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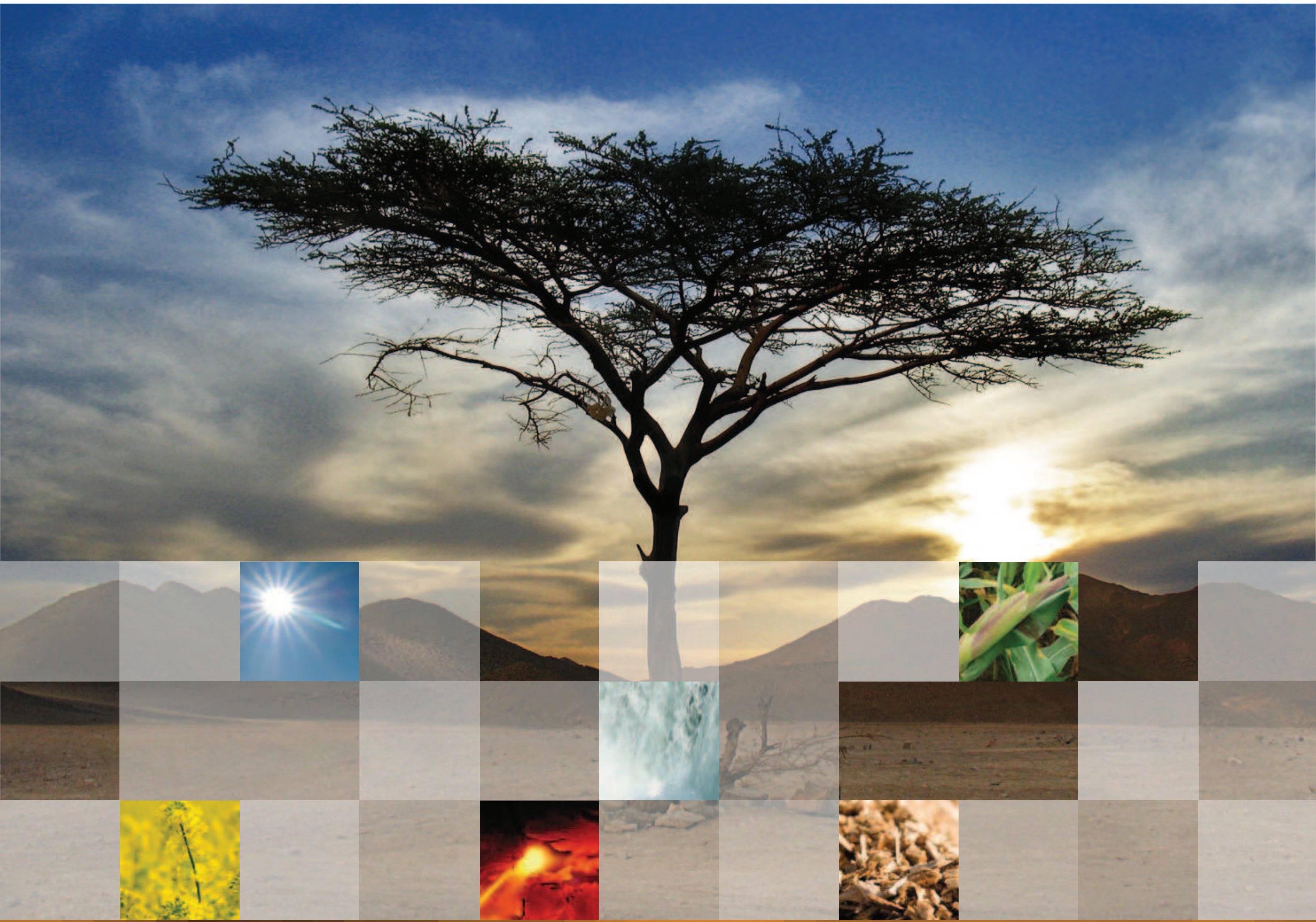

Renewable Energy Project Development Programme East Africa

Agro-Industrial Biogas in Kenya

Potentials, Estimates for Tariffs, Policy and Business Recommendations

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German Biomass Research Centre

Agro-industrial biogas in Kenya

Potentials, Estimates for Tariffs,

Policy and Business Recommendations

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On behalf of

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ABBREVIATIONS

a	Annum (per year)
AD	Anaerobic digestion
bbl	Barrel
C/N ratio	Carbon to nitrogen content ratio
CH_4	Methane
CHP	Combined heat and power
CO_2	Carbon dioxide
COD	Chemical oxygen demand
CSTR	Continuous stirred tank reactor
DBFZ	Deutsches BiomasseForschungsZentrum gGmbH (German Biomass Research Centre)
DM	Dry matter
EEG	Erneuerbare Energien Gesetz (Renewable energy act)
EOI	Expression of interest
ERC	Energy Regulatory Commission
EUR	Euro
FiT	Feed-in-tariff
FM	Fresh matter
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit GmbH (German Technical Cooperation)
GW	Gigawatt
GWh	Gigawatt-hour
KenGen	Kenya Electricity Generating Company Limited
KES	Kenyan Shilling
KPLC	Kenya Power and Lighting Company
kV	Kilovolt
kVA	Kilovolt-ampere
kW	Kilowatt
kWh	Kilowatt-hour
MSW	Municipal solid waste
MW	Megawatt
MWh	Megawatt-hour
RE	Renewable energy
REP	Rural Electrification Programme
UASB	Upflow anaerobic sludge blanket
USD	US-Dollar
VS	Volatile solids

0 EXECUTIVE SUMMARY

0.1 Potentials for biogas in Kenya

This study considers data on theoretical potentials from 13 selected groups of biomass available from the agro-industrial business in Kenya and for municipal solid waste in Nairobi. Since the data is necessarily incomplete, and since future potentials are not considered, the actual potential could well be higher. Most promising sectors for electricity production from biogas from anaerobic digestion based on this study are:

Table 0-1 Possible installed electric capacities for major biogas potentials considered in this study

	Potential installed capacity [MW_{el}]		
	Mean	Min	Max
Municipal solid waste	37.5	11	64
Sisal production	20	9	31
Coffee production	10	2	18
Total all sub-sectors	80	29	131

The total potential installed electric capacity of all sub-sectors ranges from 29 to 131 MW_{el}, generating 202 to 1,045 GWh_{el}/a of electricity, which is about 3.2 to 16.4 % of the total Kenyan electricity production of 6 360 GWh_{el} as of 2007/08. The extent of actual realisation of this potential will depend on the incentives provided for investment, in particular the tariff framework.

0.2 Economic and technical analysis of selected case studies

The production costs of electricity from biogas for different technologies and plant capacities were calculated by using the annuity method in accordance with German VDI 2067. For each technology minimum (best case) and maximum (worst case) electricity production costs for small scale (50 kW_{el}) and medium scale (250 kW_{el}) model biogas plants were calculated. The resulting specific production costs are an estimate which may differ from production costs under real conditions. The calculated electricity production costs are listed in the table below.

Table 0-2 Production costs depending from technology and plant scale considered.

Technology	System	CHP capacity [kW_{el}]	Specific production costs [USD ct/kWh_{el}]
Batch system	Dry fermentation		10.95 – 24.33
CSTR	Wet fermentation	50	11.18 – 28.65
UASB	Wastewater treatment		7.46 – 19.43
Batch system	Dry fermentation		7.58 – 15.24
CSTR	Wet fermentation	250	7.74 – 18.90
UASB	Wastewater treatment		6.14 – 14.81

0.3 Recommendations for an electricity tariff system

Basic tariff We suggest establishing three basic tariffs, depending on the installed electric capacity of the CHP, since the specific costs of small plants are higher than the costs of larger plants. Based on this calculations average production costs of 12.52 and 18,05 USD ct/kWh_{el} for small scale biogas plants can be assumed respectively. The production costs for medium and large scale applications (>500 kW_{el}) are estimated not to be higher than 10 USD ct/kWh_{el}. In the following an additional charge of 10 % on the average production costs is considered as realistic to achieve a basic-tariff. The final decision on the tariff remuneration should assume that a higher payment might act as a strong incentive to maximize realisation of the potentials.

Table 0-3 Proposal for basic tariffs for electric power from biogas in Kenya

Installed capacity of exemplary plant	Production costs (USD ct/kWh_{el})	Basic-FiT (USD ct/kWh_{el})			suggested share
		+ 5%	+ 10%	+ 15%	
50 kWel	18.05	18.96	19.86	20.76	0 - 50 kWel
250 kWel	12.52	13.15	13.77	14.40	50 – 250 kWel
500 kWel	10.00 1	10.50	11.00	11.50	250 – 500 kWel
1,000 kWel	9.00 1	9.45	9.90	10.35	> 500 kWel

[1] Production costs for 500 and 1,000 kW_{el} are estimates

Plant size related degression Generally the basic FiT should be paid in steps of production for each plant. The degression of the FiT should provide a better economic framework for small-size biogas plants and takes a significant cost reduction with growing plant size into account. It can be shown, that a widespread range of different plant scales can be covered by the suggested tafiff.

