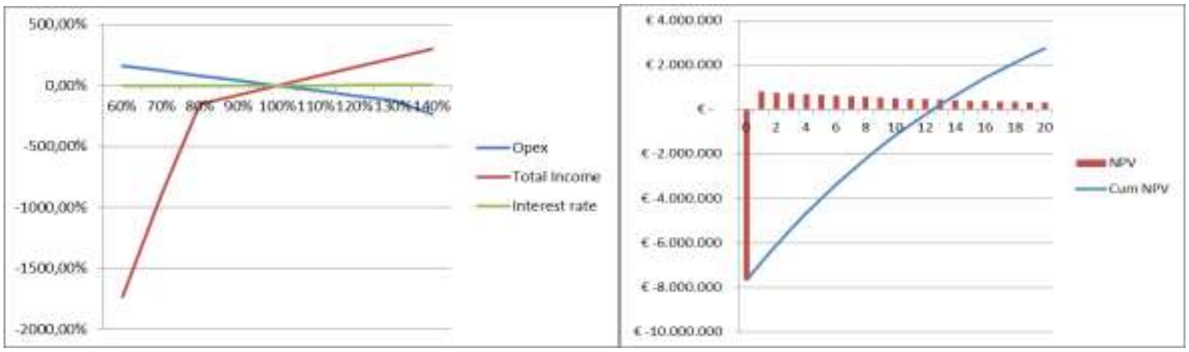


Figure 17. (Left) The cumulative NPV for animal feed and biogas production: 300 EUR/t, 0,20 EUR/m3 for a 2 MW biogas digester. The IRR in this situation is 8,96% (Right) Sensitivity of the OPEX, revenues and interest rate on the NPV.

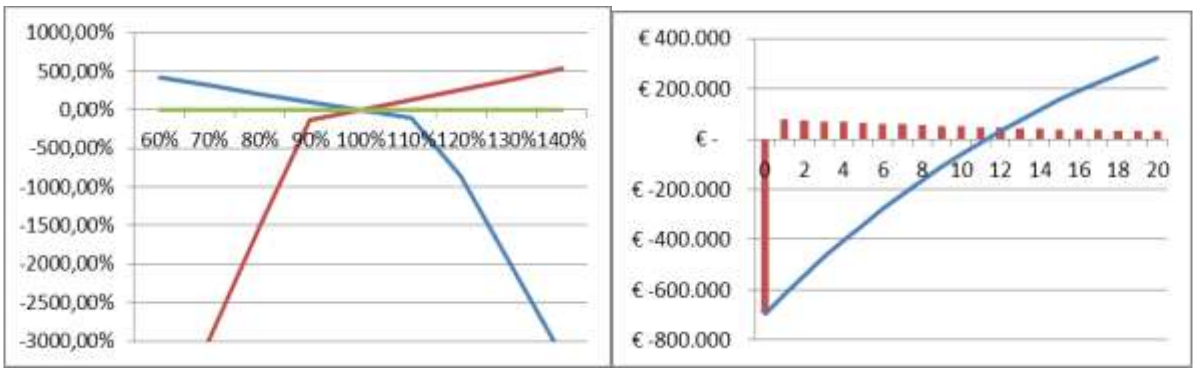


Figure 18. (Left) The cumulative NPV for Silage production: Price 10 EUR/kg Capacity 1 ha/day. The IRR in this situation is 10,03% (Right) Sensitivity of the OPEX, revenues and interest rate on the NPV.

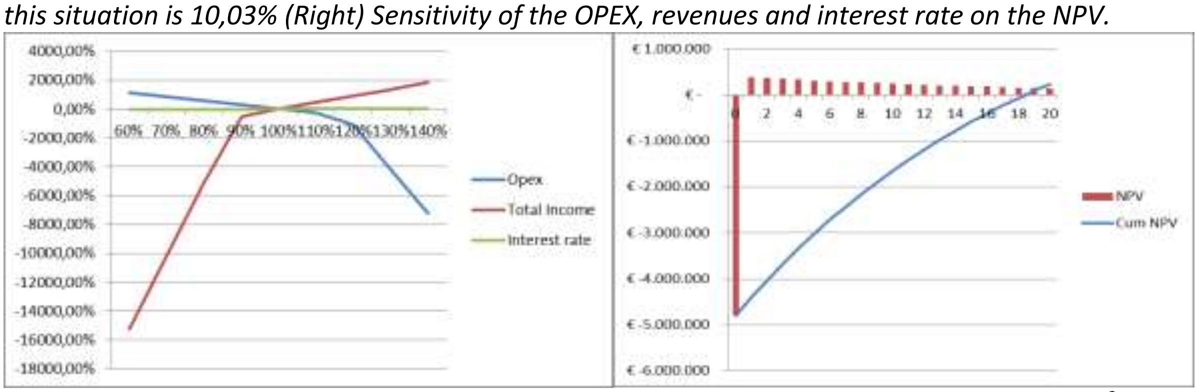


Figure 19. (Left) The cumulative NPV for Feed and Biogas Production: 300 EUR/t, 0,25 EUR/m$^{3.}$ The IRR in this situation is 5,59% (Right) Sensitivity of the OPEX, revenues and interest rate on the NPV.

It was found that the production of electricity and compost are not feasible. The initial investment is too high compared to the returns. The NPV of these operations is negative so investment is not recommended. Compost will not yield any profits because the investment is too high compared to the returns. Composting can however be done at smaller operations. The water hyacinth can then be manually be harvested or with cheaper equipment. Composting is the cheapest option with regards to investment in processing facilities. Especially in scenarios where there is not a lot of water hyacinth present composting is the best solution as the initial costs are low whereas high initial investment for the production for biogas and animal feed are required. Production of compost is in such a case the only economic option.

The investment in processing facilities for animal feed and biogas production has a positive NPV. The IRR also increases when the capacity of the processing facilities increase. The highest IRR is found when the water hyacinth is used for the production of silage. Also for silage production the IRR goes up if the capacity is increased. In table 7 it can be found that the IRR is highest for silage production because the initial investment is much smaller compared to the other processing options.

5.8.1 Sensitivity

There are several factors which have an effect on the feasibility of a water hyacinth harvesting process. It is required to assess the effects on the feasibility if these factors are changed. A sensitivity analysis was conducted to determine which factors have the largest effect when changed. The effects can have an impact on the operation costs and on the revenues of an operation. The external factors that have an effect on the project are mostly influenced by global market prices. This means that the project will have to deal with them or change strategy if the impact is too high. The operation is most sensitive to changes in diesel and animal feed prices.

The sensitivity to the different external factors can be found in figure 20. The energy required for the operation will be generated by diesel engines or a diesel generator. If the diesel price increases there will be a large increase in operational costs. Whereas an increase or decrease in labor price will only have a limited effect on the operational costs. Little labor is required because most of the processes are automated. As the water hyacinth problem mostly occurs in the developing world the labor prices are also relatively low compared to wages in the western world.

The price of animal feed will have the largest effect on the project. An increased demand for animal feed is expected due to a growing world population, higher demand for animal products and different use of biomass (Nonhebel and Kastner 2011). A bigger demand for animal feed will increase the prices. This will have a positive effect on the likelihood of implementing an operation to produce animal feed from water hyacinth.

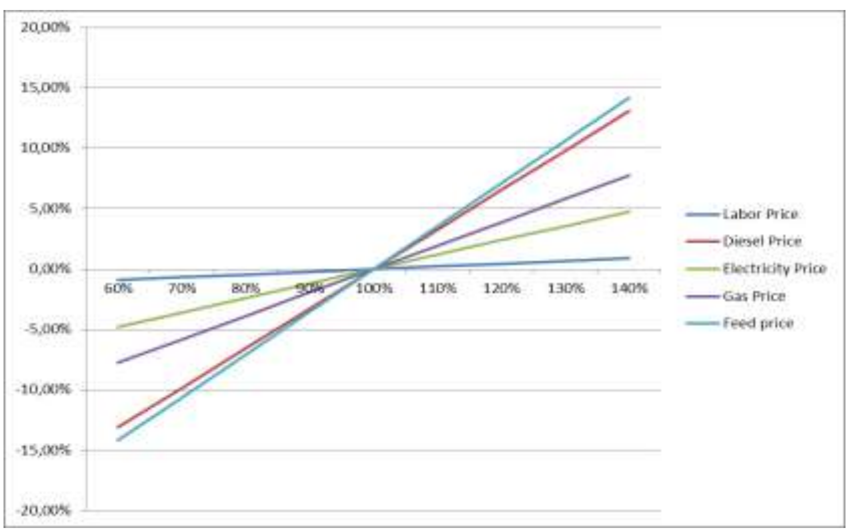


Figure 20. Sensitivity of prices on operational costs and income for the production of animal feed and biogas form water hyacinth

5.9 Value Chain Cost structure

In figure 21 the costs per operational activity as described in chapter 4.5 can be found. The costs are calculated per harvested ton fresh weight water hyacinth. The costs of operations were calculated by dividing the total production costs, the capital investment and the operational costs for the lifetime of the production plant, by the total production for the lifetime of the processing plant. For the calculations of these graphs a lifetime of 20 years is used. The costs structure found in figure 21 are based on a 3 hectares harvest per day. The main costs are due to harvesting and processing of the plant. From the two graphs it can be concluded that with the expected market prices there is still a relatively high margin. The two graphs differ because in the graph below the capital investment is also taken into account. Also in this graph there is a margin which indicates that over the lifetime of the processing facilities the investment is profitable.

The costs of outbound logistics, marketing & sales and services still have to be determined.

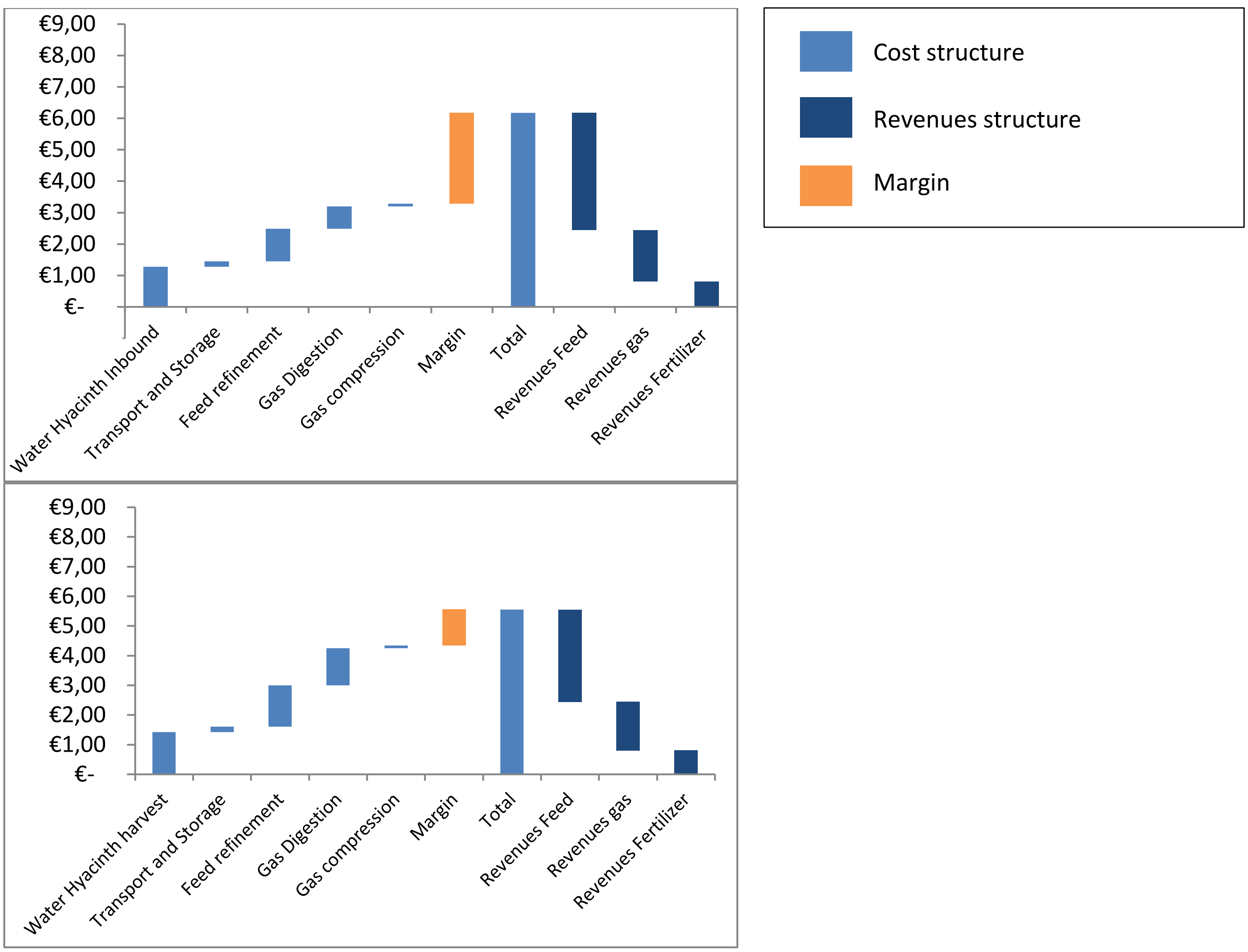


Figure 21. Cost and profit structure, in Euros per harvested ton, for a water hyacinth harvesting and processing plant based on OPEX and CAPEX above and OPEX alone below

6 Business Case

In the previous chapter the feasibility of water hyacinth processing has been assessed based on theory and assumptions. It is necessary to assess if it is possible to start a project somewhere in the world in a real situation. For this reason it was decided to conduct a field trip in Kisumu, Kenya, to assess if it is feasible to start a water hyacinth project in the area. Kisumu was chosen because it is known to be an area where water hyacinth thrives and because of the available literature about water hyacinth in Lake Victoria. The field trip served as fact finding trip to collect data about water hyacinth, market data and identify local stakeholders. The data collected during the field investigation was use to define a business case. The result of the business case shows that it is financially feasible to use water hyacinth as a resource. The constraints are however the availability of water hyacinth and the governance system. The economic model as described in Chapter 5 is more of a theoretical exercise, whereas the validation of the developed business case is meant as an evaluation of the economic model in a real world situation. The purpose of the business case is to:

1. Assess the occurrence, impact and initiatives to control water hyacinth
2. Assess water hyacinth value chain in Kenya and identify potential partners for a project
3. Assess market information
4. Assess how the potential markets can be reached and how to best startup a project
5. Define the sensitivity of the project by a Monte Carlo simulation

6.1 Study Area

6.1.1 Kenya

Kenya is a country in Eastern Africa on the Indian Ocean bordering Tanzania, Uganda, Ethiopia and Somalia. Nairobi is the capital city of the country, the second city is Mombasa. Mombasa is the biggest port of the country and important for the import of goods for the whole of east Africa. The country is divided into 74 administrative counties. Kenya is characterized by a varying topography and geology resulting in very varied land use and livelihoods. The economy is mainly based on services, 53,3% of GDP, and agriculture, 19,3 % of the GDP. Kenya has a population of 45 million of which around 75 % of the working population works in agriculture and only 25 % work in services (CIA, 2014).