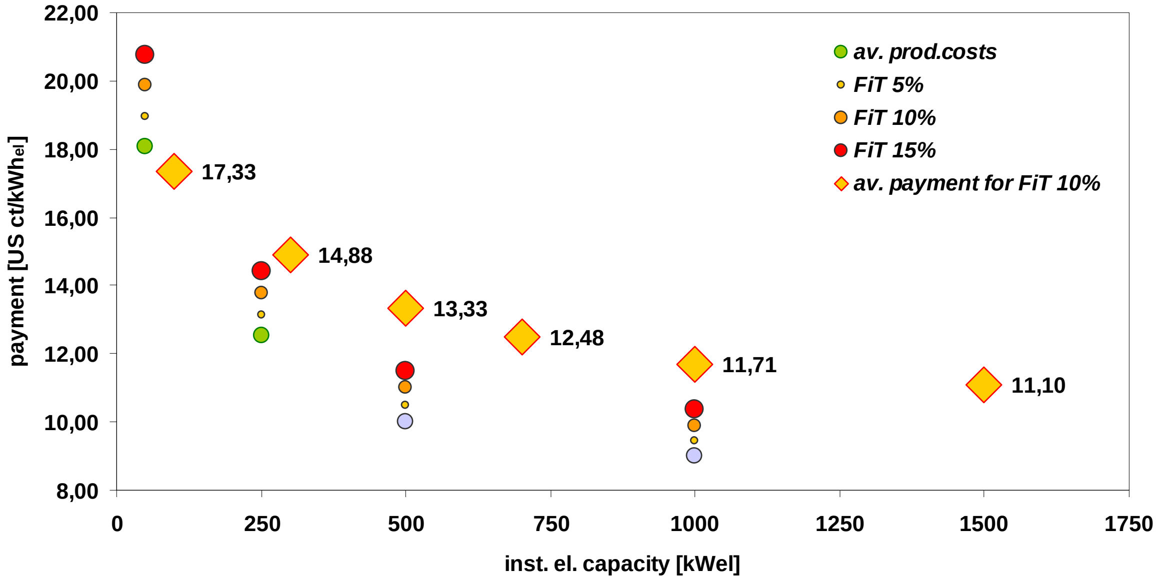

Figure 0-1 Demonstration of the specific FiT paid for different plants at 100 – 1,500 kW_{el} (orange). The calculated production costs for 50 and 250 kW_{el} (green) and the estimated production costs for 500 and 1000 kW_{el} (light grey) as well as the suggested FiT at three different levels (5, 10 and 15 %) are also shown.

Since the mean production costs are used to estimate the suggested FiT, it will offer fair remunerations for biogas plants at installed capacities up to 1,500 kWel.

Bonus tariffs Tailored incentives can be introduced in addition to the basic-tariff system in order to achieve specific desired targets. Such incentives could be additional bonus payments (e.g. 0.01-0.02 USD / kWh) on top of the basic tariffs if a certain requirement or objective is met by the plant design. The rationale is that adapting the plant layout in order to meet such objectives implies additional costs for the investor. The following bonuses could act as effective regulatory instruments:

- Early mover bonus to accelerate development of biogas in Kenya
- Peak load supply bonus for grid stabilisation at high load times;
- Energy efficiency bonus as an incentive for efficient power generation,

Price indexing of FiT This instrument should be introduced to provide investors security with regards to inflation and energy cost risks.

The overall investment for 100 MW_{el} at average specific investment costs of 4,000 USD/kW_{el} will be 400 Mio USD. With the available information about the cost for power production from biogas and actual production costs for electricity in Kenya, difference costs were calculated for three scenarios. Due to the unknown future spreading of biogas in Kenya, the first scenario focuses on small scale agricultural plants, the second scenario emphasizes medium sized plants, whilst the third scenario takes industrial biogas production into account.

Table 0-4 Approximation of installed biogas plants for three scenarios.

	Scenario 1		Scenario 2		Scenario 3	
Biogas plants at	installed [MW_{el}]	count [-]	installed [MW_{el}]	count [-]	installed [MW_{el}]	count [-]
100 kWel	50	500	25	250	25	250
500 kWel	25	50	50	100	25	50
1,000 kWel	25	25	25	25	50	50
Total	100	575	100	375	100	350
Mean Remuneration (USD/kWhel)	0,1492		0,1392		0,1352	

If average generation costs for electricity are set to 10.00 USD ct/kWh_{el}, difference costs of 26.3 to 36.9 Mio USD/a may arise.

0.4 Recommendations on complementary regulations

Grid access Power generation from biogas is an effectual way to supply base-load and is highly recommended under the aspect of decentralisation. Grid access regulations are of central importance, if biogas energy should be fed into grid at any suitable plant site in Kenya.

Regulatory approval and constructive regulations In Europe many biogas projects stagnate due to the complexity of regulations and a great variety of engaged authorities. Often the approval for investing in a plant takes much time. Clear and transparent general regulations for the realisation of bioenergy projects are necessary.

Granting of loans In case of large-volume and high-interest loans the break-even point of recapitalisation has to be in a very short time. This would restrict the implementation of biogas plants to only a few plants with very good preconditions. It is important to provide a guideline for the evaluation of biogas projects to credit institutions in Kenya. Such a guideline for the evaluation of biogas projects can help enhance security for credit institutions. An extra credit programme may be provided by regional or international financing institutions as a further incentive (e.g. World Bank, African Development Bank).

Monitoring The assessment estimates the proportion of electricity generation from biomass, gives detailed information about the distribution of biomass plants and discusses misguided developments as well as positive effects.

0.5 Kenyan Electricity sector and investment recommendations

Due to the considerable biogas potential and the expected regulation of an attractive feed-in-tariff system by the Kenyan Government, the Kenyan market is an interesting entrance to the East-African biogas market for investors. Climate investment and regulations for foreign investments are evaluated as positive, although political stability has deteriorated in the past years.

Investors, which are interested to entry into the promising Kenyan biogas market, need a long-term strategy and should base their activities in Kenya on the cooperation with experienced and well connected local cooperation partners. Joint-ventures with Kenyan partners would facilitate the implementation of the projects due to the familiarity with national and local licensing procedures (e.g. plant construction, environmental licences).

Since realisation of this potential depends also upon the political and regulatory framework conditions, investors, plant manufacturers and technology providers should follow closely the reformulation and implementation process of the feed-in-tariffs for biogas energy. If the feed-in-tariffs would be implemented as recommended within this study, framework conditions for biogas projects would be favourable.

Furthermore, for companies where agricultural residues accrue during processing, the installation of biogas plants could help satisfy the own energy demand as a first step. Another option is the direct sale of biogas electricity to bulk consumers (e.g. cement industry) whereas the national grid is only used for the transmission of electricity, but a regulatory framework for power wheeling yet has to be set up. Summing up, alternative energy provision, biogas production and electricity generation could be one interesting and economic option, even without feeding into the national electricity grid.

0.6 Synopsis

- Usage of local substrates and production of clean energy allows to improve local value chains, operation, service and maintenance will create new jobs without additional cost for the municipality;
- A viable local biogas industry with local manufacture and maintenance capacity depends on a critical mass of installed capacity and number of power plants, i.e. realisation of substantial numbers and investment in all three market segments;
- Only the biomass potentials considered in this study could provide a reliable generation capacity of up to 131 MWel, which could then cover approx. 16 % of the electricity demand of Kenya;
- Additional biomass potentials in the industrial and agricultural sector are given, but could not be quantified;
- A basic Feed-in-Tariff is suggested, which is differentiated according to power generation plant size;

- Calculated remunerations are very close to the least cost power generation projections provided by the Government of Kenya;
- To provide tailored incentives for specific objectives, bonus payments on top of the basic tariff can be introduced, e.g. for peak load, rural electrification, or energy efficient power generation, a mechanism to balance out inflation is proposed;
- A clear set of complementary regulations for both plant owners and grid operators has to be implemented;
- The total expected investment volume at 80 MWel will be approx. 338 to 508 Mio USD;
- Due to the considerable biogas potential and the expected regulation of an attractive feed-in-tariff system by the Kenyan Government, the Kenyan market could be an interesting entrance to the East-African biogas market for German biogas technology and component providers.
- Climate investment and regulations for foreign investments are evaluated as positive, although political stability has deteriorated in the past years.
- Companies are strongly advised to cooperate with Kenyan agricultural companies and engineering office when trying to project and implement biogas plants in Kenya, since knowledge of the local conditions and the adjustment of the concepts to the local framework will be critical for the success of the projects.
- Biogas will provide clean and sustainable power with small additional costs.

1 INTRODUCTION

1.1 Background

Kenya is facing an acute electricity shortage not only due to the limitations of installed capacity but also due to the over-reliance on hydro power that threatens security of supply in times of drought. Following a crisis in 1999/2000, several fossil fuelled power stations were installed. In addition, in order to meet short term demand, emergency suppliers were contracted. These fossil fuelled power plants nowadays drive the cost for the consumers, since the fuel costs for the fossil powered plants are passed through directly to the consumer, at a rate of about 2 to 8 KES/kWh$_{el}$[1] [1] [2], amounting to 20-50% of the consumer prices.

1.2 Objectives

As one of the possible options to help stem this shortage, GTZ is promoting large-scale, agro-industrial biogas. However, there are several barriers that need to be overcome in order to promote large-scale biogas in Kenya. The main obstacles for uptake of this technology so far have been a lack in awareness on the side of potential investors and policy makers about the viability of biogas as a source of electricity, and a regulatory framework that does not provide adequate tariffs for electricity production and sales to the grid operator from biogas. These – and various other related issues – also pose effective barriers for foreign direct investment and market involvement by the private sector both local and foreign.

The objectives of this study are:

- Potential assessment: to provide estimates of the potential for biogas in Kenya based on both aggregated as well as site-specific data for different sub-sectors, referring here to medium and large scale use of biogas for heat and electricity production;
- Policy Recommendations: to derive recommendations for electricity producer tariffs and complementary regulation based on selected case studies;
- Business recommendations: to provide German and Kenyan companies with a set of recommendations for doing business in Kenya e.g. co-invest in the field of agro-industrial biogas;

This information will be passed on to private sector and the policy makers. Representatives from the Ministry of Energy and the Energy Regulatory Commission in Kenya have explicitly requested for it, and expressed willingness to include specific

[1] 0.14 to 0.21 USD/kWh$_{el}$ with a medium exchange rate 2008 of 71.45 KES/USD.

tariffs for biogas based on these figures. This represents a critical step to initiate the private-sector led take-off of the biogas industry in Kenya.