6.1.2 Kisumu

The field investigation was conducted in Kisumu, the third city of the country located on the banks of Winham Gulf of Lake Victoria. Figure 22 shows the location of Kisumu on a map. Kisumu is Kenya's most important port on Lake Victoria with a ferry connection to both Uganda and Tanzania (CIA, 2014).

Figure 22. Kisumu, Kenya

There is a bi modal rain system in the Kisumu area with rains in October-December and February-May. Due to an increase in population and agriculture and the subsequent eutrophication the quality and ecology of the water changed drastically (Kiage and Obuoyo 2011). During the two rainy seasons the eutrophication is largest because of the run off from the agricultural fields and urban areas. Water hyacinth is a tremendous problem in Lake Victoria as it for example blocks the water for fishermen. The aggressive character of the plant is most pronounced in the Winam golf drainage area of which includes large areas of intensive agriculture and urban areas (Kiage and Obuoyo 2011). In figure 23 the distribution of water hyacinth can be found in the Kenyan part of Lake Victoria. Because water hyacinth causes such a large problem in Kisumu and it surroundings several initiatives varying in size have been set up in the area. During the fieldtrip it was found that weevils have been bred for biological control of the plant but manual removal of the plant has also been encouraged. The water hyacinth is abundant in cycles. The water hyacinth arrives from October onward in the Kisumu bay. By December the bay is packed with large mats which cause a huge problem for the local inhabitants. Only by April/May when the next rainy season starts the water hyacinth are blown towards the big lake by the winds. At this time the water hyacinth are overgrown by several other plants such as hippo grass. The plants then sink because of the weight of the other plants. The next year the plant returns once the seeds germinate.

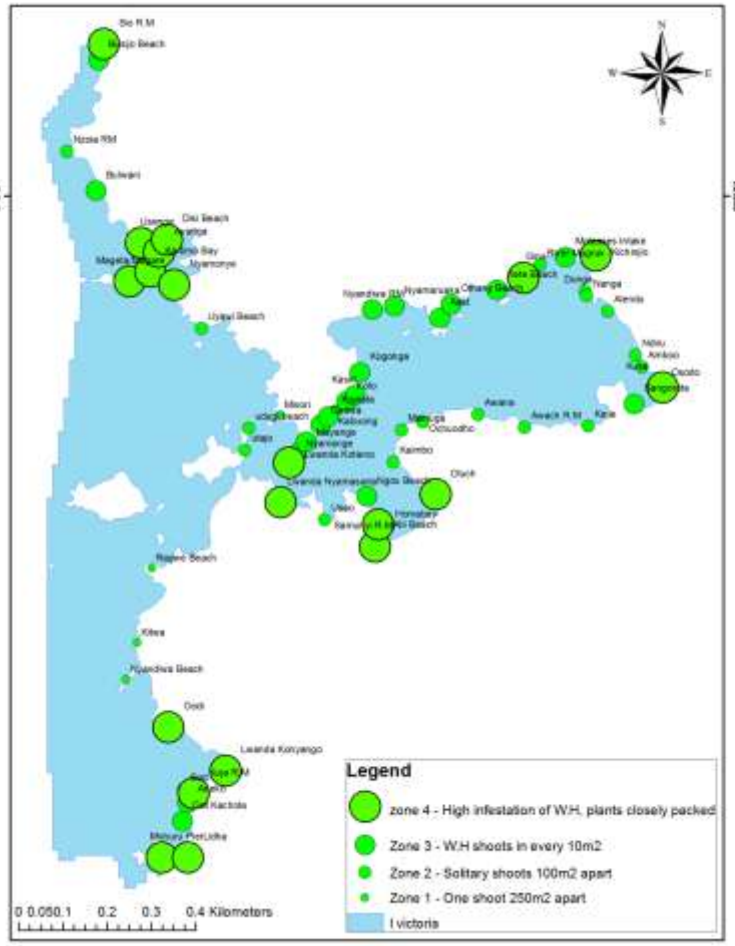


Figure 23. Distribution of water hyacinth in the Kenyan Part of Lake Victoria (LVEMP, 2014)

6.2 Possibilities for feed production in Kenya

To assess the impact of water hyacinth, interviews with the main stakeholders were conducted. The results of the interviews can be found in Appendix Appendix VI. The interviews were only held with the main stakeholders such as local governments, governmental and private organizations. Because of limited time in the study area no individual farmers or fisherman have been interviewed. It can be concluded that there are possibilities to start a water hyacinth harvesting and processing plant in the area because there is need for removal of the weed and the products obtained from the plant. For processing and harvesting water hyacinth collaboration with a private partner is desired. The private partner can be a company which manufactures one of the products that can be obtained from water hyacinth. Kenya is ranked 145th in the corruption index by Transparency International (2014). Collaboration with local government is therefore not recommended. The government can be a customer of the products but should not be a partner. There are also physical and socio-economic constraints as the plant is not abundant throughout the year and because of different interests of local policy makers and corruption.

To be able to come to such a conclusion the following aspects have been discussed during the interviews:

1. The impact of the weed on the inhabitants of the area
2. Use of water hyacinth biomass and opportunities for products obtained from the plant
3. Challenges for the use of water hyacinth biomass

6.3 Water hyacinth has a large socio-economic impact in Kisumu

The large mats of water hyacinth which occur during the summer time, as described in chapter 6.1.2, have a huge impact on the day to day life. The pollution of Lake Victoria is one of the main reasons why water hyacinth flourishes in the Winham Gulf.

Run off from agricultural fields and pollution from the city are the main causes of pollution. Some of the policy makers even described the lake as a big septic tank. Because of sedimentation dredging is needed in the port and other areas of the lake. The mats of water hyacinth are considered a huge pest by the local population impacting the accessibility of the lake and clean water. The impacts of infestation of water hyacinth include the following:

- Stops fisherman fishing
- Fisherman trapped by water hyacinth mats can't get back to shore and are killed on the lake
- Blocking of water intakes
- Boats can't enter the Kisumu Port
- More chemicals are required for water treatment
- Snakes, bilharzia and malaria thrive in water hyacinth

The economic impacts from the effects of the weed are high but difficult to quantify. The local fishermen have restricted access to their fishing grounds. According to the research done by LVEMP I (Wawire and Ochiel 2012) water hyacinth caused a decrease of 21,7% in the revenues from local fisherman. A lot of the people living around the lake are also dependent on fishing for their livelihood. Fishing in the Winham Gulf is an important contributor to the national economy of Kenya (Wawire and Ochiel 2012). It can be concluded that the impact of water hyacinth on the economy due to water hyacinth is high because of a decline in fishing revenues. The plant also prevents cargo ships from entering the port. According to the port manager there is a 90% decrease of cargo transport activity when water hyacinth covers the port. Water intakes in the lake are also blocked by the water hyacinth. The water company in Homa-Bay has 16000 KSh (equals 141 euro, 1 EUR= 113 KSh, 16-12-14) extra costs to unblock and repair the intakes every month when the water hyacinth is around. They have also built protective cages around the intakes to prevent them from being damaged. There are also extra 5000 KSh (equals 44 euro, 1 EUR= 113 KSh, 16-12-14) extra costs to clean the water when there is water hyacinth in the lake. This is only the costs for one water intake.

6.4 Use of water hyacinth is not propagated

There have been several initiatives from LVEMP (Lake Victoria Environmental Management Program) to reduce the water hyacinth infestation. LVEMP and the local governments do however not pay for the removal of water hyacinth.

The water hyacinth management initiatives have been diverse and include:

- Weevils are used as a biological control agent

- Manual harvesting
- One mechanical harvester is in operation, 3 others are ordered
- Prevention of pollution of the water

As some of the water hyacinth will be manually harvested and mechanical harvesters have been ordered, policy makers have been looking at the opportunities for using the biomass. National Policy makers are aware that the water hyacinth can be used as a resource for several activities. The use of harvested material is however not promoted. The intention is to harvest the weed and then dispose the biomass at a designated location. The water hyacinths should not have too high metal content if the biomass is used. There are also no large scale initiatives for the use of harvested water hyacinth. The weed is currently used for weaving by the local inhabitants to make art, baskets and furniture. This harvesting and weaving is done by Beach Management Units (BMU). The BMU's also received training from NGO's to compost the water hyacinth and use it as fertilizer for their fields.

From interviews it was concluded that there are also opportunities for using the biomass of the water hyacinth as animal feed, fertilizer and biogas. There is a huge milk deficit in the area. Diary programs will therefore by initiated in the upcoming years. The local production of animal feed for these programs is a problem. Apart from this, there are opportunities for animal feed In Kenya as animal feed is more costly than world market prices in Kenya. There is also a market for biogas in the Lake Victoria area. LPG cylinders are for instance even bought by farmers who live in remote areas. Biogas can replace the use of LPG and charcoal as it is a cheap alternative. Biogas is currently not commercially exploited in Kenya. Apart from selling the biogas in cylinders the gas can be used for electricity generation. KENGEN purchases electricity from generators with a minimum size of 200 KWe. Because of the low efficiencies of electricity generation from biomass this would require at least a 1 MW biogas digester. During the production of biogas also fertilizer is produced. There is a large market in the area around the lake for fertilizer as a large part of the local economy still depends on agriculture.

Kenya Organic Research Centre for Excellence (KORCE) was founded recently by an Indian investor. The purpose of this institute is to use biomass, including water hyacinth, as a source for energy. KORCE is located at on strategic point at the shore of lake Victoria. From this point several bays in the lake can be easily accessed. Figure 24 shows the location of the KORCE facilities. KORCE facilities can be used as a pilot for the project. KORCE has already purchased a water hyacinth harvester so that it can use the weed for briquetting. The investments and returns required for processing at the KORCE mentioned in the interview are however doubted. The investment costs and the return on investments differ a lot from data found for this thesis, literature. The facilities can still be a suitable place to start a pilot for a project because of the location and infrastructure to the facilities.

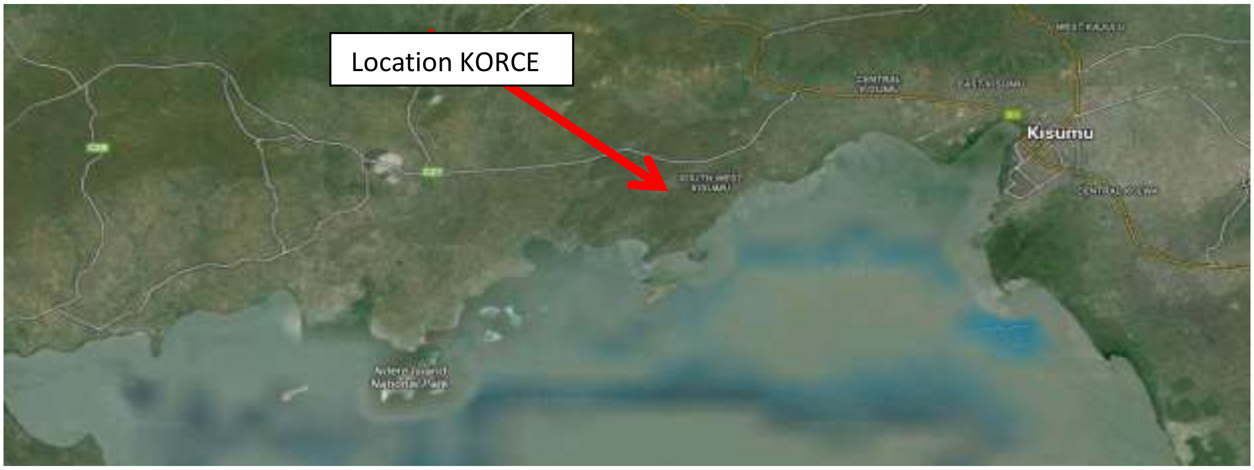


figure 24. Location KORCE facilities

During the interviews with local governments it was found that there is a high demand for animal feed. It was mentioned by several persons that the government can be involved in the production of animal feed and fertilizer through a Public Private Partnership (PPP). The government can use the feed for programs which subsidize animal feed for local farmers.

6.5 Challenges are due to governance system and availability of water hyacinth

There are however challenges for harvesting and processing of water hyacinths in a country like Kenya. The problems will be mainly due to the abundance of biomass and the governance of the country, nationally and locally. From interviews it was concluded that water hyacinth infestation occurs in annual cycles. There will not be sufficient biomass to feed the processing facilities continuously. The processing facilities however need a continuous supply of feeds to be profitable. A solution could be to cultivate water hyacinth to assure year round supply. Cultivation of the weed is not desired by the local communities and policy makers. The other solution is to use different sources of biomass as feed for the processing facilities. Purchasing and transportation of the feed will however have a major impact on the profitability. The cultivation of water hyacinth is therefore considered as the best solution. Cultivation will also contribute to the total control of water hyacinth as it will be managed throughout the year. It has also been acknowledged that water hyacinth mats contribute to the production of some fish and prevent over fishing. Consequently, a small amount of water hyacinth on the lake can also have some positive effects.

From corruption indices it can be concluded that corruption in Kenya can be a risk. It is also not recommended to use governmental land. There is a risk that after investments have been made and the project is in operation the land is reclaimed. The government can on the other hand be one of the customers of the products as long as they are not part of the project. Another problem encountered is that policy makers do not take responsibility. With other projects in Kenya large investments have been made in equipment and facilities by Western governments and NGO's. Problems have however occurred once an NGO withdraws from the project. It is recommended to have a local private investor involved in a pilot to prevent this.

For a pilot project, equipment from Europe has to be imported if protein will be extracted from the biomass. In that case, import duties will be very high due to the expensive equipment. The payment of high import duties can be prevented by collaborating with a local university. This needs to be assessed before a pilot project is initiated.

6.6 Stakeholder Grid

During the field trip several stakeholders have been identified and interviewed. To start an actual project it is necessary to assess the relation, interest and potential influence of these stakeholders to the project. In figure 25 a power, interest diagram can be found with all the stakeholders included.

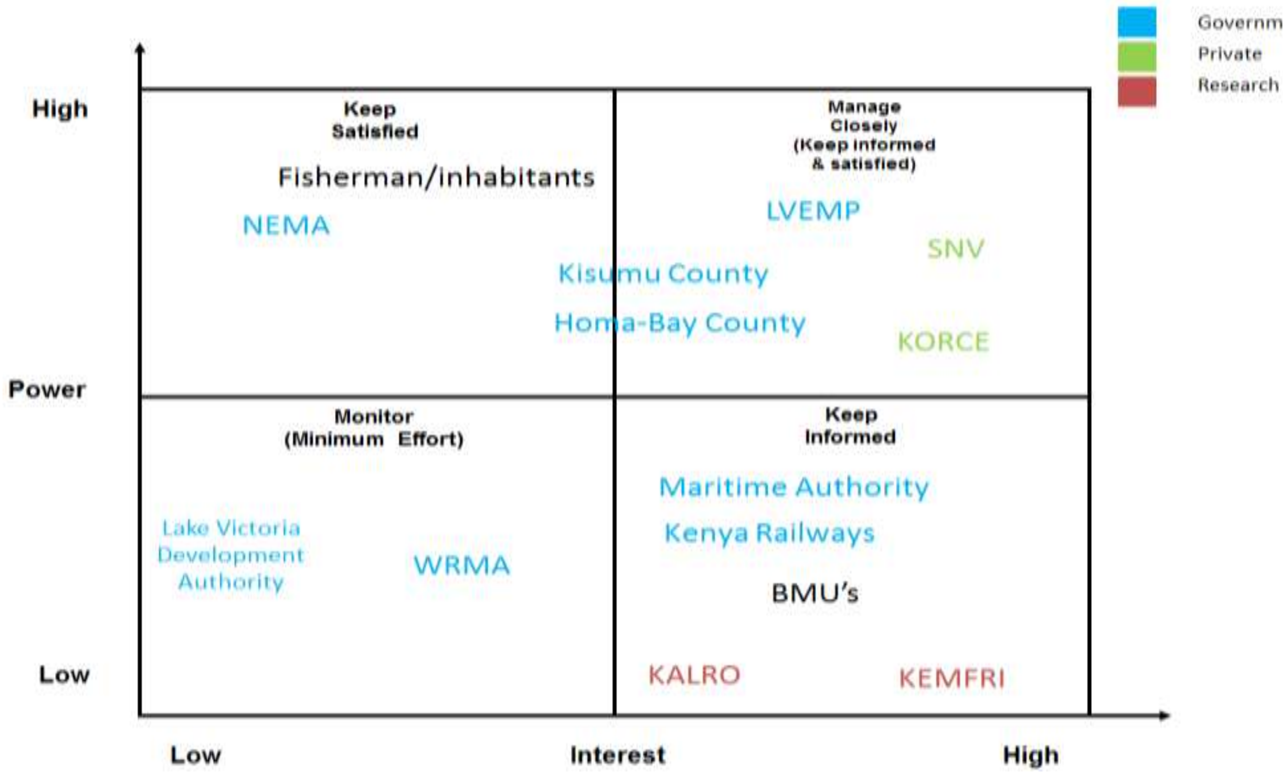


Figure 25. Interest-Power grid for water hyacinth stakeholders in Kisumu

Potential Partners

- SNV Netherlands Development Organization

SNV has several projects in biogas and dairy development. SNV has knowledge of the local market and some funds available for innovative projects for animal feed.

- Dutch Embassy

The Dutch Embassy can be a potential investor in a project. If it is decided to conduct a pilot in Kenya the embassy will publicly support the initiative as it aligns with their strategies and priorities. They also have assured support for setting up a project.

- KORCE

The facilities of KORCE can be used as a location for the pilot. KORCE is also interested in using water hyacinth biomass to produce different sources of energy. Dutch investors have already invested in clean water supplies at the KORCE facilities.

Potential Customers

- County governments (Homa-Bay and Kisumu)

The governments of Homa-Bay and Kisumu can be a potential customer of the animal feed and fertilizer. There are national and local initiatives to distribute subsidized animal feed and fertilizer.

- Private initiatives
- Local Farmers

Other Governmental Organizations that should be informed

- Lake Victoria Environmental Management Program (LVEMP)

LVEMP should be managed well as they propagate the governmental policy with regards to water hyacinth and managing other factors in the lake. LVEMP also has funds from the World Bank to control water hyacinth.

- Water Resource Management Authority (WRMA)

WRMA controls the water quality if funds are available. The water quality has not been assessed the last three years. WRMA is mostly important for intake points of drinking water.

- National Environmental Management Authority (NEMA)

For the start of any project in Kenya approval from NEMA is required. An Environmental Impact Assessment has to be conducted and approved by NEMA before operations can be started.

- Maritime Authority

Maritime Authority rescues people who are trapped on the lake by water hyacinth. The authority has recently used prisoners to manually control water hyacinth. The Authority will manage the new harvester that will be acquired by LVEMP.

- Kenya Railways

Kenya railways manage the port in Kisumu.

- Lake Victoria Basin Development Authority (LVBDA)

Research

- Kenya Marine and Fisheries Resource (KMFRI)

KMFRI has conducted research to assess to distribution, occurrence and impact of water hyacinth.

- Kenya Agriculture and Livestock Research Organization (KALRO)

KALRO has a program to breed weevils for the control of water hyacinth.

Local Inhabitants

- BMU's

Beach Management Units use water hyacinth to make crafts and furniture. Local people who use the water hyacinth as a resource should not be forgotten. If water hyacinth is used for a project biomass for the BMU's should be secured to ensure that they still have possibilities to use the water hyacinth for crafts. The weed should be made available for these people as this is an important source of income.

- Fisherman

Most of the people living around the lake are dependent on fishing. It is needed to keep these people satisfied. People will otherwise oppose a project to use water hyacinth.

6.7 Financial Feasibility Water Hyacinth processing and harvesting in Kenya

The aim of this research is to determine if it is feasible to harvest and process water hyacinth at large scale. Market data are collected in Kisumu to assess the economic feasibility in a real world situation.

During the field visit market data was collected to assess the potential revenues and costs. Using the market data collected the financial feasibility of water hyacinth processing was assessed. In appendix III the market information from in Kenya is presented. In the figures 26 and 27 the results from the economic model can be found for a capacity of 1 MW and 2 MW biogas production. From these figures it can be concluded that it is feasible to harvest and process water hyacinth. The IRR for a 2 MW digester is 16,24 % which can be considered as a promising rate of return.

The average of the market data found was used for the NPV calculation. The prices of the raw outputs from the processing plant could not be assessed. Some assumptions were made to calculate the prices for the outputs from the water hyacinth processing facilities. Biogas or CNG is not commercially sold in Kenya. To calculate the price of biogas the LPG price was multiplied by a factor of 0,25. This factor is based on the energy density of biogas. It is also assumed that biogas is cheaper than LPG .The prices of the fertilizer sludge were calculated based on the Nitrogen content of the plant. The prices of fertilizer are multiplied with a factor 0,025 as the nitrogen content of water hyacinth was found to be 0,025. The feed prices are all based on dry matter. The feed prices were multiplied with a factor 0,65 to ensure only the dry matter of the output is used to calculate the revenues. It was assumed that the protein output from the feed refinery has a dry matter content of at least 65 %.

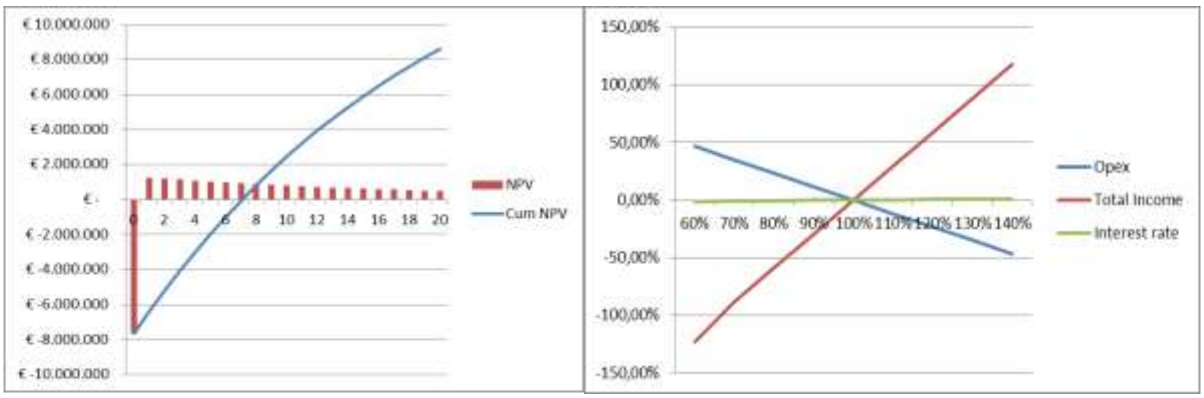


Figure 26. (Left) The cumulative NPV for animal feed and biogas production with a 2 MW biogas digester in Kenya. The IRR in this situation is 16,24% (Right) Sensitivity of the OPEX, revenues and interest rate on the NPV.

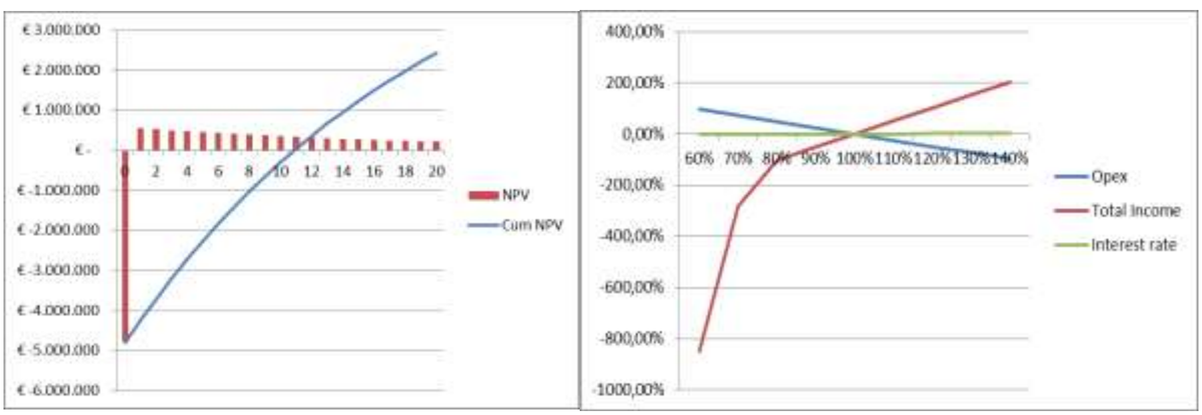


Figure 27. (Left) The cumulative NPV for animal feed and biogas production with a 2 MW biogas digester in Kenya. The IRR in this situation is 10,46% (Right) Sensitivity of the OPEX, revenues and interest rate on the NPV.

The sensitivity of market prices is also assessed based on the data found in Kenya. Figure 28 shows the senility of market prices for the business case in Kenya. The sensitivity of the prices for the operational costs and the revenues are different from the sensitivity found in Chapter 5.8.2. The gas price has the largest influence on the revenues. This is due to the high price of cooking gas in Kenya compared to the assumed price. The diesel price in Kenya is lower than expected and a price change in diesel will have a lower effect on the operational costs compared to the sensitivity in Chapter 5.8.