2 THEORETICAL POTENTIAL FOR BIOGAS IN KENYA

2.1 Definition of the term "Potential"

The potential of the different bioenergy sources to be used for energy can be categorised as theoretical, technical, economic and realisable potential (see Figure 2-1).

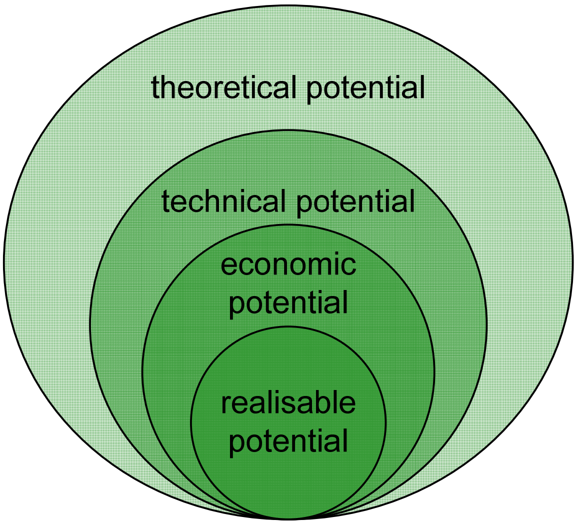

Figure 2-1 Definition of the term potential

The theoretical potential of renewable energy is derived from the physical supply of renewable energy sources (all phytomass and zoomass) and represents a theoretical upper limit of the available energy supply. Generally only a small percentage of this potential can be tapped due to insurmountable technical, ecological, structural and administrative restrictions. The technical potential, however, refers to the percentage of theoretical potential that can be used given current technical possibilities. Calculating the technical potential takes into account the available utilisation technologies, their efficiency, availability of sites (including the impact of competing uses), as well as "insurmountable" structural, ecological (e.g. nature conservation areas) and other non-technical restrictions.

The economic potential of an option of using renewable energy refers to the percentage of the technical potential that can be used economically in the context of given basic energy industry conditions. Before the economic competitiveness of the renewable energy source or system can be assessed, other competing energy supply systems must be defined for the application areas. The economic potential for using renewable energy sources is affected by the opportunity costs of conventional energy systems and therefore mainly depending on the oil price as primary source of energy.

The realisable potential refers to the expected actual contribution of an option for using renewable energy sources. It is typically lower than the economic potential, since it usually cannot be exploited immediately and can be only used to its full extent over the long term (e.g. due to limited manufacturing capacities or lack of information). However, the realisable potential can even be greater than the economic potential, if for example the option for using renewable energy is subsidised (e.g. market introduction program).
In this study, the estimation of the biogas potentials is not representing the total theoretical nationwide biogas potential but rather the technical potential for selected subsectors and producers.
The potential for biogas production from agricultural residues, agro-industrial and municipal wastes was estimated on the data previously collected by GTZ. This data was reviewed critically and data gaps were closed in cooperation with GTZ within a field trip to Kenya. The basic data for the estimation of biogas potentials is the amount of residues in different subsectors. Within a subsector the total amount of residues is calculated by the sum of the amount of residues from different producers.

It is important to note that the potential identified here is lower than the actual potential a) since the information collected only represents part of the total agro-industrial sector, and b) since it does not include future investments. In addition, other subsectors that have not been addressed here due to lack of data (like large scale cattle farming, tea production, pyrethrum production…) imply additional potentials that have not been included. In essence, the potential assessment presented in this study is conservative, the actual potential is very likely considerably higher.

Farming of energy crops e.g, production of maize or wheat silage as a feed for biogas digesters is not considered here either due to its implications on food security.

2.2 Methodology

To calculate the biogas potential for solid substrates the following information is required:

- Amount of residue (tons per year)
- Seasonal availability of the residue (for biogas production a residue should be available during the whole year or should be storable)
- Dry matter (DM) content of the residue (% fresh matter, FM)
- Volatile solids (VS) content (% DM)
- Biogas potential for the substrate (m^3/t VS)
- Methane content in the biogas (%)

For the calculation of potentials from wastewater the following information is needed:

- Amount of wastewater (m^3 per year)
- Seasonal availability of the wastewater
- Chemical oxygen demand (COD) of the wastewater (kg COD/m^3)
- COD degradability (%)
- Biogas potential for the wastewater (m^3/t $COD_{removed}$)
- Methane content in the biogas (%)

Based on this information the amount of methane produced from a residue can be calculated. The further conversion efficiency from methane into heat and electricity is depending on the technical specifications of the CHP generation plant (see Table 2-1).

Table 2-1 Conversion factors and full load hours used for the calculation of biogas potentials

	Total energy [kWh /m^3 methane]	Efficiency of heat generation [%]	Efficiency of electricity production [%]	Full load hours CHP [h/year]
Min	10	38	30	7,000
Max		42	36	8,000

Biogas potentials figures and tables in this study are expressed by minimum, maximum and average values (see annex 1 and 2). Minimum and maximum values are calculated by low respectively high DM content, VS content, biogas potential, methane content and conversion efficiency (CHP) values. Minimum and maximum values tend to deviate strongly because of differing values reported in literature and known from practice. This can be explained due to shifting composition of substrates depending on plant variety, habitat, climate, processing and many other factors. It has to be considered that anaerobic digestion of single substrates (mono-fermentation) is limited due to biological and chemical reasons (C/N ratio, nutrients, trace elements, inhibitors…) and not feasible for all substrates. Most biogas plants use at least two different substrates (such as cow manure and agricultural residues or energy crops) to achieve a stable anaerobic process. Generally inoculum is needed in all cases to start the anaerobic process. This can be manure from ruminants, effluent from a nearby biogas plant or sewage sludge.

2.3 Characterisation of substrates

A list of the substrates and their average characteristics examined in this study is presented in Table 2-2 for solid substrates and in Table 2-3 for wastewaters. The suitability of different solid substrates for anaerobic digestion can be expressed by the methane potential per ton of fresh matter (FM). These values range from 37 m^3 for sisal pulp to 159 m^3 for spent tea leaves.

Table 2-2 Characteristics (mean values) of solid agro-industrial wastes for anaerobic digestion; (Data adapted based on literature review, see Annex)

Substrate	DM content [% FM]	VS content [% DM]	Biogas potential [m^3/ton VS]	Methane content [%]	Methane potential [m^3/ton VS]	Methane potential [m^3/ton FM]
Coffee pulp	20	93	390	63	244	45
Cut flowers wastes	27	92	360	55	201	54
Tea waste	78	97	358	55	200	159
Sisal pulp	12	85	523	60	330	37
Old sisal plants	29	93	611	60	368	103
Sugar filter cake	25	70	475	55	262	47
Pineapple solid wastes	15	96	610	58	358	52
MSW Nairobi	45	60	398	64	260	85
Pig manure	23	83	514	64	335	66
Chicken manure	25	73	435	63	277	54
Vegetable wastes	13	83	525	55	295	39

For wastewaters the methane potentials per m^3 of wastewater are much lower compared to solid substrates due to the low content in organic material and high water content. Values range from 0.7 m^3 for nut processing wastewater to 22 m^3 for distillery stillage. Those values may vary strongly depending on specific technical preconditions of the processing.

Table 2-3 Characteristics (mean values) of agro-industrial wastewaters for anaerobic digestion; (Data adapted based on literature review, see Annex)

Substrate	COD in wastewater [g/l]	COD degradability [%]	Biogas potential [m^3/ton COD_{rem}]	Methane content [%]	Methane potential [m^3/ton COD_{rem}]	Methane potential [m^3/ton FM]
Coffee processing wastewater	14.3	90	375	70	265	4.3
Dairy wastewater	4	88	367	80	295	1.1
Slaughterhouse wastewater	8	77	340	69	236	1.8
Distillery stillage	90	66	390	73	290	22
Nut processing wastewater	4.2	70	330	75	250	0.7
Pineapple processing wastewater	5.5	85	375	75	289	1.6
Sisal decortications wastewater	11.5	87	475	84	400	4.3

The major disadvantage of wastewaters is the low energy density, but considering technical aspects they are easier to pump and to stir than solid substrates. If wastewaters are used in CSTR (Continuous stirred tank reactor) biogas plants a large digester volume for the fermentation process is needed. Thus, wastewaters are treated in customized wastewater treatment systems like UASB (Up flow anaerobic sludge blanket; the most common system), fluidized bed, fixed film, sequencing batch etc. Those systems are working with an immobilisation of the microorganisms whereby the retention time and digester volume can be reduced.

2.3.1 Sub-Sector 1: Coffee production

Coffee is one of the most important agricultural cash crops in Kenya. It is produced by small scale farmers, cooperatives and large scale estates. The main harvest season is from October to December. After harvesting the coffee cherries are mainly processed by wet fermentation to obtain the parchment coffee (dried beans covered by paper-like coating). During this process large amounts of organic wastes like pulp and wastewater are produced. The pulp can be used as organic fertiliser. According to the Coffee Research Foundation in Kenya [3] for each ton of parchment about 2.15 tons of pulp and 80 m^3 of wastewater (without recirculation of process water) are produced. In case of future change to more optimized fermentation methods with recirculation of process water the amount of wastewater would decrease drastically, but the amount of COD would be roughly the same.

The feasibility of anaerobic digestion of coffee wastes has been documented by many authors but the biogas yield tends to vary in literature. *Hofmann and Baier* [4] reported a biogas yield of 380 m^3/t VS (57-66 % methane) from coffee pulp (16.2 % DM, 92.8 % VS) in lab scale batch experiments and a biogas yield of 900 m^3/t VS for semi-continuous experiments. *Kivaisi and Rubindamayugi* [5] reported methane potentials of 650 and 730 m^3/t VS of Robusta and Arabica coffee solid waste (mixture of pulp and husks). Different digester designs like CSTR, plug-flow and two stage systems (CSTR for hydrolysis, UASB for methanogenesis) can be used for the anaerobic digestion of solid coffee wastes.

The anaerobic treatment of wastewaters can be done by high performance reactor systems for wastewater treatment with immobilisation of microorganisms. Due to fermentation processes, sugar compounds in the wastewater are converted into acids, leading to very low pH values in the wastewater [6]. Thus, neutralisation may be necessary before the anaerobic treatment.

The potential of biogas production from coffee wastes in Kenya is calculated for the coffee harvest 2008/2009. According to the Coffee Board of Kenya 57,000 t of parchment coffee were produced. Because 90 % is processed by wet fermentation in Kenya, 51,300 t of parchment coffee are obtained by this fermentation method. Assuming that each ton of parchment is producing 2.15 t of pulp and 80 m^3 of wastewater [3] the total amount of residues would be 145,125 t of pulp and 4,104,000 m^3 of wastewater per year. Table 2-4 summarizes the potential electricity production from coffee residues in Kenya.

Table 2-4 Potential methane yield, heating oil equivalent, electricity production and installed capacity from coffee wastes in Kenya

	Methane yield [m^3/a]	Heating oil equivalent [tons/a]	Electricity production [kWh/a]	Installed Capacity [MW_{el}]
Min	4,227,000	3,500	12,681,000	2
Max	41,027,000	34,000	147,698,000	18
Mean	**22,627,000**	**18,750**	**80,189,500**	**10**

2.3.2 Sub-Sector 2: Chicken production

The production of chicken is prevalent in the whole country. Only large production units were considered for the potential assessment, since only they generate appreciable amounts of chicken manure.

Chicken manure is a well known substrate for biogas production with a high energy content compared to cow dung, but difficult to handle due to high contents of nitrogen and inorganic compounds like chalk and sand [7]. *Webb and Hawkes* reported a beginning inhibition of biogas production from poultry manure with ammonium-nitrogen (NH_4-N) concentrations above 4,275 mg/l and ammonia-nitrogen concentrations (NH_3-N) above 435 mg/l [8]. If sand is a component of the manure, it accumulates over the years at the bottom of the digester and therefore reduces the available volume. In this case the digester has to be opened every few years to remove the sediment, leading to an operational break and additional costs. Usually chicken manure is only used in addition (about 30 %) to other substrates as a co-substrate or has to be diluted with water to maximum total solids concentrations between 5 and 10 % [9]. The composition of chicken manure varies depending on the husbandry system (layers, broilers, free range, battery cage, deep litter…), feeding, age and other factors. Depending on these factors the biogas yield may differ in broad range. Values reported in literature vary from 250 to 620 m^3/t VS [10] [11]. The methane content reaches values between 60 and 65 % [10] [12].

The total amount of residues from chicken production is calculated on the data (54,000 t/a of chicken carcass) provided by GTZ, resulting in 82,125 t/a of fresh chicken manure. Table 2-5 presents the potential electricity production from chicken manure in Kenya.

Table 2-5 Potential methane yield, heating oil equivalent, electricity production and installed capacity from chicken manure in Kenya

	Methane yield [m^3/a]	Heating oil equivalent [tons/a]	Electricity production [kWh/a]	Installed Capacity [MW_{el}]
Min	1,940,000	1,650	5,820,000	0.8
Max	6,867,000	5,800	24,723,000	3
Mean	**4,403,500**	**3,725**	**15,271,500**	**1.9**

2.3.3 Sub-Sector 3: Cut flowers production

Kenya is one of the most important exporters of cut flowers worldwide and the most important exporter to the European Union. Horticulture is one of Kenya's main sources of foreign currency earnings. The main products are roses, mixed flowers and carnations [13]. Kenya exported 91,193 t of cut flowers in 2007 [14]. According to the data provided by the GTZ the amount of wastes and rejected cut flower is one third of the export volume, resulting in a total volume of 27,357 t of fresh matter per year. These wastes accrue from a large number of different producers and exporters, mainly centralized at Naivasha, Limuru and Thika in the surroundings of Nairobi.

Specific scientific data on the biogas production from cut flowers wastes is rare, but some authors report about anaerobic digestion of horticultural residues like waste flowers and waste leaves [15] [16]. Own batch-experiments with roses (TS: 28 % FM, VS: 92.4% TS) resulted in a biogas yield of 293 m^3/t VS with a methane content of 59 %.

Due to the high total solids content this substrate seems to be feasible for CSTR and dry-fermentation systems.

In general it might be reasonable to integrate biogas production to horticultural greenhouse production systems, if waste heat and exhaust gas from the CHP can be used for heating and CO_2 fertilization in the greenhouse.

Table 2-6 presents the potential electricity production from cut flowers wastes in Kenya. In addition about 3,080,000 – 8,930,000 kWh of thermal energy and 750,000 – 2,000,000 m^3 of CO_2 could be used for horticultural production in greenhouses.

Table 2-6 Potential methane yield, heating oil equivalent, electricity production and installed capacity from cut flowers wastes in Kenya

	Methane yield [m^3/a]	Heating oil equivalent [tons/a]	Electricity production [kWh/a]	Installed Capacity [MW_{el}]
Min	810,000	680	2,432,000	0.3
Max	2,126,000	1,800	7,654,000	1
Mean	**1,468,000**	**1,240**	**5,043,000**	**0.65**

2.3.4 Sub-Sector 4: Instant tea production

In the year 2008 Kenya was the third largest producer of tea after China and India [17] with a production of 345,817 tons [18]. For the calculation of biogas potentials from tea production only the data on wastes for one processing facility of instant tea was considered. According to the data provided by the GTZ the amount of organic dry matter generated in this facility is 7,312 tons per year.

Only very few articles in literature report about the anaerobic digestion of wastes from instant tea production [19] [20]. *Goel et al.* [20] showed the general feasibility to use spent tea leaves as input substrate for two-stage anaerobic digestion system with separated hydrolysis and methanogenesis reactors. Due to the high total solid content in spent tea leaves dry-fermentation could be a possible technical solution as well. Table 2-7 presents the potential electricity production for tea wastes from one instant tea producing facility.

Table 2-7 Potential methane yield, heating oil equivalent, electricity production and installed capacity from instant tea wastes

	Methane yield [m^3/a]	Heating oil equivalent [tons/a]	Electricity production [kWh/a]	Installed Capacity [MW_{el}]
Min	892,000	750	2,678,000	0.4
Max	2,168,000	1,800	7,805,000	1
Mean	**1,530,000**	**1,275**	**5,241,500**	**0.7**

2.3.5 Sub-Sector 5: Sisal production

In 2003 Kenya was the fourth largest producer of sisal fibres after Brazil, China and Mexico with a production of 25,000 tons [21]. During the sisal processing large amounts of residues are generated, because the exploitable fibres are representing only 5 % of the total leave weight. During the decortications process, about 100 m^3 of wastewater and 25 t of solid residues (pulp) are generated for each ton of sisal fibres [22]. Old sisal plants (sisal balls) which are removed during replanting are providing additional amounts of valuable biomass. For each hectare of sisal farm size about 6 t of old plants (sisal balls) are removed (assuming planting every ten years and 3,000 plants per hectare; each sisal ball weighs about 20 kg).

With a total sisal fibre production of 24,602 tons in 2007 planted on 20,000 ha [23] the following amounts of residues can be calculated for one year:

- 615,050 t of sisal pulp
- 2,460,200 m^3 of wastewater
- 120,000 tons of sisal balls from replanting

Anaerobic digestion of sisal residues is reported by many authors [24] [25] [26] [22] [27]. *Mshandete et al*. is reporting a methane yield between 180 and 480 m^3 CH_4/t VS for sisal pulp [28] [24] [29]. An increase of up to 59-94 % in methane production was observed in co-digestion with fish wastes compared to the pure fractions [24]. An aerobic pre-treatment of sisal pulp increased the methane yield from 190 to 240 m^3 CH_4/t VS [25]. Methane content in the biogas from sisal pulp varied between 51 and 70 % in a two-stage system [26] and 82 to 86 % in a system with biomass immobilisation [27]. Apart from laboratory experiments there are two pilot biogas plants for biogas production from sisal waste, one located in Tanzania (Hale, Katani Estate) and one in Kenya (Biogas Power Ltd; Kilifi), showing the feasibility and economic viability of this technology. The accumulated total potential of biogas production from sisal pulp, wastewater and sisal balls in Kenya is presented in Table 2-8.

Table 2-8 Potential methane yield, heating oil equivalent, electricity production and installed capacity from sisal wastes in Kenya

	Methane yield [m^3/a]	Heating oil equivalent [tons/a]	Electricity production [kWh/a]	Installed Capacity [MW_{el}]
Min	21,811,000	18,500	65,433,000	9
Max	68,959,000	58,600	248,252,000	31
Mean	**45,385,000**	**38,550**	**156,842,500**	**20**

2.3.6 Sub-Sector 6: Sugar production

The biogas potential for sugar filter cake (press mud) is calculated based on the data provided by the GTZ. In five sugar producing facilities about 6,423,500 t of sugarcane are processed and 192,705 t of filter cake are generated per year. The filter cake is a residue originating from sedimentation of suspended solids from the cane juice. It has an average total solids content of 20 to 30 % with 70 % VS and contains mainly phosphorus, nitrogen and potassium [30] [31]. Additional potentials may arise from waste water treatment in sugar processing. These have not been included due to lack of data.