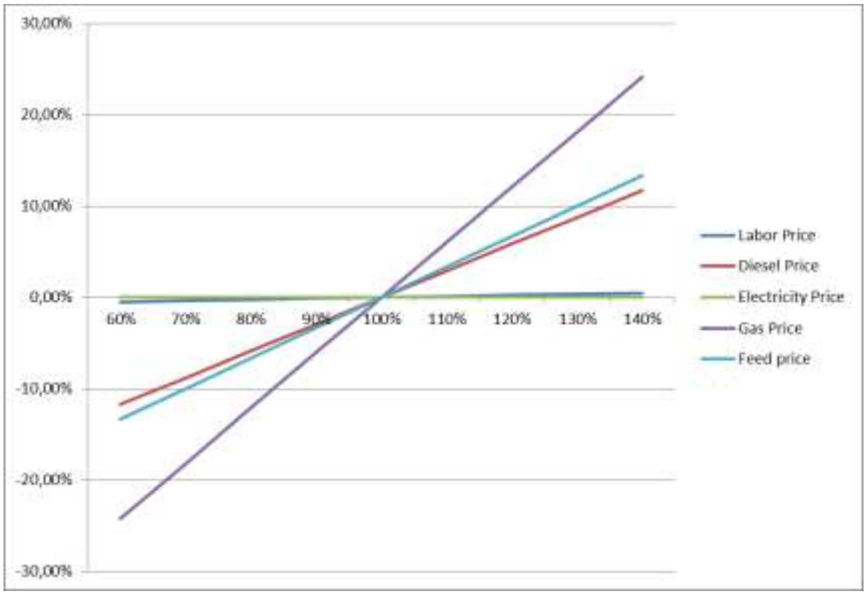


Figure 28. Sensitivity of Kenyan market prices on the operational costs and revenues for water hyacinth processing into nutrients and biogas.

6.8 Monte Carlo Simulation

The NPV is calculated to assess if an investment in water hyacinth processing facilities is recommended. Because there are several variable factors, such as market prices, diesel price and discount rate a Monte Carlo simulation was conducted. A Monte Carlo simulation is a process simulated a large number of times, for this research 1000 simulations were done. The parameter values differ each time between set ranges. Because of the different parameter values the Monte Carlo simulation produces a distribution of the potential results. Figure 29 represents the NPV distribution derived from the Monte Carlo simulation. Figure 29 shows that the distribution found from the Monte Carlo simulation is a normal distribution (μ= 4.500.000 and σ= 1.600.000) the chance of a negative NPV was calculated to be 0,065.

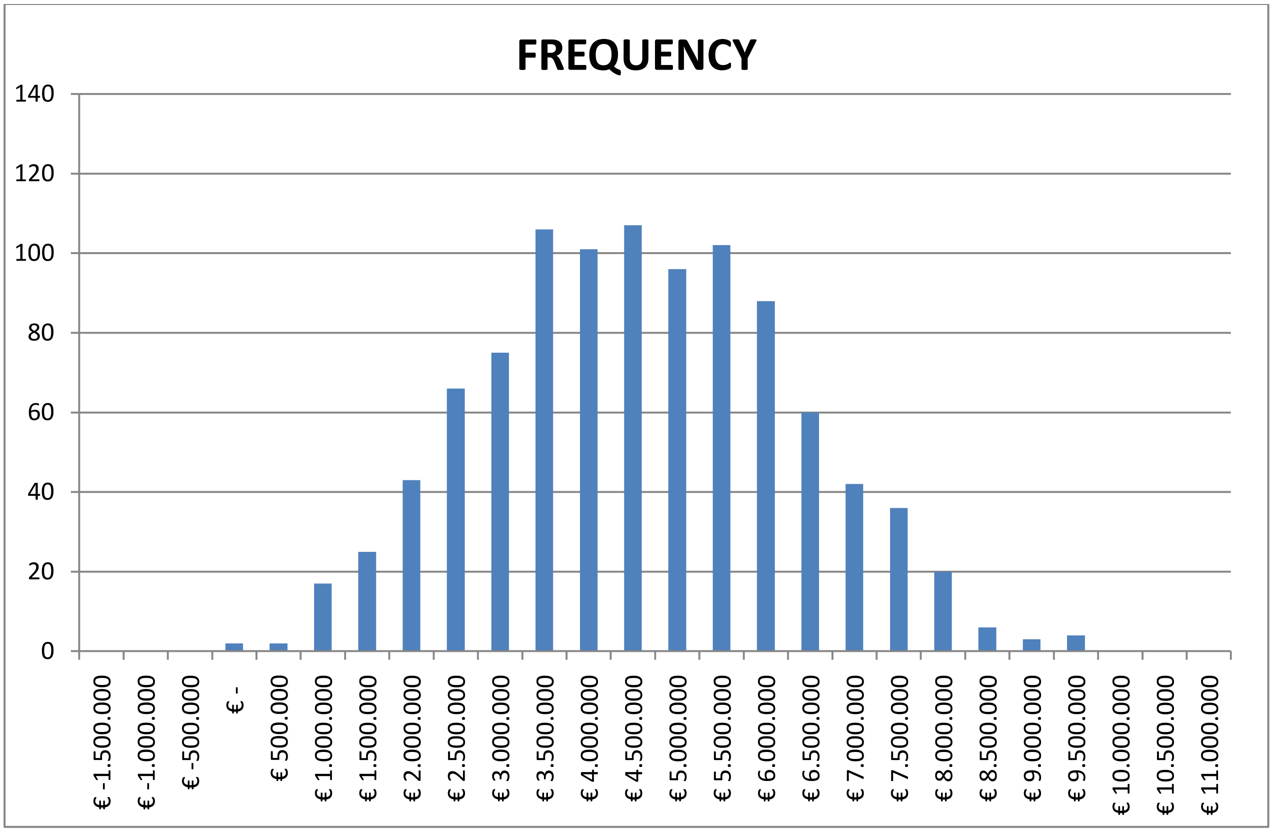


Figure 29. NPV distribution Monte Carlo Simulation Kenyan business case

For the Monte Carlo simulation the following variables were used:

- The revenues

  A normal distribution (μ= 2.683.000 and σ= 144.440) for the revenues was used based on the feed, gas and fertilizer prices found in Kenya. To calculate the revenues a thousand random numbers between the minimum and maximum prices found in Kenya were multiplied with the proposed outputs from the facilities. It was found that the 1000 revenues calculated are distributed normally. The revenue input for the Monte Carlo simulation was a random number from this normal distribution.

- The operational costs

  The variable prices for the operational costs are the diesel prices and the maintenance costs. It was assumed that these both have a triangular distribution. Table 8 shows the values used for this distribution. The maintenance costs are a percentage of the capital investment. This percentage is assumed to have a triangular distribution. The input for the Monte Carlo simulation is the sum of all the operational costs which are based on random numbers of the triangular distributions.

- The discount rate

  A random discount rate based on a triangular distribution is used as input for the Monte Carlo simulation. Table 8 shows the inputs for this distribution.

Table 6. Triangular distribution values which were used for the Monte Carlo simulation

	Diesel	Maintenance costs	Discount rate
Minimum	0,75	3,50%	4
Expected	0,95	5,00%	5
Maximum	1,1	6,50%	10

The economic results of a water hyacinth project in Kenya are promising. Based on the economic model and the Monte Carlo simulation it can be concluded that the risk for an investment is low. A water hyacinth project is economically feasible in Kenya. The rate of return is even higher than estimated in chapter 5.

7 Discussion

This research studied the feasibility of developing a large scale water hyacinth harvesting and processing project. The research is based on a literature study, economic modeling and a business case for a real life situation in Kenya. For the business case all relevant stakeholders identified have been interviewed. The main findings of this research are as follows. First, processing water hyacinth into protein, gas and fertilizer was identified as the best solution. Second, it is financially feasible to invest in processing and harvesting facilities if water hyacinth is abundant throughout the year. Third, the large differences in location and therefor culture and economy make it impossible define a general conclusion. Fourth, adaptations in harvesting equipment are required to make the investment successful. Fifth, water hyacinth removal and use will contribute to the economic and agricultural development and re-use of nutrients. Below these findings are discussed.

7.1 Animal feed production as best option.

From the literature study it is concluded that water hyacinth can be used as a resource. For production of animal feed pre-treatment is however required due to characteristics of the plants. The heavy metal content of the plant can cause problems for all sorts of usages of the plant, in particular for animal feed production. For the production of proteins and silage no research has been done on the effects of heavy metals on the animal feed. Before water hyacinth is used for large scale production of animal feed the effect of heavy metals on the animal feed should be researched. The heavy metal thresholds should then also be determined for the production of animal feed. In the literature review, several usages of the water hyacinth biomass have been described. Based on the current status of techniques and low education of personal, it was recommended that the best processing option is protein extraction integrated with digestion of the roots and waste products of the protein extraction. Low skilled labor should be able to operate and maintain equipment to make sure that little education is required for operation of the facilities. If large investments are not possible it is recommended to ensile water hyacinth. By producing animal feed, gas and fertile sludge, risk is spread because there are several products. In the Kenyan case, most revenues come from cooking gas sales. It was however indicated in interviews that the largest demand comes from animal feed. Over time the prices might change, the production of multiple products is therefore a suitable way to mitigate risk.

The extraction of valuable products from waste biomass at large scale is relatively new. The techniques used for the extraction of valuables from proteins are fairly new and still in the development phase. It is therefore recommended to keep track of technological developments. If it is decided to not start a pilot, it is advised to reconsider this again in a couple of years when the techniques are more developed. Another aspect that should be assessed which could not be done during this thesis is gold extraction from the water hyacinth roots. Around Lake Victoria there are several gold mining projects. The gold is washed into the lake and can be adsorbed by the roots. It should be assessed to what extent gold is adsorbed by the roots. If substantial amounts of gold are adsorbed by the plant, the slurry which is produced during digestion can be processed to extract the gold from the biomass.

7.2 Economic Feasibility of Processing Water Hyacinth

The NPV of the cases based on assumptions and on real data from the Business case are all positive, thus feasible. Where there is uncertainty about the outcome of an investment analysis, looking at the best estimate scenario is not always helpful (Maklan *et al*. 2005). This is why a Monte-Carlo simulation was conducted to find the distribution of the NPV. The IRR found in the theoretical model is not that high. The investment can therefor most likely not compete with other projects. The rate of return in the real life case was however a bit higher than that of the theoretical model. This scenario might be interesting for investors with a focus on sustainable development.

A project combining gas, feed and fertilizer production is economically feasible. It was found that the electricity production from water hyacinth is not feasible. The price per unit electricity and the efficiency of electricity generation are too low. Silage production has a high rate of return because no large investments are required for the treatment of the leaves into silage. The production of biogas and protein requires a large investment and has therefore a relatively low rate of return compared to silage production. Smaller initial investments giving short-term returns are favored in NPV calculations because the discount rate – the time value of money – dramatically reduces benefits that are realized only in the long term (Maklan *et al*. 2005) This also applies for the production of silage. If there is a high risk for an investment it can be decided to only produce silage because the initial investment is much smaller.

There are still some uncertainties in the economic analysis and production quantities as these are still based on assumptions or on research at laboratory scale. A specialized harvester separating roots and shoots has for example never been built and prices need to be assumed. The costs for other equipment are based on interviews or tools used by W+B. The production of biogas might be under estimated because an efficiency of 70% of potential yield was used to calculate the production. (Gebrezgabher *et al*. 2010) used an efficiency of 80% because of a low retention time, while a relatively long digestion time is suggested for the production of biogas.
In literature very high yields are described. These yields can be questioned as these are often found from research conducted under ideal circumstances at small scale. The production per hectare might therefore be lower than the yields used for calculations in this research. The annual production of water hyacinth per hectare should be assessed locally before a project is started. If water hyacinth is abundant throughout the year lower yields will probably not be a constraint. In the Kenya case the plant is however not available throughout the whole year, but only 5/6 months a year. In such a case, to secure feed for the processing facilities, the weed has to be cultivated. The production per hectare is in such a case of importance because an area for cultivation has to be designed or other bio-waste streams have to be added to ensure year round production. The ownership of the plant should also be secured. Currently no government desires ownership of the plant. If the plant generates profits this might be different. It is therefore recommended to secure water hyacinth feed with local policy makers.

To understand the business model and value chain a canvas business model was used. The canvas business model is a static tool while it might be important to take the dynamics of all boxes of the canvas business model into account. The business canvas is however a good map to simply show and understand the business model of the company (Henriksen *et al*. 2012). Based on the business model and interviews, it can be concluded that there are possibilities for cooperation with the dairy and animal feed industry. It was found that dairy production is lagging. It is likely that projects will be started to reduce the milk deficit. By cooperation with dairy enhancing projects the customers are easily available. A plan for a consortium should be presented to companies like FrieslandCampina and De Heus to investigate partnerships.
If biogas and animal feed are produced this will affect carbon emissions because land use and fossil fuels are reduced. Possibilities for carbon credit revenues have not been assessed. During interviews the potential of carbon credits were mentioned. The revenues mentioned during these discussions are however not realistic. The potential benefits of carbon credits need further evaluation.

7.3 No Silver Bullet solution for water hyacinth use

Policies and governance and economic impact of the weed are based on interviews. Because water hyacinth use is a sensitive topic, and local governments are hoping for western investments the results of the interviews may be different from the real situation. During the interviews it was noticed that there are a lot of different interests in the management of the weed. Stakeholders would often point at each other with regards to responsibilities for the management of the plant.

As mentioned previously water hyacinth is distributed all over the tropics in water bodies that are very different in size and shape. It is therefore not possible to have one conclusion on the feasibility of water hyacinth processing. The use of biomass does differ in the world (Parikka 2004). Not only do economic, technological development and acceptance of use of water hyacinth differ per area but also market prices can differ. In Kenya, it was found that cooking gas is a relatively expensive and an important source for the revenues. Other locations might not be dependent on cooking gas, (charcoal or wood) for cooking. The price of gas might be much lower. There can be several cultural or market based factors which influence the revenues of a project and therefore the feasibility. The water hyacinth has different economic impacts. This also means that the way of management should be adapted accordingly. A cultivation system would not be desired in a hydropower system because of the high evaporation of water. Cultivation may however be an option in a lake system like Lake Victoria.