Anaerobic digestion of sugar filter cake is reported in literature by different authors. *Sharma et al.* investigated the biogas production from filter cake mixed with banana stem and water hyacinth [31]. Another study from Tanzania reported a methane yield of 230 m^3 CH_4/t VS from sugar filter cake [5]. The biogas yield can be increased up to 490 m^3/t VS due to an enzymatic treatment of the filter cake prior to anaerobic digestion [30]. The total potential of biogas production from sugar filter cake in Kenya is presented in Table 2-9.

Table 2-9 Potential methane yield, heating oil equivalent, electricity production and installed capacity from sugar filter cake in Kenya

	Methane yield [m^3/a]	Heating oil equivalent [tons/a]	Electricity production [kWh/a]	Installed Capacity [MW_{el}]
Min	6,205,000	5,200	18,615,000	2.7
Max	11,898,000	10,100	42,831,000	5.4
Mean	**9,051,500**	**7,650**	**30,723,000**	**4.1**

2.3.7 Sub-Sector 7: Milk processing

The biogas potential for dairy wastewater is calculated based on the data provided by GTZ for total milk processing of 361,000 m^3 per year. According to *Kansal et al.* each m^3 of processed milk generates 3 m^3 of wastewater [32], resulting in a total amount of 1,083,000 m^3 per year with a COD content of 2-6 g/l [33]. COD removal efficiency varied from 85 to 92 % [34] [35]. Gas yield varied from 287 to 359 m^3 CH_4/t COD removed [36]. The potential from dairy wastewater in Kenya is presented below.

Table 2-10 Potential methane yield, heating oil equivalent, electricity production and installed capacity from dairy wastewater

	Methane yield [m^3/a]	Heating oil equivalent [tons/a]	Electricity production [kWh/a]	Installed Capacity [MW_{el}]
Min	460,000	390	1,381,000	0.2
Max	1,988,000	1,600	7,158,000	0.9
Mean	**1,224,000**	**995**	**4,269,500**	**0.55**

2.3.8 Sub-Sector 8: Pineapple processing

The biogas potential for pineapple processing wastes is calculated based on the data provided by GTZ for a large pineapple processing facility. In this facility 75,000 t of solid waste and 840,000 m^3 of wastewater are generated per year.
Biogas technology has been shown to be applicable for pineapple waste by different authors [37] [38][39] [40]. According to *Rani and Nand* fresh pineapple peels yielded 550 m^3 of biogas (51 % methane) per ton of VS added and ensilaged pineapple peel yielded up to 670 m^3 (65 % methane) [39]. *Gunaseelan* reported methane yields of 357 and 355 m^3 /t VS for pineapple peels and leafy shoots [40]. Own batch-experiments with solid pineapple wastes (mixture of 2/3 peels and 1/3 crown; TS: 15.5 % FM, VS: 93.4 % TS) resulted in a biogas yield of 586 m^3 /t VS with a methane content of 53 %, giving a ultimate methane yield of 309 m^3 /t VS.
The total potential of biogas production from pineapple waste and wastewater is presented in Table 2-11.

Table 2-11 Potential methane yield, heating oil equivalent, electricity production and installed capacity from pineapple wastes

	Methane yield [m^3/a]	Heating oil equivalent [tons/a]	Electricity production [kWh/a]	Installed Capacity [MW_{el}]
Min	3,191,000	2,700	9,573,000	1.4
Max	7,377,000	6,200	26,556,000	3.3
Mean	**5,284,000**	**4,450**	**18,064,500**	**2.35**

2.3.9 Sub-Sector 9: Municipal Solid Waste

The biogas potential for MSW is calculated based on the data provided by GTZ for the amount of MSW generated in Nairobi, which is about 996,450 tons per year.
Local authorities are responsible for collection and disposal of municipal solid waste (MSW) in Kenya. Most local authorities use centralised MSW management systems. But in developing countries many local authorities spend more than 30 % of their budget on collection and disposal of refuse but do not collect more than 50 to 70 % of accruing MSW [41]. While the generation of MSW has grown rapidly, the capacity to collect and safely dispose the residues has declined. Most of the dump sites are not connected by all-weather roads and thus access during rainy season is difficult or even impossible. Local authorities tend to concentrate their limited services mainly in the central business districts and the more wealthy communities with better infrastructure.
The organic and thus biodegradable fraction (VS content) of the total collected waste is estimated to be about 60 % [41] [42]. Depending on season and rainfall the content of DM varies considerably between 30 and 60 % [43]. The methane potential of MSW

varies depending on the composition of the organic fraction of MSW and the employed technology (see Table 2-12).

Table 2-12 Methane potential of Municipal Solid Waste in literature

Source	Methane potential [m^3 CH_4/ton VS]
Chynoweth and Legrand 1988 [44]	300
Juanga et al. 2006 [45]	184 – 239
O'Keefe et al. 1993 [46]	180 – 220
Owens and Chynoweth 1993 [47]	230
Rivard et al. 1990 [48]	340

According to *Vandevivere et al.* most existing full-scale plants for the anaerobic treatment of MSW have a single-stage reactor system. Two-stage systems are used when sanitation is required. Batch systems may be more successful in developing countries due to the low investment costs [49]. Furthermore batch systems do not need substrate pre-treatment like separation of inert solids. This may facilitate the process and lower the production costs significantly.
The total potential of biogas production from MSW in Nairobi is shown in Table 2-13.

Table 2-13 Potential methane yield, heating oil equivalent, electricity production and installed capacity from municipal solid waste in Nairobi

	Methane yield [m^3/a]	Heating oil equivalent [tons/a]	Electricity production [kWh/a]	Installed Capacity [MW_{el}]
Min	26,874,000	22,800	80,623,000	11
Max	142,377,000	121,000	512,556,000	64
Mean	**84,625,500**	**71,900**	**296,589,500**	**37.5**

2.3.10 Sub-Sector 10: Distillery stillage

The biogas potential for distillery stillage (residue of alcohol distillation) is calculated based on the data provided by GTZ for a large distillery. In this facility 5,400 m^3 of alcohol and 108,000 m^3 of stillage are produced per year. For each m^3 of alcohol about 20 m^3 of wastewater accrue. Stillage, which is rich in protein, can be used for animal nutrition or as organic fertiliser.
For the anaerobic digestion of distillery stillage the input substrates for the distillation have to be considered (Cereals, potatoes, sugar cane…). Grain and especially wheat can cause high protein contents in the stillage. This can induce ammonia inhibition and high H_2S contents in the gas. *Rajeshwari et al.* reported a biogas yield of 450 m^3 /t COD_{rem} and 70 % methane content with a fixed film reactor system [50]. Similar values are reported by using a hybrid UASB reactor reaching 80 % methane

content and a specific biogas yield of 400 m^3 CH_4/t COD [51]. The total potential of biogas production from distillery stillage is presented in Table 2-14.

Table 2-14 Potential methane yield, heating oil equivalent, electricity production and installed capacity from distillery stillage

	Methane yield [m^3/a]	Heating oil equivalent [tons/a]	Electricity production [kWh/a]	Installed Capacity [MW_{el}]
Min	612,000	520	1,835,000	0.3
Max	4,131,000	3,500	14,871,600	1.9
Mean	**2,371,500**	**2,010**	**8,353,300**	**1.1**

2.3.11 Sub-Sector 11: Meat-processing

The biogas potential for meat processing wastewater is calculated based on the data provided by GTZ for one of the largest slaughterhouses in Kenya. This slaughterhouse is slaughtering about 80,000 pigs and 10,000 cattle per year and is generating 60,000 m^3 of wastewater per year.

Anaerobic digestion of slaughterhouse wastewater is often reported in literature. *Borja et al.* reported a gas yield of 350 m^3 CH_4/ton VS and Rodriguez-Martinez et al. from 343 to 349 m^3 CH_4/ton VS with COD removal efficiencies from 75 -98 % [52] [53]. Removal efficiency can be much lower as reported by *Joshi and Polprasert* with a value of 55 % [54]. Table 2-15 shows the potential of biogas production from slaughterhouse wastewater.

Table 2-15 Potential methane yield, heating oil equivalent, electricity production and installed capacity from slaughterhouse wastewater

	Methane yield [m^3/a]	Heating oil equivalent [tons/a]	Electricity production [kWh/a]	Installed Capacity [MW_{el}]
Min	32,000	27	95,000	0.01
Max	181,000	150	652,000	0.08
Mean	**106,500**	**89**	**373,500**	**0.05**

2.3.12 Sub-Sector 12: Pig production

The biogas potential for pig production is calculated based on the data provided by GTZ for a large pig farm. This pig farm is generating 10,920 tons of pig manure per year.

Gas yields in literature tend to vary due to different substrate composition and technology used. *Eder and Schulz* reported a gas yield of 240 m^3 CH_4/t VS while other authors mentioned a biogas yield of 450 m^3 CH_4/ton VS with methane content varying between 60 and 70 % [11] [55] [10]. The total potential biogas production from pig manure is presented in Table 2-16.

Table 2-16 Potential methane yield, heating oil equivalent, electricity production and installed capacity from pig manure

	Methane yield [m^3/a]	Heating oil equivalent [tons/a]	Electricity production [kWh/a]	Installed Capacity [MW_{el}]
Min	393,000	330	1,179,000	0.2
Max	1,055,000	890	3,798,000	0.5
Mean	**724,000**	**610**	**2,488,500**	**0.35**

2.3.13 Sub-Sector 13: Vegetable wastes

The biogas potential for vegetable waste is calculated based on the data provided by GTZ for exports from one company. About 798 tons of vegetable waste accrue per year.

Biogas production from vegetable waste is documented in different publications [56] [40] [57]. Reported gas yields varied from 269 to 400 m^3 CH_4/t VS. The total potential biogas production from vegetable wastes in this installation is shown in Table 2-17.

Table 2-17 Potential methane yield, heating oil equivalent, electricity production and installed capacity from vegetable wastes

	Methane yield [m^3/a]	Heating oil equivalent [tons/a]	Electricity production [kWh/a]	Installed Capacity [MW_{el}]
Min	6,000	5	18,000	0.003
Max	56,000	47	202,000	0.025
Mean	**31,000**	**26**	**110,000**	**0.01**

2.4 Total theoretical biogas potential based on delivered input data

The total theoretical biogas potential can be expressed as potential installed electrical capacity, in electricity production, heat generation and heating oil equivalent. In this study only energy conversion by CHP is considered, generating (waste-) heat and electricity at the same time.

The substrates can be classified as high and low potential substrates. Figure 2-2, Figure 2-3 and Figure 2-4 are showing the potentials for installed capacity, heat generation and electricity production for high potential substrates.

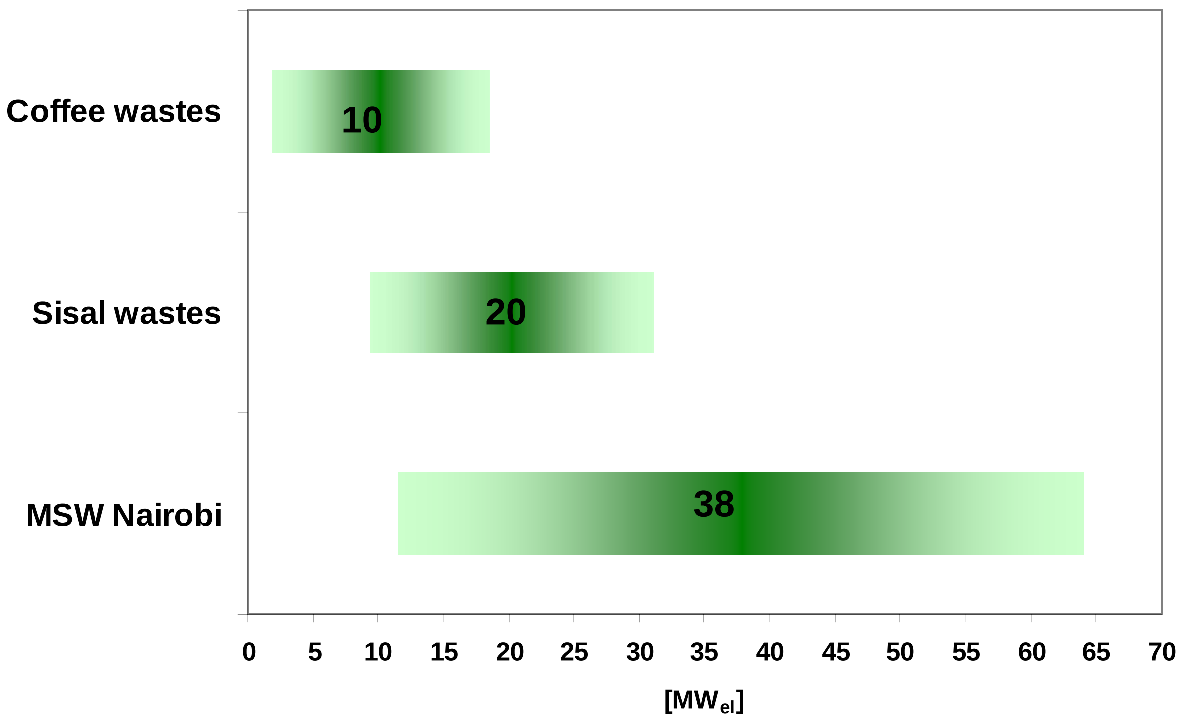

Figure 2-2 *Range of the potential installed electrical capacity from anaerobic digestion of high potential substrates in MW$_{el}$*

The highest potential for a single substrate lies in Municipal Solid Waste from Nairobi with potential installed capacities from 11 to 64 MW$_{el}$, a heat generation from102 to 598 GWh$_{therm.}$/a and an electricity production from 81 to 513 GWh$_{el}$/a. Due to possible differences in the substrate composition and theoretical biogas yield of MSW, the minimum and maximum values differ a lot, making it difficult to give accurate values.

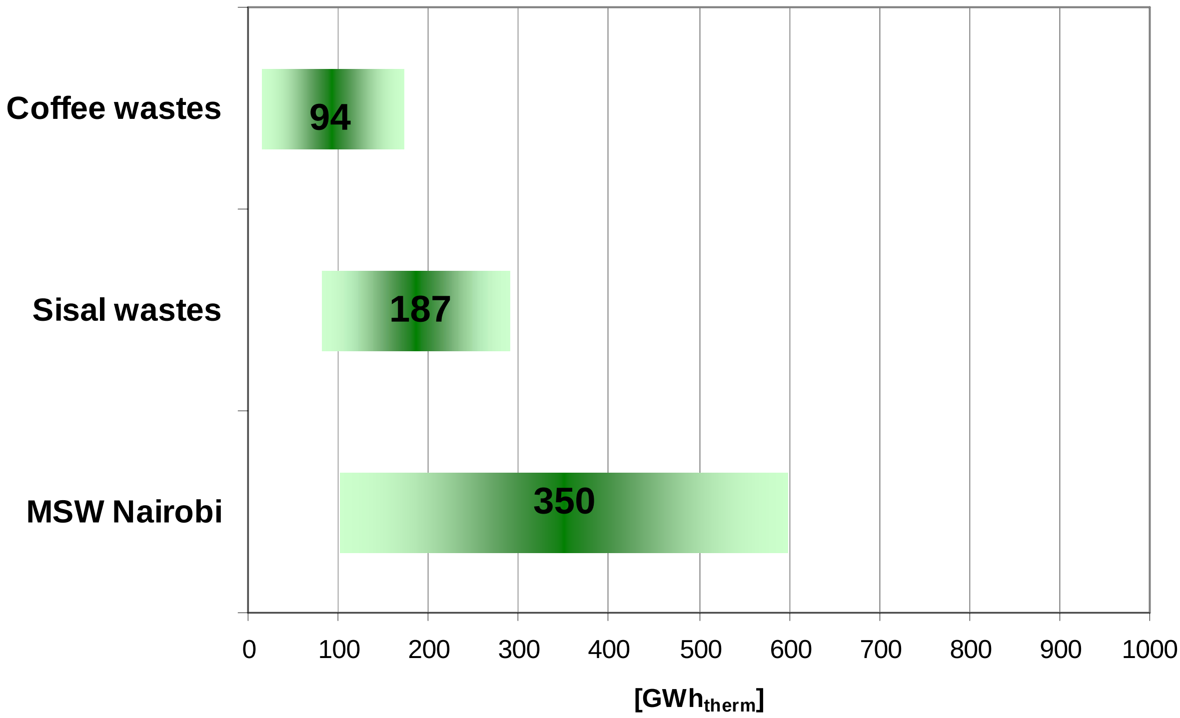

Figure 2-3 Range of the potential heat generation from anaerobic digestion of high potential substrates in GWh thermal energy

The next best potential substrates are sisal wastes (pulp, wastewater and balls) with a potential installed capacity from 9 to 31 MW$_{el}$, a heat generation from 83 to 290 GWh$_{therm.}$/a and an electricity production from 65 to 248 GWh$_{el}$/a, followed by coffee wastes (pulp and wastewater) with a potential installed capacity from 2 to 18 MW$_{el}$, a heat generation from 16 to 172 GWh$_{therm.}$/a and an electricity production from 13 to 148 GWh$_{el}$/a.

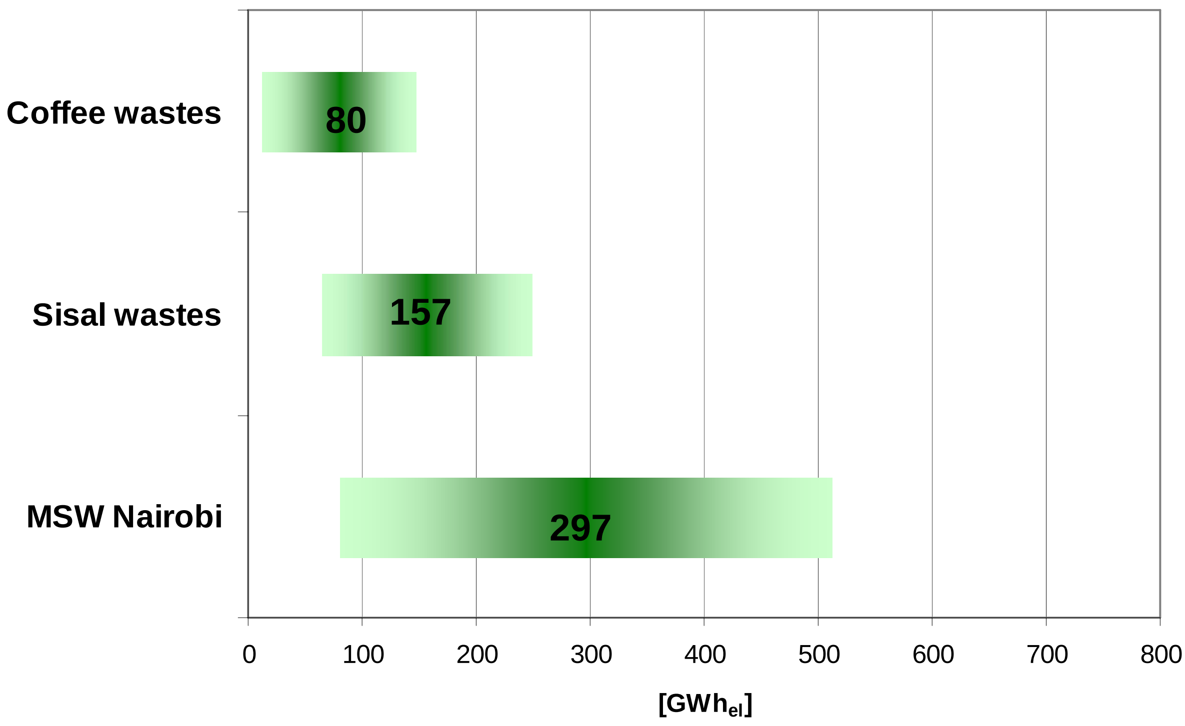

Figure 2-4 Range of the potential electricity generation from anaerobic digestion of high potential substrates in GWh electrical energy

Figure 2-5 shows the potential installed capacity for low potential substrates. The values range from 0.002 to 0.004 MW_{el} for nut processing wastewater and 2.7 to 5.4 MW_{el} for sugar filter cake. All values for heat generation, electricity production and heating oil equivalent for the low potential substrates can be found in annex 1 and annex 2.