No ongoing projects were found which use water hyacinth on large scale. There is a lot of interest in using water hyacinth but as has been described in chapter 3.4 there are only small projects identified. The absence of large scale projects can be explained by the differences in the demand for products obtained from water hyacinth. Furthermore, the possibility of using water hyacinth for animal feed production has not been assessed using state of the art technologies. Other companies, like Royal HaskoningDHV, have been examining the possibilities of using the weed as a source for animal feed recently. If it is proven by a pilot that water hyacinth can be used as feed it is believed several projects will start. Animal feed is a major constraint in a lot of areas. The rising demand for animal feed will also contribute to this development.

7.4 Water hyacinth will contribute to development of an area

The removal of water hyacinth will contribute to economic development. By using the plant as a resource an extra stimulus is given to agricultural and economic development. If the weed is not removed economic growth is prevented. As has been indicated before the weed has severe impact on the local and even national economy. In Kisumu a decrease in economic activities and an increase in costs to control the weed were found. In a large lake system, such as Lake Victoria, fishing is an important contributor to inhabitants' livelihood and the local and national economy. If economic activities are stopped due to water hyacinth infestations there will be an impact on the economy. It was not possible to quantify the exact effect of water hyacinth infestation during the business case. There was no time for interviews with local fishermen and other affected parties. The economic effect is only assessed by estimates from governmental officials and relative old data. To get a better picture of the economic impact more research is required. The purpose of this thesis was only to get an overview of the economic impact of one location. Before a pilot is started the local impact of the weed should be mapped.

By the production of high quality animal feed and fertilizer agricultural production is likely to increase. The usage of water hyacinth products contribute to the re-cycling of nutrients. Figure 30 shows how the nutrients are re-cycled. Low fertility of land is often found as a constraint for crop and animal production (Waddington *et al*. 2010). The water hyacinth products will use the nutrients which are eroded into the water and captured by the water hyacinth. The nutrients will be captured from the water bodies and therefore not contribute to pollution of the lake. Too many nutrients have a negative impact on aquatic ecosystems (Ansari *et al*. 2011). If nutrients are managed properly and are re-cycled from the water, fisheries and agriculture will benefit. Nutrients which are re-cycled from water and used for agricultural purposes will most likely increase agricultural yields.

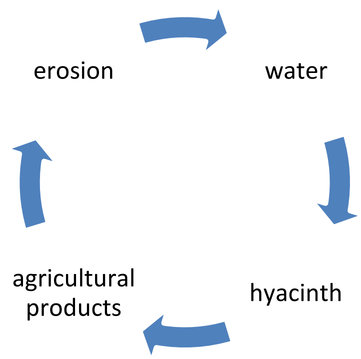


Figure 30. Nutrients that are eroded into water bodies can be recycled by water hyacinth use.

A growing world population and dietary change will put considerable additional claims on natural resources (Kastner *et al*. 2012). Currently, 36% of the calories produced by the world's crops are used for animal feed, only 12% of those feed calories ultimately contribute to the human diet (as meat and other animal products) (Cassidy *et al*. 2013). The supply of animal feed is likely to be a constraint in rural areas, as was indicated in interviews in Kisumu. Livestock production is likely to if water hyacinth is used as a source of animal feed. The production of animal feed is mostly done by crops which can also be used for human consumption. By using aquatic crops for animal feed, land is available for other purposes. To compare the amount of land that is required for the amount of animal feed production similar to the production from the suggested water hyacinth refinery. Water hyacinth production is compared with feed production from pastures. In literature (Wirsenius *et al*. 2010) it was found that the average pasture production is 1,0 ton DM per hectare. Depending on the capacity of processing facilities up to 16000 hectares of land can be used for different purposes than the production of animal feed. These numbers are based on a daily harvest of two hectares of water hyacinth. For this calculation 29 tons water hyacinth per hectare were used. Because only the leaves can be used as animal feed the potential production of animal feed is 23 ton DM per hectare.

7.5 Harvest equipment needs to be adapted

To harvest the water hyacinth equipment should be adapted to ensure that the leaves and the roots are separated during harvest. This is a new feature for harvesting equipment for water hyacinth. In the past Royal IHC has done research to build an aquatic weed harvester. Discussions with V. Toet, (2014), a designer of dredging equipment who has been involved in the research to build a water hyacinth harvester, concluded that it is possible to adapt boats to separate roots and shoots during harvest. The leaves of the plants can be harvested by using a cutter block. This is a method of mowing which is used by farmers for mowing grass. The harvested water hyacinth are then transported by a conveyer belt to a shredder and finally to a barge. Once the leaves are cut the roots are transported by another conveyor belt. It should be assessed if this is the best way forward. This study has not focused on the design of the harvesting equipment. The propulsion of the boat can be done on several ways, i.e. anchoring and cables, spud carriers tracks and propeller. It should be taken into account that the boat should be able to operate in shallow waters. Fishing nets can also be a problem if the boat is propelled by a screw. The propulsion of the boat should not require a lot of energy due to high of diesel costs and emissions. The direction and schemes for harvesting need to be determined to design the boat. It is possible that the equipment will be on the front end of the boat or on the side. The position of the mower, shredder and barges for transport all depend on how the weed is harvested. Overall more research is needed for the design of a new harvesting boat.

8 Conclusion and recommendations

The main question addressed in this thesis is the feasibility of harvesting and processing water hyacinth on large scale. From the economic model and from the business case it can be concluded that processing water hyacinth on large scale is feasible when feedstock is secured. The hypothesis which recommends governmental support is however not true. The corruption index from Transparency International (2014) ranks Kenya as country where corruption is a major risk. It is therefore concluded that local governmental involvement is not advisable due corruption risk. The conclusions of the research can be clarified by a SWOT analysis which can be found in Figure 31.

To start a large scale water hyacinth processing project the biomass should be used to produce high valuable animal feed. If proteins are produced the other waste streams can be used for the production of biogas and fertilizer. The unique selling point of the results of the thesis is the separation of the leaves and roots during harvest. If it is decided to continue and to start a pilot project for water hyacinth removal it is most important to secure a reliable local partner to run the project and secure feedstock for the processing facilities.

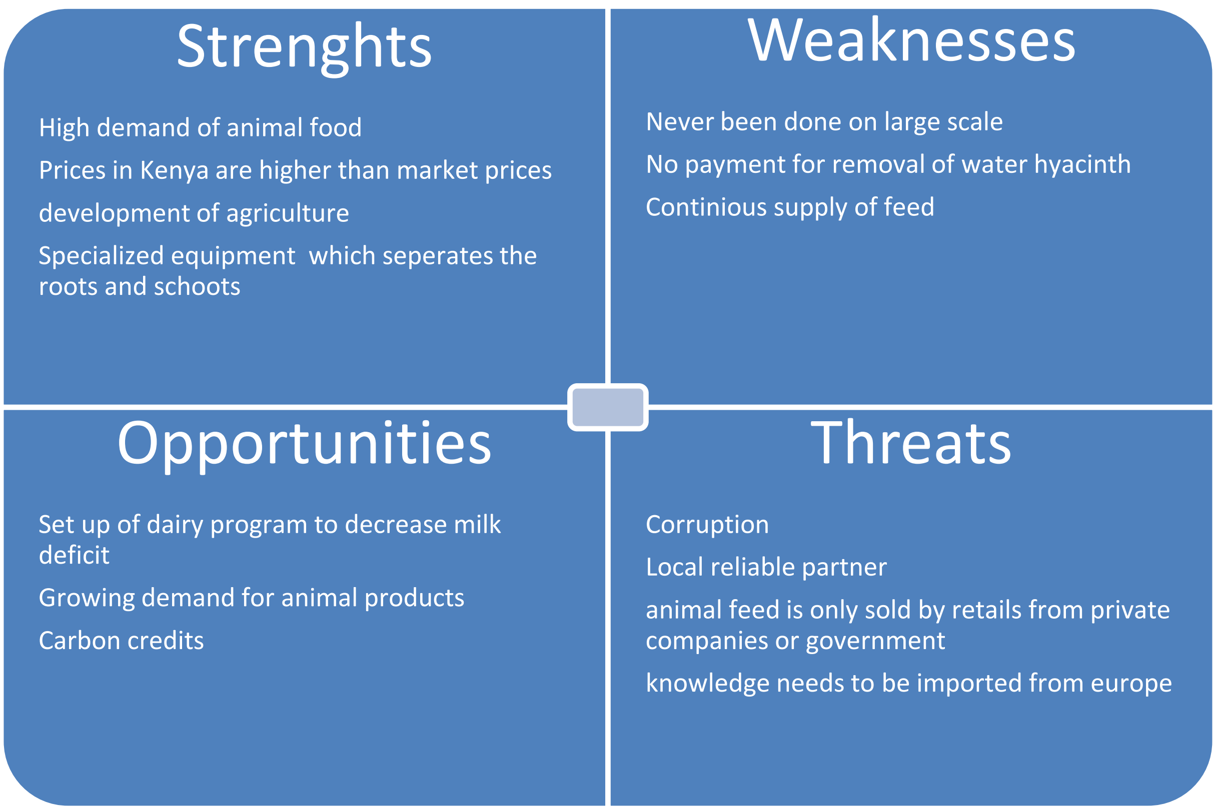


Figure 31. SWOT analysis for the set-up of a water hyacinth harvesting and processing plant based on the business case in Kenya

Harvest equipment should be adapted to separate roots from shoots for processing during harvesting. The separation of the roots and shoots is only needed when it is decided to produce animal feed. The production of animal feed is recommended because prices in developing countries are relatively high. Other projects that have been assessed do not separate the roots from the shoots during harvest. The revenues from animal feed production from biomass are also relatively large compared to other feasible options. The demand for animal feed is estimated to rise in the future, which will probably drive up prices. If a pilot is started it is therefore recommended to invest in facilities which can be used for the production of animal feed. The investment in water hyacinth processing should be promoted as a sustainable development project. One of the key strengths of such a project is that it will contribute to agricultural and economic development. The strength of a project using equipment built based on this research is that a pre-treatment step can be done during harvest. IHC harvesting equipment for removal of water hyacinth will most likely be specialized and costly. The design of the harvesting equipment was not in scope of this project. It is therefore recommended that IHC researches the possibilities of adapting equipment to optimize water hyacinth harvesting.

If it is decided to conduct an investment in a pilot project it will be important to get a reliable local partner in order to be successful. IHC and W+B are not likely to run the project themselves. To ensure a sustainable project it is required that if ICH and W+B are not involved, the project continues. The knowledge about the processing technologies is most likely lacking in the areas where water hyacinth causes a problem. The knowledge needs to be imported from the western world. Flying in people from Europe to remote locations is costly. The knowledge should therefore be transferred to the local people. One of the threats mentioned in Kenya is that once an NGO leaves a project, the project stops. Because large investments are required it is not possible to have the project stop once IHC and W+B pull out. This is a major risk for investing in facilities and people and should be minimized by working with a reliable local partner. Before starting a project the length of time to be involved in the project should be defined. The possibility should be there to step out after an agreed amount of time. It is recommended to select a partner which has worked with other western projects and is recommended by these parties. An NGO such as SNV can be a good party to help assess a potential local partner because of local experiences. Another way to start a pilot project is to look for collaboration with large companies working in the animal feed or dairy industry. It should be mapped where water hyacinth causes a problem throughout the year and if there is a deficit in animal products and animal feed. If animal feed is the constraining factor it can be decided to start a pilot project to ensure the whole value/supply chain is present. If Dutch subsidies are requested these should be in line with the new governmental policy "the underground value pyramid of the bio based economy, 2014". This is the newest guideline for subsidies regarding bio based economy. A project for water hyacinth usage will also operate within these guidelines.

Before an investment is made, a constant feed source has to be secured for the processing facilities. It is recommended to assess the possibilities of cultivation of water hyacinth or to assess other possible feed sources to mitigate the risk of feed shortage. As mentioned it can be assessed if there are other possible feed sources. If water hyacinth is going to be used on industrial scale it is likely that there will be some kind of collaboration with an industrial partner. Their facilities might have waste sources which can be used as feedstock. It should be assessed what possibilities exist for using other waste streams of industrial partners.

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Appendix I

An overview of investment in different products and the operational products can be found in this appendix. Investment prices for equipment are based on the ADP calculator from W+B. Prices for the harvester and shredder are based on discussions with persona from IHC.