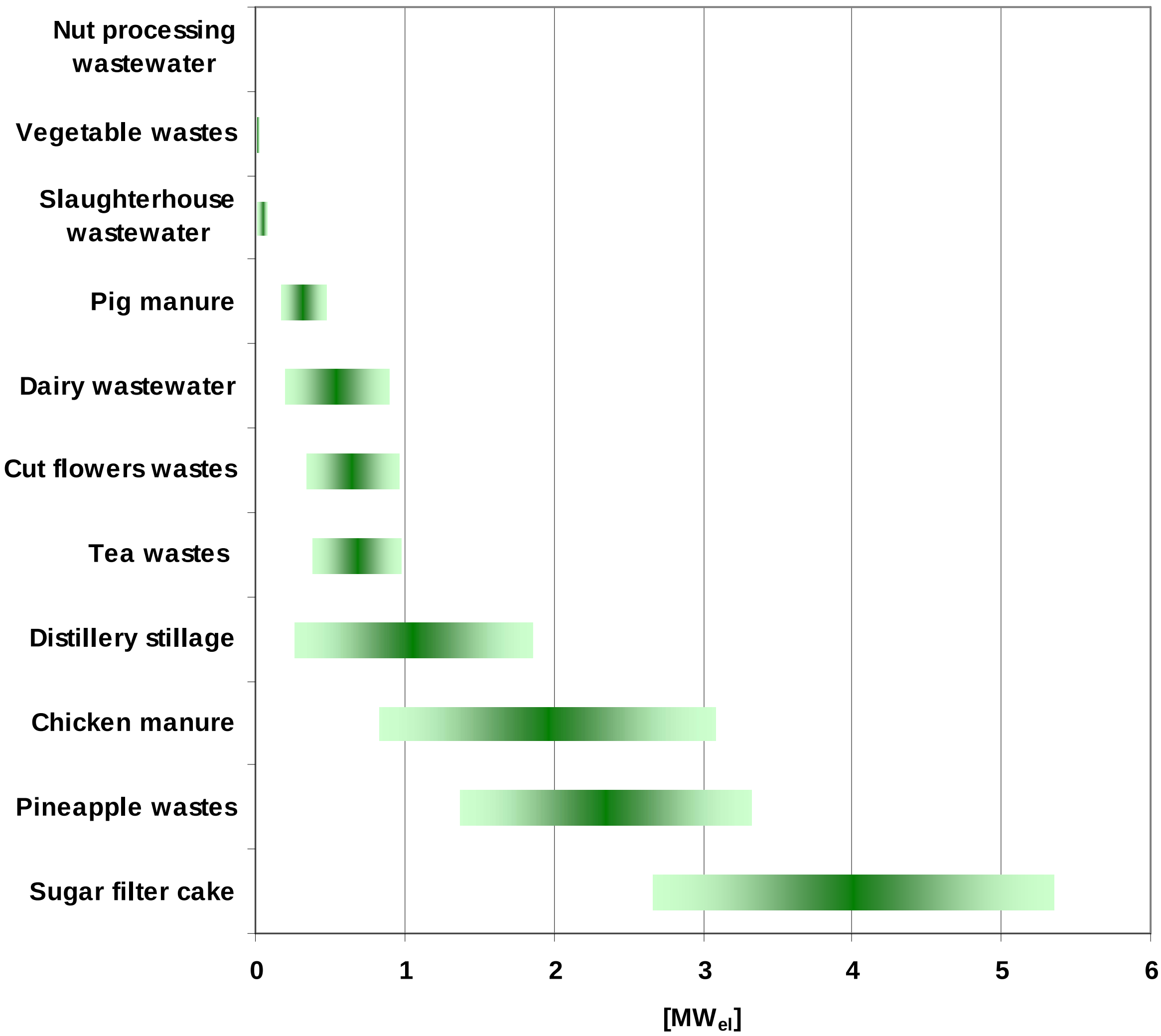

Figure 2-5 *Range of the potential installed electrical capacity from anaerobic digestion of low potential substrates in MW_{el}*

The total theoretical potential for energy production from agro-industrial wastes and wastewaters considered in this study is presented in Figure 2-6.

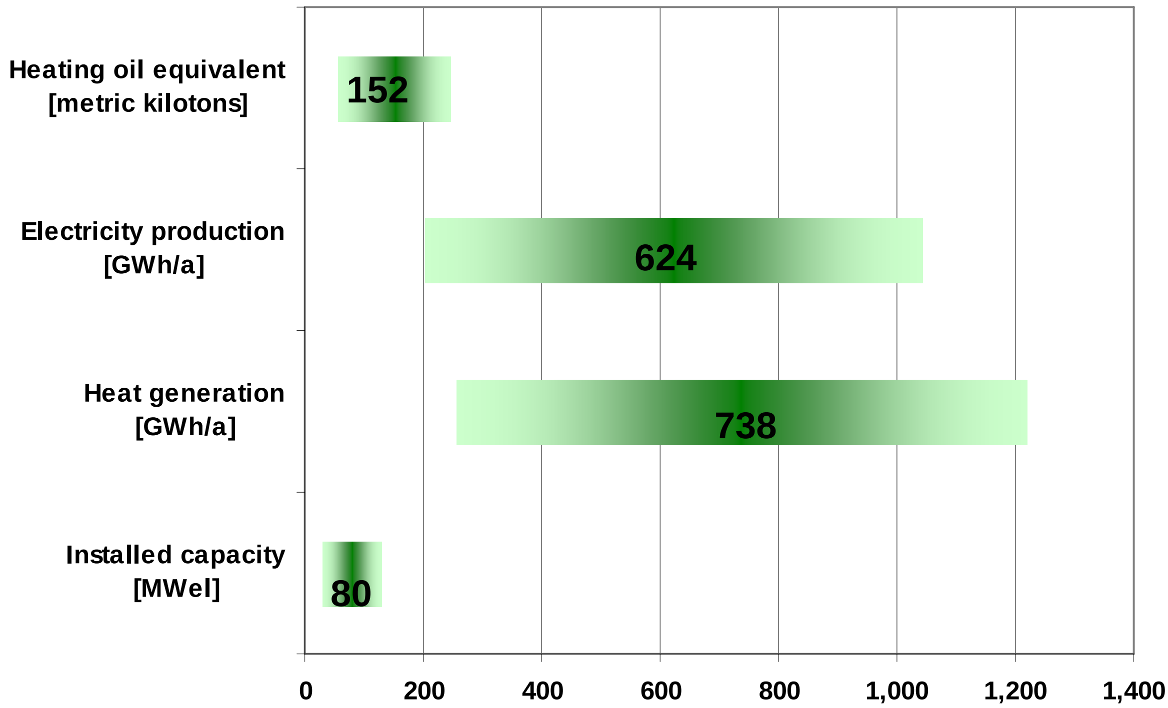

Figure 2-6 *Range for potential heating oil equivalent, electricity production, heat generation and installed capacity from anaerobic digestion of agro-industrial wastes and wastewaters in Kenya*

The total installed electric capacity of all sub-sectors ranges from 29 to 131 MW_{el}, generating 256 to1,219 $GWh_{therm.}$/a of heat and 202 to1,045 GWh_{el}/a of electricity, equivalent to 57-247 metric kilotons of heating oil (weight: 0.85 kg/l). With a price of 377 USD/t of refined heating oil [58] in June 2009, the total savings by substitution of heating oil would amount from 21,489,000 to 93,119,000 USD/a.
Biogas production from agro-industrial wastes and wastewaters could produce 202 to 1,045 GWh_{el}/a, which is about 3.2 to 16.4 % of the total electricity production of 6,360 GWh in 2007/08 (see chapter 6.1.3). A large number (116 to 525) of biogas plants with an installed capacity of 250 kW_{el} each would be necessary to implement this potential. In some sub-sectors, where big amounts of waste are accrued at the same place (MSW, sisal wastes, food processing and more), even bigger plants with a capacity of 500 or 1,000 kW_{el} can be feasible.

The most promising sub-sectors for the implementation of biogas technology are municipal solid waste, sisal production and coffee production, and selected large facilities for food processing.
In the case of MSW only the amounts in Nairobi are considered in this study. Including other big towns like Mombasa, Kisumu and Nakuru would increase the potential tremendously. Unlike the most others substrates MSW is not generated at one central place, but has to be collected prior to further utilization and biogas effluents have to be

dumped or combusted. This leads to logistical problems and additional costs. MSW management is organized by local authorities. This makes the implementation of biogas technology more complicated than in the case of private investors due to financing, political interests and corruption.

Otherwise the biogas production from MSW could decrease the total costs of MSW management, extend electricity production at the “hot spots”, where most of the electricity is consumed, and improve environmental and sanitary situation.