Table 1. overview of capital investments for equipment and the energy requirements of the equipment

Capital Investment (CAPEX)	**Costs (Euro) Accuracy range 20 %**	**Energy requirements (kW)**
Land Acquisition	€ 30.000	-
Power Generator	€ 250.000	
Harvester	€ 650.000	400
Shredder	€ 250.000	500
Connection Electrical grid	€ 120.000	
CHP	€ 812.250	10
Onsite transport		
Conveyer belts	€ 7.500	50
Pipes 100 m	€ 2.860	
Transport harvest to plant		
barge	€ 162.500	
Gas production		
Fermenter	€ 3.740.000	20
Gas improver	€ 2.200.000	50
Gas compressor	€ 50.000	50
Feed Production		
Feed processing plant	€ 2.450.000	400
Heating installation	€ 100.000	20

Not used for business case

Table 2. Overview of the operational costs and use of equipment

Maintenance and repair costs	amount	unit	Costs		Hours/day
Harvester			€	32.490	
Shredder			€	12.500	
Connection Electrical Grid			€	6.000	
Digester			€	186.800	
Compressor			€	2.500	
Feed processer			€	121.838	
CHP			€	40.613	
Heating installation			€	5.000	
Energy requirements					
Harvester	6400	kWh	€	191.300	8
shredder	6498	kWh	€	194.300	8
Conveyor Belt	800	kWh	€	23.920	8
CHP	80	kWh	€	525	8
fermenter	780	kWh	€	32.750	24
gas compressor	650	kWh	€	23.200	8
Feed processer	5198	kWh	€	218.200	8
Heating installation	160	kWh	€	1.000	8
labor					
Plant operator	24	months	€	17.640	
Harvester	24	months	€	7.080	
Plant Manager	24	months	€	21.120	
workers	3120	days labor	€	31.200	
Additives for silage					
Sugar	171500	kg	€	51.200	

Appendix II

Expected balance for the first 20 years of operation

Year	Start-up	1	2	3	4	5	6	7	8	9	10
Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Production	0	1	2	3	4	5	6	7	8	9	10
Annual Production	0	0	0	0	0	0	0	0	0	0	0
Cumulative production	0	0	0	0	0	0	0	0	0	0	0
Revenues											
Product revenues	€ -	€ 2.048.476	€ 2.048.476	€ 2.048.476	€ 2.048.476	€ 2.048.476	€ 2.048.476	€ 2.048.476	€ 2.048.476	€ 2.048.476	€ 2.048.476
Rolyalty	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Resiudal value	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
total revenues	€ -	€ *2.048.476*	€ *2.048.476*	€ *2.048.476*	€ *2.048.476*	€ *2.048.476*	€ *2.048.476*	€ *2.048.476*	€ *2.048.476*	€ *2.048.476*	€ *2.048.476*
Costs											
Opex	€ -	€ -916.152	€ -916.152	€ -916.152	€ -916.152	€ -916.152	€ -916.152	€ -916.152	€ -916.152	€ -916.152	€ -916.152
Indirect costs	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
EBITDA	€ -	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324
Depreciation	€ -	€ -382.544	€ -382.544	€ -382.544	€ -382.544	€ -382.544	€ -382.544	€ -382.544	€ -382.544	€ -382.544	€ -382.544
Ammortization	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
EBIT	€ -	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781
interest	€ -	€ -153.017	€ -145.367	€ -137.716	€ -130.065	€ -122.414	€ -114.763	€ -107.112	€ -99.461	€ -91.810	€ -84.160
Carried forward loss	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
EBT	€ -	€ 596.763	€ 604.414	€ 612.065	€ 619.716	€ 627.367	€ 635.017	€ 642.668	€ 650.319	€ 657.970	€ 665.621
Taxation @ 20%	€ -	€ -119.353	€ -120.883	€ -122.413	€ -123.943	€ -125.473	€ -127.003	€ -128.534	€ -130.064	€ -131.594	€ -133.124
Net Profit	€ -	€ 477.410	€ 483.531	€ 489.652	€ 495.773	€ 501.893	€ 508.014	€ 514.135	€ 520.255	€ 526.376	€ 532.497
Investment Analysis											
Cash Flow											
EBIT	€ -	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781
Depreciation	€ -	€ 382.544	€ 382.544	€ 382.544	€ 382.544	€ 382.544	€ 382.544	€ 382.544	€ 382.544	€ 382.544	€ 382.544
Carried forward losses	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Cash in	€ -	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324
Cash Out											
tax	€ -	€ -119.353	€ -120.883	€ -122.413	€ -123.943	€ -125.473	€ -127.003	€ -128.534	€ -130.064	€ -131.594	€ -133.124
Investment	€ -7.650.871	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Working capital	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Cash out	€ -7.650.871	€ -119.353	€ -120.883	€ -122.413	€ -123.943	€ -125.473	€ -127.003	€ -128.534	€ -130.064	€ -131.594	€ -133.124
Net operational cash flow											
Cash in	€ -	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324
Cash out	€ -7.650.871	€ -119.353	€ -120.883	€ -122.413	€ -123.943	€ -125.473	€ -127.003	€ -128.534	€ -130.064	€ -131.594	€ -133.124
Net operational cash flow	€ -7.650.871	€ 1.012.971	€ 1.011.441	€ 1.009.911	€ 1.008.381	€ 1.006.851	€ 1.005.321	€ 1.003.790	€ 1.002.260	€ 1.000.730	€ 999.200
Net present value	€ -7.650.871	€ 964.735	€ 917.407	€ 872.399	€ 829.597	€ 788.894	€ 750.186	€ 713.375	€ 678.369	€ 645.080	€ 613.422
Net present value @ 5%	€ 4.822.288	€ 4.822.288									
Return of investment rate	12%										
EBITDA/revenues	55,28%										
Financial Cash flow											
Interest	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
loan repayment	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
FCF	€ -7.650.871	€ 1.012.971	€ 1.011.441	€ 1.009.911	€ 1.008.381	€ 1.006.851	€ 1.005.321	€ 1.003.790	€ 1.002.260	€ 1.000.730	€ 999.200
Loaned sum	€ 7.650.871	€ 7.650.871	€ 7.268.327	€ 6.885.784	€ 6.503.240	€ 6.120.696	€ 5.738.153	€ 5.355.609	€ 4.973.066	€ 4.590.522	€ 4.207.979
		€ 153.017	€ 145.367	€ 137.716	€ 130.065	€ 122.414	€ 114.763	€ 107.112	€ 99.461	€ 91.810	€ 84.160

11	12	13	14	15	16	17	18	19	20
2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
11	12	13	14	15	16	17	18	19	20
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
€ 2.048.476	€ 2.048.476	€ 2.048.476	€ 2.048.476	€ 2.048.476	€ 2.048.476	€ 2.048.476	€ 2.048.476	€ 2.048.476	€ 2.048.476
€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
€ 2.048.476	***€ 2.048.476***	***€ 2.048.476***	***€ 2.048.476***	***€ 2.048.476***	***€ 2.048.476***	***€ 2.048.476***	***€ 2.048.476***	***€ 2.048.476***	***€ 2.048.476***
€ -916.152	€ -916.152	€ -916.152	€ -916.152	€ -916.152	€ -916.152	€ -916.152	€ -916.152	€ -916.152	€ -916.152
€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324
€ -382.544	€ -382.544	€ -382.544	€ -382.544	€ -382.544	€ -382.544	€ -382.544	€ -382.544	€ -382.544	€ -382.544
€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781
€ -76.509	€ -68.858	€ -61.207	€ -53.556	€ -45.905	€ -38.254	€ -30.603	€ -22.953	€ -15.302	€ -7.651
€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
€ 673.272	€ 680.923	€ 688.574	€ 696.224	€ 703.875	€ 711.526	€ 719.177	€ 726.828	€ 734.479	€ 742.130
€ -134.654	€ -136.185	€ -137.715	€ -139.245	€ -140.775	€ -142.305	€ -143.835	€ -145.366	€ -146.896	€ -148.426
€ 538.617	€ 544.738	€ 550.859	€ 556.980	€ 563.100	€ 569.221	€ 575.342	€ 581.462	€ 587.583	€ 593.704
€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781	€ 749.781
€ 382.544	€ 382.544	€ 382.544	€ 382.544	€ 382.544	€ 382.544	€ 382.544	€ 382.544	€ 382.544	€ 382.544
€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324
€ -134.654	€ -136.185	€ -137.715	€ -139.245	€ -140.775	€ -142.305	€ -143.835	€ -145.366	€ -146.896	€ -148.426
€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
€ -134.654	€ -136.185	€ -137.715	€ -139.245	€ -140.775	€ -142.305	€ -143.835	€ -145.366	€ -146.896	€ -148.426
€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324	€ 1.132.324
€ -134.654	€ -136.185	€ -137.715	€ -139.245	€ -140.775	€ -142.305	€ -143.835	€ -145.366	€ -146.896	€ -148.426
€ 997.670	€ 996.140	€ 994.609	€ 993.079	€ 991.549	€ 990.019	€ 988.489	€ 986.958	€ 985.428	€ 983.898
€ 583.317	€ 554.688	€ 527.463	€ 501.572	€ 476.952	€ 453.539	€ 431.274	€ 410.102	€ 389.967	€ 370.821
€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
€ 997.670	€ 996.140	€ 994.609	€ 993.079	€ 991.549	€ 990.019	€ 988.489	€ 986.958	€ 985.428	€ 983.898
€ 3.825.435	€ 3.442.892	€ 3.060.348	€ 2.677.805	€ 2.295.261	€ 1.912.718	€ 1.530.174	€ 1.147.631	€ 765.087	€ 382.544
€ 76.509	€ 68.858	€ 61.207	€ 53.556	€ 45.905	€ 38.254	€ 30.603	€ 22.953	€ 15.302	€ 7.651

Appendix III

The market data found in Kenya can be found in this appendix

Table 1. Fertilizer prices found in Kisumu in Kenya Shilling

	kg	Agrovet	Farmline	lake basin agrovet	Farm shop Duka la kilimo	Homa-Bay county	Next to united millers	Kisumu	Korce	Average prices
CAN	10	700	700	700						700
DAP	10	800	800	800						800
Fertilizer 1 (NPK)	50				3700	4000				3850
Fertilizer 2 (Urea)	50				4000	3500		3000		3500
Fertilizer 3 (DAP)	50				-	4000	3100	3400		3500
Fertilizer 4 (CN)	50					3500				3500
Fertilizer 5 (CAN)	50					2600		2600		2600
Fertilizer 6 (NHSO)	50							2600		2600
Fertilizer 7 (MOP)	50							4500		4500
Fertilizer 8 (MgS)	20							3300		3300
Organic Fertilizer	20					1600				1600
Compost	50				-	300				300

Table 2. Gas prices found in Kenya in Kenya shilling

Gas cylinders (kg)	Total	Shell	Kenol	Kenoil	Total	National	Average
3	720				720		720
6	1430	1450	1390	1390	1430	1330	1403
13	3100	3100	2990	2990	3100	2800	3013
22,5	5360				5360		5360
50	11910				11910	-	11910

Table 2. Feed prices found in Kisumu in Kenya Shilling

	Sakina Feeds	Pembe Feeds	Kisjoga feeds	Unga	Bangani Feed Nairobi	Homa Bay	Teddy Bear	Unga 2
Kg/bag	70	70	70	50	50	1	70	50
Soy meal					2300	100		
Omena						100		
Maize						30		
Sunflower kick						25		
Chicken Feeds								
Broiler Finisher	3800		3150	3250			3050	2900
Broiler starter	3950		3800	2980		50	3150	3250
Growers mash	2500	3150	2600	2200		37	2100	
Chick mash	2900	3650	3200	3350		35		2600
Kienyeji mash	1850							
Boiler Finisher		4200		2900			3250	
Layers mash	2800	3200	2800	2350			2400	2350
Diary Feeds								
Dairy meal ordinary	1900	2300		1650		26	1500	1650
Dairy meal high yield	2200	2660		1930			1750	
Dairy cubes				1715				
Calf Pensel				1930				
Calf pellets				2390				
Fugo Balanced								
Pig Feeds								
Pig finisher	2200			2000			1750	2000
Pig starter	2300			2000				
Saw/weaner	2250			2050				
Other								
Fish feed					2400			
Bone meal					1400	27		

Appendix IV

Table 1. Contact list of all the people spoken during the research

Name	Organisation	Role	Mail	Address	Telephone number
Johan Sanders	WUR/Grassa	Professor/founder	johan.sanders@wur.nl	Bornse Weilanden 9,Bode: 206 708WG, WAGENINGEN, NETHERLANDS	0317 487213
Adrie van der Werf	WUR biobased economy	Co-ordinator Biobased Economy	adrie.vanderwerf@wur.nl	Droevendaalsesteeg 1, Bode: 52, 6708PB, WAGENINGEN NETHERLANDS	0317 480518
Lourens Zwart	ABCKroos	Founder	zwart@technologytomarket.nl	Oude Apeldoornseweg 4, 1Oak Building / A2.15, 7333 NR Apeldoorn, Netherlands	+31 (0) 6 46 21 61 70
Hans Derksen	ABCKroos	Refinery	h.derksen@innostart.nl	Oude Apeldoornseweg 4, 1Oak Building / A2.15, 7333 NR Apeldoorn, Netherlands	
Henry Neufeldt	ICRAF	Head of Climate Change Unit at World Agroforestry Centre	H.Neufeldt@CGIAR.ORG	ICRAF, Nairobi Kenya	Skype: henryneufeldt
David Guerena	Cornell university		dtg37@cornell.edu		
Adriaan Vernooij	WUR Livestock Research	Project leader	adriaan.vernooij@wur.nl	Wageningen/Lelystad	0320 293363
Sanjay Vadhera	KORCE (Kenya Organic Resource Centre for Excellence)	Founder	sanjay@greenergialtd.com	Kenya	M+254737358224
Niels van Stralen	Chaincraft	Founder/Director	nielsvanstralen@gmail.com	Hornweg 61, 1044 AN Amsterdam, Netherlands	31613441707
Harm Duiker	SNV	Country Director Kenya	hduiker@snvworld.org	Ngong lane, off Ngong	M +254 733 969 157

				road, Nairobi, Kenya	
Chiranjibi Tiwari	SNV	Sector leader WASH	ctiwari@snvworld.org	Ngong lane, off Ngong road, Nairobi, Kenya	M +254 733608034
Wario, Abdi	SNV		wbonaya@snvworld.org	Ngong lane, off Ngong road, Nairobi, Kenya	
Mr oseimo	NEMA		hosiemo@nema.go.ke	Kisumu	M +254726477635
George Onyango	Kenya Pipeline company	Pipeline Coordinator Kisumu	kisumupipecor@gmail.com; ongangogeorge86@yahoo.com	Kisumu	M +254710924999
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Rudolf de Bruijn	De Heus			Ede	

Appendix V

A sketch of the proposed design can be found in this appendix.

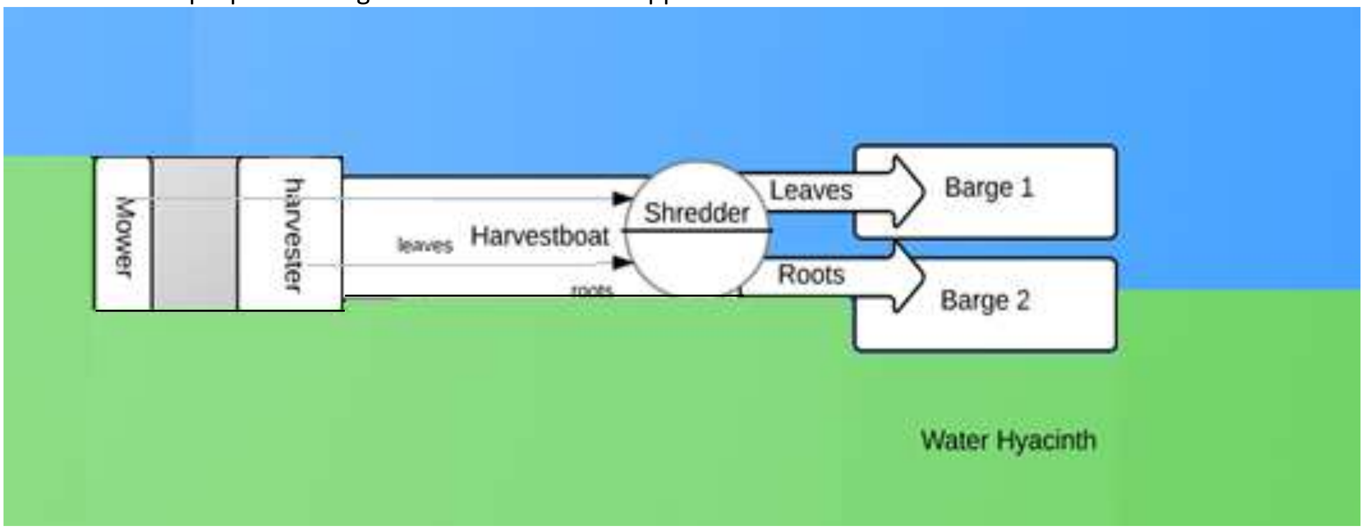

Figure 1. Plan view of proposed harvesting equipment

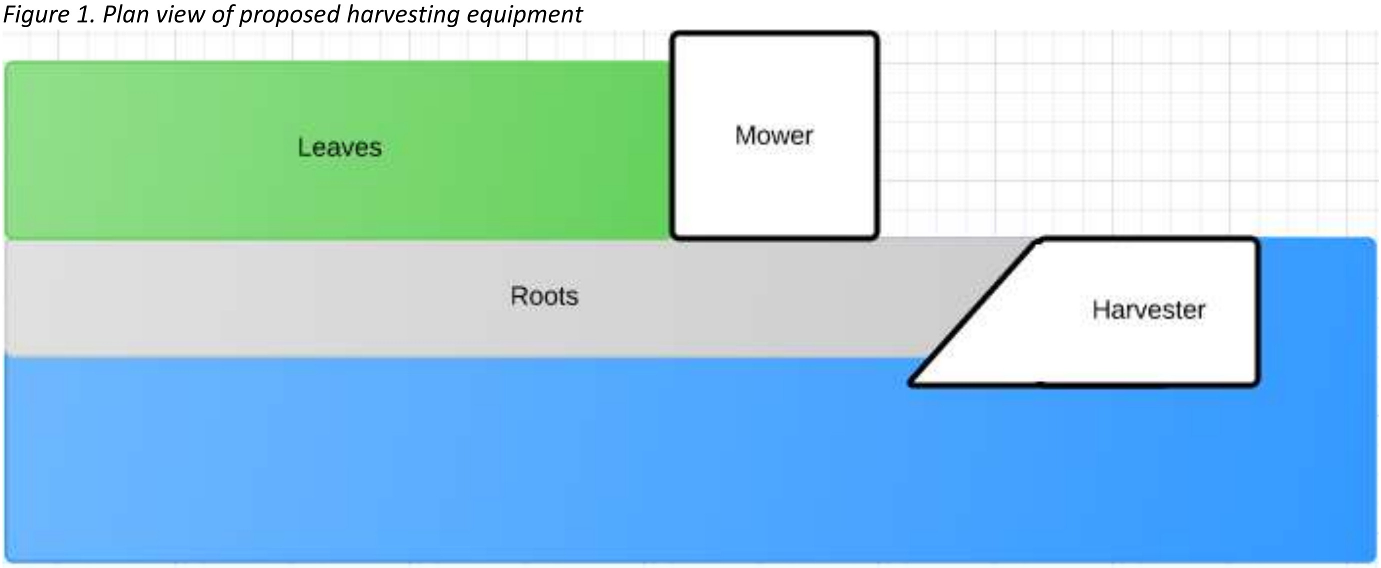

Figure 2. Side view of proposed harvesting equipment

Appendix VI

In this appendix the summaries interviews with stakeholders in Kenya can be found below.

Meeting Royal Dutch Embassy Nairobi **06-10-2010**
Nouke Ruiter, Rose Makenzi

- Nouke started last month at the Dutch embassy in Nairobi
- The Dutch embassy is not involved in any projects with regards to water hyacinth
- Budget for water project in Kenya is 30 million euro
- In Kenya water hyacinth only occurs as a problem in Lake Victoria and the Nairobi dam
- WRMA regulate the use of water WASEP regulates the service providers. Maybe get in touch with them in Nairobi once you are back from your trip in Kisumu. Embassy can help to get me around the table with these parties.
- Public Private Partnership (PPP) best way to go forward to an pilot
- Nouke advices to contact Thomas Luijtelaar from RVO
- In Kisumu there is a Dutch company that recently started a ferry, contacts will be send
- Mombasa harbor is expanding. The Rotterdam port was however not interested to be involved
- Most stakeholders the embassy came up with appointments were already made

University of Nairobi **06-10-2014**

- Currently there are a couple of projects ongoing to produce biogas. These are initiated by NGOs at several slaughter houses. The biogas has however not been commercially exploited.
- Once NGO leave the biogas project the biogas production will stop
- There is no big market in compost, people get biomass from their own land

Meeting SNV **07-10-2014**
Abdi Wario

Discussion to arrange last things for travel to Kisumu

- SNV is currently not involved in any projects dealing with water hyacinth
- SNV water projects are all WASH. 5 years ago Integrated Water Resource management (IRWM) was still included in SNV Kenya projects
- There are three counties around Lake Victoria that can be involved, Kisumu, Homa-bay and Migori.
- Diary in Kenya can mainly be found in Nairobi, Rift valley and especially Eldoret
- Diary feeds companys: Unga, Pioneerd, Sigma, Tausi, Jubillee

Meeting KORCE **08-10-14**
Sanjay Vadhera

- Korce is run by four partners.
- Purpose is to generate value from wastes. Deltares, UNEP, ICRAF have all collaborated with KORCE
- According to Cornell lake Victoria is the biggest solar panel in the world as it converts sunlight into biomass.
- Intention to develop a research centrum which can be used by research institutes and universities.
- The intention is to grow to 340 employees by 2025.
- The facility will have zero emissions to air, soil and water. The plant will be ISO 19001 certified.
- The intention of KORCE is to set up a seven phase project. The first steps are building a briquetting plant and a pyrolysis plant. The briquetting will be done with molasses and water hyacinth biomass.
- The charcoal from the pyrolysis can be sold for 60-80 KSh/kg and if made from coconut shells 400 KSh/kg. 900 ml of fuel can be sold for 80 KSh. The OPEX of producing 1 kg of coal and 900 ml of fuel is 9 KSh.
- The pyrolysis will mainly be done with urban waste as feed, ie plastic bottles. The proposed plant will convert 1 kg of plastic into 1 liter of fuel.
- A later phase of the project is the construction of a biogas digester with a capacity of 6 MW, corresponding to 140000 m3 of gas.
- The biogas digester will be a dual multi feed reactor which van produce biogas from several waste and not only water hyacinth. If there is a shortage of water hyacinth other wastes can be used.
- The biogas will exist of 60 % methane and 40 % CO_2. The CO_2 will be separated and can be used by fisherman for cooling of fish.
- Production of organic fertilizer will also be started. The fertilizer will have a moisture content of 35 % which can be sold for between 85-100 shilling per kg.
- For the distribution of gas rubber sacks will be used. The sacks will have a content of 1-5 kg which can be refilled at the plant.
- 1 m3 of water hyacinth removal equals 2,95 euro carbon credits.
- Permission for harvest of water hyacinth is granted by the national government.
- There is currently 1 harvester, another two have been ordered from India.
- The government does not pay for the removal of water hyacinth.
- Current harvester has the capacity of 150 ton per day, whilst the required harvest will be 600 ton per day. The boat requires 6 l of diesel per hour.
- Harvest is done from 7 till 4 because after 4 the winds at the lake become a problem for the boat.
- The harvester does not have an propeller because a propeller can get clogged by water hyacinth and fishing nets.
- Investment costs
    - Pyrolyis plant 40000 dollar

    - Biogas digester from civil structures 30000 dollar
    - CO2 washing unit 11000 dollar
    - Energy Turbine 1.5 million dollar
- Labor costs are 432 KSh per day per person and food costs
- The project is not supported by local government and does not collaborate with them because corruption risks.
- The depth of the lake is very low due to sedimentation of the lake.
- There are a lot of effluents from the waste water plant coming into the lake due to the low capacity of the waste water plant.
- For the sales of the project no marketing is required according to Sanjay as people come to his place to get the products.
- KORCE is willing to work together for a pilot project. IHC + W+B can make use of facilities and KORCE can even run the project.

KEMFRI **09-10-14**
Ruben Omondi

- There are currently no ongoing projects for water hyacinth removal by mechanical harvesting of the plant.
- Non- removal of the plant has a bad effect on the local biology, ecology and water quality.
- KARI has been working with biological control.
- No research has been done to define specific growth rate of the plant in the lake.
- Control can be done by:
    - Mechanical harvesting
    - Biological control (effective but slow)
    - Manual control (not very effective)
    - Plant succession (the plant sinks when overgrown by hippo grass)
- There are local groups making art from the water hyacinth for sale.
- The water hyacinth does not have a high heavy metal content.

KALRO **09-10-14**
Daniel Oketch

- Water hyacinth growth in LV has 90 % negative economic impact.
- Fertilizer could not be produced from WH because of pollutants.
- All utilization options have been tried.
- KALRO breeds weevils for biological management of WH.
- BMU also breed weevils with help from KALRO.
- The weevils bred are not sold.
- Lake Victoria basin commission is established for eastern Africa, LVEMP operates within that body.
- The irrigation systems in the area are not affected severely by the water hyacinth.

- Manual removal of WH is encouraged at strategic beaches 1) fisherman do it themselves to be able to fish 2) mechanical harvesting is too expansive

Homa Bay County Water Department **10-10-2014**
John Saranga **Director Water**

- Water Hyacinth is a major problem for the water department of the county:
  - Blocking water hyacinth
  - The force of water hyacinth destroys the suction lines
  - More chemicals required for the treatment of water
- In Homa-bay there is normally more water hyacinth than in Kisumu throughout the year
- Costs due to water hyacinth infestations
  - Chemicals costs go up by 10 % 5000 KSh per week
  - Repairs
    - valve blocking: 1500 KSh per week
    - piping system 5000 KSh 2 per month
  - Protective cage
  - Hand harvest
- No payment will be done for the removal of water hyacinth.
- LVEMP contracts people to harvest water hyacinth.
- The county propagates people to starts clearing the lake of water hyacinth.
- An EIA has to be conducted before a harvester can be used on the lake.
- LVEMP is a World Bank funded program.
- The county relies on donor for funding of initiatives.
- The irrigation schemes do not encounter problems from water hyacinth infestations.
- Only small scale irrigation schemes which use water from the lake encounter WH as a problem
- The benefit of WH is that fish breed under the mats.
- Nutrients wash into the lake from the Kisi highlands and contribute to the growth of WH.
- There is no market for the sales of biogas. A biogas toilet is supposed to sell the gas but is not in operation.

For a project the county can be involved by helping with the EIA, community mobilization. The county can contribute in costs for a harvester through a Public Private Partnership

Homa-Bay County Ministry of Agriculture **10-10-2014**
David Okeyo **Minister of Agriculture**

- There is a milk deficit of 40 million liters:
  - Supply from Homa-bay 32 million liters
  - Demand Homabay 72 million liters
- 2025 the demand will have increased to 99 million liters.
- Diary is steadily growing but development is required to reduce the local deficit.

- Livestock feed production is a problem in the area.
- There is no commercial production of animal feed in the county.
- The local county government buys raw products to make animal feed and fertilizer to sell subsidized to the local community.

If feed is going to be developed the county is interested in being a partner in the production of animal feed from water hyacinth. The government can also be a customer of the feed and distribute the feed throughout the county.

LVEMP agriculture specialist 10-10-2014
Eng Isaac Ngugi

- LVEMP was founded to prevent the "dying of Lake Victoria". One of the reasons the lake was degrading is WH. There is a cycle in the growth of WH:

  WH→Hippograss grows ontop of the WH→Sinking of WH→Sedimentation (lake is getting shallower)→WH comes back
- Water hyacinth is an environmental problem/noxious weed that is tried to be eradicated over the past 20 years.
- Sustainable management of the WH is required as it could not be eradicated.
- Because it is a noxious weed the governmental policy is not to propagate the use of water hyacinth.
- There are better sources for fiber than WH and there are also better wastes for bio digestion than WH.
- Water hyacinth is not supposed to be moved from place A to B (on shore). Processing at the lakes shore is however possible.
- NEMA has to approve the harvesting and processing of water hyacinth.
- Currently LVEMP is acquiring a WH harvester from the UK.
- Control options:
  - Mechanical harvesting (not yet done)
  - Biological control (weevils are currently used by BMU)
  - Chemical (not done in LV)
  - Manual (Encouraged but not payed)
  - Preventive measures will be taken
- Other authorities like the Nile Basin, Uganda and Tanzania also do not want to propagate the use of water hyacinth
- In the past others have visited LVEMP to investigate the opportunities of utilizing WH. They were looking for guarantees from the Kenyan government that if there would be losses the Kenyan government would back these up.
- If WH can be used in a good way and does not interfere with any other activities in the lake the government can tolerate the use of WH and then change policy.
- Policy has been changed in the past a couple of times.

KEMFRI **10-10-14**
Ernest Yongo: Social economist/ ecology

- WH started to appear in 1993,
- New publication about distribution due to winds is in progress.
- Due to WH fish species started to reoccur because fisherman can't fish in certain areas because of the WH mats.

Donga ecotourism group BMU LVEMP **11-10-14**

- The groups works on environmental conservation, renewable energies and ecotourism
- The WH has been very bad in 2012 but now it is not too much of a problem. During that time there were a lot of extra mosquitos and fisherman could not go out to fish.
- The people here especially the youth and woman are trained to make paper, weaving and baskets from the WH
- Farmers are also trained by the Kenia red cross to develop manure from WH
- Charcoal and briquettes are also made from the WH. The people have however never seen how to make biofuels from the WH
- During harvest of the WH most people do not have access to gloves and are exposed to snakes and bilharzia.
- The WH Is cut and dried in the shade before weaving
- Before using the WH fibers the biomass is treated with sodiumbimetasulphates

Kisumu County
Chief Officer of water **12-10-14**

- There are no ongoing projects with WH, LVEMP is been working on eradication of the WH.
- There are problems with the intake of water at our water station Kiwasko (only problems for the water department in the county).
- A prototype of a machines was used for harvesting WH but it was not successful.
- The wastewater treatment plant has recently been up scaled so no more waste water is de disposed in the water.
- Only the effluent of the treatment plant is disposed in the lake.

WRMA Charles **12-10-14**

- WRMA monitors the nutrients levels in the water 2 times a year in the lake. The monitoring of nutrients is however an expansive exercise and is therefore conducted not as often as desired.
- There are various stations in the lake that are monitored by WRMA.
- No permits are required for the harvesting of WH from WRMA.
- The waste water treatment plant is working as it has been upgraded recently and improved a lot since.
- LVEMP will contribute to the expansion of the waste water treatment plant.

- The coverage of the waste water treatment plant of the total population is Kisumu is low due to local waste latrines and septic tanks.
- Run off from commercial areas are a major source of pollution and minerals into the lake.
- Maintenance of sewage network is not done properly and leads to waste water run off into the lake.
- Pollution sources of the lake:
    - Raw water from rivers
    - Groundwater
    - Waste water
- Monitoring of water is mainly restricted to nutrients and is not done very regular last time was 3 years ago.
- There is some run off of mercury in the water from gold handlers who mine besides the riverside.
- Furtheremore there is some lead zinc and copper in the water which comes from the waste heaps.

Mary Obade Kisumu County Director of Agriculture 12-10-14

- WH should not be cultivated for the production of fertilizer as it interferes with fishing and other activities.
- Fertilizer are manufactured country wide to subsidize fertilizer for local farmers.
- WH fertilizer needs to be certified before it can be sold on the markets.

Jon Oloo Kisumu County Director of Livestock Production 12-10-14

- There is no information of local prices of animal feed.
- No subsidy of animal feed is given by the Kisumu county government
- The demand for livestock feed is high in the county because of urban demand of animal products.
- There are no livestock/diary stimulating projects but they plan to start diary projects in the sugar zones because of the molasses.
- During a pilot the county can help in creating a market and awareness for WH feed.

Kenya railways 12-10-14
Port Manager Michel Disi'

- The port offers docking grounds to ships and can (off) load and store cargo.
- The gulf is sometimes fully pact with WH. Vessels coming the port have problems to get to the port.
- A 600 t ship could not get in the port because of the WH.
- There are projects to eradicate the WH and we are about the receive the first equipment for the removal of WH.
- LVEMP works with other government departments from the lake basin and got funds from the world bank to buy a harvester.
- The WH will be disposed in an area marked for the disposal and destroyed completely.

- It has been tried to eradicate the WH by weevils.
- WH starts coming in October in November/December the bay is then fully packed with WH mats. The WH is then blown away arnound April. The other months of the year the bay is free of water hyacinth.
- The WH is overgrown with other plants when it is blown away. The WH that return to the port are not overgrown with other plants.
- Manual removal of the plant is possible it is however very slow.
- There is a lot of sedimentation because of run off from the high lands into the lake.
- Depth of the port has been effected by the sedimentation.
- The Lake basin community is sourcing for funding for dredging as this is required in the port.
- The port does not receive big ships the maximum depth is 4 meter when fully loaded
- JGH has a shipyard in Kisumu and Mwanza
- The economic effect of the WH on the port is large, normally 10 ships a month enter the port. When the water hyacinth mats infest the port only 1 ships a month enters the port.
- Passenger services have not been started yet in the port. It stopped in 2005 but there are projects to restart the ferry service again.
- The port does not contribute to the pollution of the lake, scientists have said that pollution of the lake comes from the urban areas.
- Diesel is sold to the boats by petrol dealers. If the boat requires a lot of full petrol is directly bought from the oil depot.

Constructer of Biogas digester (small scale) 13-10-14

- 12 m3 size gas digester produces between 6-10 hours of gas a day. The amount differs based on the amount and frequency of feed.
- Investment costs in a digester of 12 m2 vary between 80000 and 120000 KSh.
- 16 m3 is the largest digester which is constructed by this company and costs 260000 KSh.
- The distribution of gas is done by piping directly in the household using the gas.
- The construction time is 6-10 days.
- The investment in such a biogas digester used to be subsidized by SNV.
- These digester do not use plant material, only manure and human faces.
- The drain sludge is dried and later scooped to be distributed over the farm.

Lake Victoria Development Authority 13-10-14
Jared Gambo Environmental officer

- LVDA works on the whole catchment of the Lake basin 39000 km2.
- LVDA works as an governmental agency, implementing policy on the Kenyan side of the lake
- There are no direct projects for the management of WH, the LVDA however collaborates with LVEMP
- LVEMP employs youth for physical removal of WH this is however not successful because of migration of WH by winds, biological efforts have had some results
- Catchment conservation efforts are done by LVDA as the problems are a result of the destroying of the catchment. Soil erosion is for example reduced.
- A German company has been here before to assess the possibilities for cultivation of WH in the lake and utilize the plant as fertilizer. They have however not been back.
- NEMA is the regulatory authority for these kind of projects

- The LVDA can contribute in such a project through a PPP. THE LVDA reaches 16 million Kenyans through their projects
- THE LVDA can help to get the products to local people through their network
- The LVDA can also work as an investor in a PPP. The LVDA will be backed by the country government.

NEMA **13-10-14**
Mr Oseimo

- Several efforts have been done to control the WH
- Any imitative to reduce WH is much welcomed.
- Before the start of a project it is required to perform an EIA involving all the stakeholders.
- For a Pilot project an EIA project report is required done by an local consultant, local NEMA office can help to meet the timeframe of the project.
- After a pilot for a full project an EIA study report is required also done by a local consultant
- If there are benefits for cultivation NEMA can approve this after an EIA has proven that there are no negative impacts.

Maritime Authority **13-10-14**
Jeremiah Onyango

- Water hyacinth is good for the breeding of fish and cleaning the water
- Uganda harvests WH for organic manure on large scale. The WH is collected by vans to be brought to the farms in the highlands.
- The WH dries very fast and can then be used as manure.
- Jeremiah contacted the local prison to harvest the WH to use for their garden.
- LVEMP will purchase a harvester which will be managed by the maritime authority.
- The WH biomass will be send to prison to use it as manure for their garden.
- There is currently a crossway connecting an island in the lake with the shore. This crossway will be opened and replaced with a bridge. The current from the lake will then easier take the nutrients from Winham gulf and dilute them in the lake.
- The opening of this point will help to prevent the infestation of WH because there will be less nutrients and the WH can also easier migrate to the big lake.
- Rescuing fisherman is expensive because a chopper needs to come from Mombasa.
- The lake is heavily polluted by leaching from waste and disposal into the lake.
- Car washing in the lake is not allowed to prevent pollution.
- At the prison a biogas installation is used to generate gas for cooking and lighting. The biogas digester is similar to the ones shown at the facilities of local farmers
- The waste water treatment plant should be built close to a wetland to prevent the effluent going directly in the lake

Kenya Pipeline Company **13-10-14**
George Onyanjo

- There is about 11 shilling margin made by the petrol station.
- The oil companies will charge around 1 shilling if the diesel is bought directly from the pipeline company.
- Tanks for the storage of oil will however need to be built on site to be able to buy oil directly from the depot.

Water board Kisumu **14-10-14**

- The water board makes sure people have access to clean water for domestic use and works on waste water management.
- The water board does not have any ongoing projects related to WH.
- It is cheaper to use an existing docking place than to build a new one.
- There is a docking place at Kindu bay that can be used to off load harvester. It is still operational but is not used since the WH started to be a problem.
- Liaise with many governmental bodies to get approval for a docking site.
- Land close to the lake should be governmentally owned. This is however often not the case anymore and local farmers use and perceive it as their own land.
- The price of a hectare of land including an access road is 450000 KSh.
- WH takes iron from sediments and releases these in the water, the treatment plants for water are not designed to clean the water from iron and had to be adapted.
- The water price increases when WH is around because more chemicals are required to purify the water.
- Tourism is affected by the WH because tour guides can't perform boat rides.
- The fishing industry is affected by the WH because fisherman cannot fish and Tilipia and Nile perch disappear.
- The weaving industry only has business if the WH is around.

Dutch Embassy **15-10-14**
Rose Makenzy

- Local government can be used as a customer to sell the animal feed and fertilizer.
- The chicken meat market has grown a lot in Kenia because it was promoted people eat white meat.
- Dutch embassy has a food security program, including a diary program.
- One of the steps in this program is quality fodder, this is implemented by SNV. They are setting up a commercial fodder center. A feasibility study on this center was done by Friesland Campina. The embassy is going to top of the grant.
- SNV has an innovation fund and can most likely put money aside for project for water hyacinth management.
- The embassy does not have possibilities to fund a water hyacinth project.
- Lake Victoria is a new area for Integrated Water Management within the embassy.
- The embassy can support the pilot by field visits to the pilot and contacting institutions.
- For the setup of the pilot the embassy can act in the role of broker, helping by workshops, and communicating involvement of the embassy.
- This project is aligned with the strategies of the embassy. The embassy would therefor like to be informed of the next steps and decision for a pilot.

SNV **15-10-14**
Judith libaisi

- SNV has two main projects in the biogas program:
    - Kenya national domestic program
    - 4S@scale project

- For the Kenya national domestic program the first phase subsidized the installation of biogas digester. 12000 small scale digester have been installed.
- For the 4S@scale project the use of the slurry from the biogas digestion is promoted.
- People use biogas to show off, the same applies to LNG.
- There is demand for biogas cylinders.

SNV **15-10-14**
Anton Jansen

- The proteins used in animal feed are all from waste streams.
- Diary meal is mainly bought by small scale farmers.
- Large dairy farmers either farm the raw materials required for diary feed or by the raw materials.
- Brewers grain is also often used as animal feed, this might be similar to the product from made by protein extraction.
- The prices of animal feed in Kenya are higher than the world market prices.
- The quality of feed in Kenya does not correspond with the prices. The quality is not according to quality standards. There is a higher ash content and lower protein content in the animal feed.
- Proteins are a bottleneck for the production of dairy in Kenya.
- The import taxes for pilot equipment can be a problem. The embassy should help with this. It is also likely a local university needs to be involved to import the equipment.
- SNV is interested to be part of the project if it is commercially feasible and has the possibility of up scaling.
- If governmental money is going to be used for this project SNV should be part of the proposal to make sure funds are also allocated to their people.

GIZ Reimund Hoffmann **20-10-14**

- There are three large scale biogas projects in Kenya and another two in progress
- All the big biogas installations will be used for the generation of electricity
- WH biogas cannot be very successful (Khartoum 1985):
    - 95% of the plant is water
    - There is not a lot of knowledge on semi solid substrates
    - Unpredictability of the plant, as it can migrate with winds
- GIZ is involved in a biogas plant in Kirich for tea.
- A membrane foil on top can reduce the digester costs as less volume is required.
- There are not a lot of large scale biogas projects in Kenya.
- It took more than 7 year before the development of the plant in Delmonte started.
- Prices are similar to Europe as it all has to be sourced from there.
- No knowledge in Kenya about biomass digestion.
- A marketing contract with KenGen will also be key for electricity generation from water hyacinth.
- KenGen offers a price of 10 US ct/kWh with a minimum capacity of 200 KWe.

Observations and discussions animal feed stores **14-10-14**

- For 50 bags or more a discount of 120 KSh per bag is given.

- Normally a shop owner earns 100 KSh per bag and if targets are reached they get another 120 KSh per bag.
- All of the animal feed stores are either retailers of the big animal feed companies or are supported by the government.