In the case of biogas production from agro-industrial residues substrates are accrued at one place during the processing of the agricultural product (e.g. sisal decortications, coffee wet processing, pineapple canning). This is featuring the following advantages:

- Transport costs for the input substrates can be minimized;
- Electricity and waste heat can be used directly for the processing;
- Additional electricity can be feed into the national grid;
- Biogas plant effluent can be used on farm as organic fertilizer;
- Due to these advantages biogas production can make agricultural production more efficient and sustainable. The value added remains in the local market and additional employment opportunities are created;

3 ECONOMIC AND TECHNICAL ANALYSIS OF SELECTED CASE STUDIES

In the following chapter a calculation of electricity production costs for biogas plants in Kenya is accomplished. It was the aim to derive tariffs for a profitable operation of biogas plants in Kenya. Different residues and wastewaters were considered, which could be used for energy production in wet and dry fermentation plants as well as in high performance reactors (UASB). The production costs of electricity from biogas were calculated with the annuity method in accordance with VDI 2067[2]. This annuity method has the objective of valuation of buildings concerning energetic, ecological and economic aspects, whereby the energetic perception has a particular meaning. The VDI 2067 is not a construction directive. It rather shall help to find a decision in an early conception phase among various variations for a defined use.
For the conversion from Euro to US-Dollar the exchange rate 1.40 USD/EUR was used (12th June 2009, [59])

3.1 Concepts and technologies

The initial point for the calculations of electricity production costs for biogas plants was the existing data base for wastewater and residues in Kenya. Thereof was derived that there are potentials in Kenya for the technologies of dry- and wet-fermentation and wastewater treatment (UASB). The annual potential varies considerably between agro-industrial producers with small production units and low residue and/or wastewater amounts and producers with large production units and high residue and/or wastewater amounts. Due to this fact it was necessary to calculate for each technology electricity production costs for a small model plant with an installed power of 50 kW_{el} and for a model plant in the middle power range of 250 kW_{el}. The required costs for the calculations vary vastly according to reference and in-house data. Therefore, for each model biogas plant 2 scenarios were considered to calculate the minimum and maximum electricity production costs. Resultant revealed 12 model biogas plants (see Table 3-1) which are explained in detail in the following sections.

[2] The VDI is the major association of german engineers. Guidelines published by VDI can be seen as technical standards, the VDI 2067 *Economic efficiency of building installations* defines a regulatory framework for economic considerations in construction.

Table 3-1 Considered model biogas plants and scenarios

Model plant	Fermentation technology	Installed capacity (kW_{el})	Cost scenario	Model label[1]
1	Dry	50	Low	D50min.
2	Dry	50	High	D50max.
3	Wet	50	Low	W50min.
4	Wet	50	High	W50max.
5	UASB	50	Low	U50min.
6	UASB	50	High	U50max.
7	Dry	250	Low	D250min.
8	Dry	250	High	D250max.
9	Wet	250	Low	W250min.
10	Wet	250	High	W250max.
11	UASB	250	Low	U250min.
12	UASB	250	High	U250max.

[1]D: Dry Fermentation, W: Wet Fermentation, U: Upflow Anaerobic Sludge Blanket; 50/250: installed electrical power in kW_{el}; min/max: minimum/maximum cost scenario

The individual technologies cover in each case the whole sector of corresponding residues because substrate characteristics like organic dry matter, biogas yield, content of methane etc. did not affect the calculations.

3.2 Calculations for selected case studies

3.2.1 Economy factors

Local banks in Kenya expect for granting credits a minimum equity ratio of 35 % but prefer a rate of 50 %. For credits interest rates between 14 and 16 % are charged [23]. These values provided the frame parameters for the calculations. For the minimum cost scenario an equity ratio and debt capital of 50 % in each case with interest rates of 11 respectively 14 % were assumed. Inflation was assumed to be 0 % in this case. At the maximum cost scenario an equity ratio of 35 % with likewise 11 % interest rate and a debt capital of 65 % with interests of 16 % were assumed. The rate of price increase was set at 9 %, which is approximately the inflation rate of the year 2008 [60]. For all model biogas plants and scenarios a period under consideration of 15 years was taken as a basis (see Table 3-2).

Table 3-2 Economy factors [23][60][61]

Factors	Scenario	
	Min. costs	Max. costs
Period under consideration (a)	15	15
Equity ratio (%)	50	35
Debt capital (%)	50	65
Interest on equity (%)	11	11
Interest on debt capital (%)	14	16
Price increase (%)	0	9

3.2.2 Costs of equity

The calculation of the costs of equity is based on the definition of minimum and maximum specific investment costs (USD/kW_{el}). The investment costs are segmented in construction, technical equipment and the gas-Otto-CHP-unit. For the technologies of wet and dry fermentation the costs for construction and technical equipment amount to ca. 40 % each, and for a gas-Otto-CHP-unit about 20 % of the total investment costs. The operating life expectancy for the construction, technical equipment and CHP-unit amount to 15, 10 and 8 years [62]. The total investment costs for the maximum scenario of wet fermentation (W50max, W250max) include the cost for an additional silo. In that case it is presumed, that the substrate is not available all around the year, which is the fact for example for coffee pulp. Whereas the biogas plant has to operate continuously, half of the yearly requirement of substrate has to be stored. The yearly requirement for both model plants was calculated based on biogas yield (72.54 Nm^3/t FM) and methane content (62.5 %). The costs for the silos result from specific construction costs of 45 USD/m^3 (W50max) and 53 USD/m^3 (W250max) [63]. If it is possible to use coffee pulp in combination with other residues which are available throughout the year, an additional storage is unnecessary. In Table 3-3 the costs of equity for each model biogas plant are listed.

Table 3-3 Costs of equity in USD [23], [63], [61]

Model plant	Specific investment costs (USD/kW_{el})	Construction	Technical equipment	CHP-unit	Additional silo	Total investment
D50min	3,360	67,200	67,200	33,600		168,000
D50max	6,300	126,000	126,000	63,000		315,000
W50 min	3,360	67,200	67,200	33,600		168,000
W50max	6,300	126,000	126,000	63,000	63,000	378,000
U50min	2,100	35,000	35,000	33,600		103,600
U50max	4,800	87,500	87,500	67,200		242,200
D250min	2,600	264,600	264,600	133,000		662,200
D250max	4,300	434,000	434,000	208,600		1,076,600
W250min	2,600	264,600	264,400	133,000		662,200
W250max	5,400	418,600	418,600	200,200	322,000	1,359,400
U250min	2,100	203,000	203,000	127,400		533,400
U250max	4,200	403,200	403,200	242,200		1,048,600

3.2.3 Calculation of annuity

For the calculation of annuity an all-year gas production of 8,760 hours and 7,500 full-load hours per year of gas conversion was assumed. It has to be noticed, that the real full-load hours can vary from this value. If e.g. chicken manure is used as substrate in a wet fermentation, it is possible that the full-load hours are shortened because of cleaning work of the digester (sand removing). On the other hand higher full-load hours are possible if there is a good process and substrate management. For CHP-units with an installed electrical power of 50 and 250 kW, an electrical efficiency of 30 to 35 % is usual. A typical average value for electrical requirement for dry fermentation batch system is 4 % [61]. That implies 2 and 10 kW_{el} for an installed electrical power of 50 kW_{el} respectively 250 kW_{el} For the high performance fermentation (UASB) this value is 3 %, hence slightly lower with an electrical requirement of 1,5 and 7,5 kW_{el} For the wet fermentation an electrical requirement of 6 % was assumed (3 and 15 kW_{el}). The electrical requirement is obtained from the own power production, so that no costs are calculated therefore. To operate a biogas plant, at least one skilled worker (technician) is needed. The annual salary amounts circa 5,000 USD [23]. For additional personnel costs e.g. for supply (unskilled worker) and a periodically needed engineer 1,400 USD per year were assumed. Maintenance and inspection costs as well as insurance costs sum up to annual costs of 2 respectively 1 % of the total investment costs. Not considered in the calculation are costs for required consumables. Also costs for disposal or income from disposal of residues and side-income/savings for the use of heat are not considered because of missing data, but could be a substantial additional benefit. The factors of annuity are listed in Table 3-4. A summary of the most important variables is listed in Table 3-5.

Table 3-4 Factors of annuity [23], [61]

	Model biogas plants					
Factors of annuity	D50min, D50max	W50min, W50max	U50min, U50max	D250min, D250max	W250min, W250max	U250min, U250max
Full-load hours of gas production [h/a]	8,760		8,760	8,760		8,760
Full-load hours of conversion [h/a]	7,500		7,500	7,500		7,500
Electrical efficiency of the CHP unit [%]	30		30	35		35
Electricity demand of the plant [kW]	2	3	1.5	10	15	7.5
Number of employees	1		1	1		1
Specific personnel costs [USD]	5,000		5,000	5,000		5,000
Additional personnel costs for supply, etc. [USD]	1,400		1,400	1,400		1,400
Maintenance and inspection [% of investment]	2		2	2		2
Insurance [% of investment]	1		1	1		1

Table 3-5 *Summary of financial variables*

	Model biogas plant											
	D50min	D50max	W50min	W50max	U50min	U50max	D250min	D250max	W250min	W250max	U250min	U250max
System size (MW)	0.05	0.05	0.05	0.05	0.05	0.05	0.25	0.25	0.25	0.25	0.25	0.25
Cost of Plant and Equipment (USD)	168,000	315,000	168,000	378,000	103,600	242,200	662,200	1,076,600	662,200	1,359,400	533,400	1,048,600
Estimated Costs of Civil Works (USD)	67,200	126,000	67,200	126,000	35,000	87,500	264,600	434,000	264,600	418,600	203,000	403,200
Capital Structure (Debt & Equity)	50% 50%	65% 35%	50% 50%	65% 35%	50% 50%	65% 35%	50% 50%	65% 35%	50% 50%	65% 35%	50% 50%	65% 35%
Cost of Finance (cost of debt & equity as appropriate)	84,000 84,000	204,750 110,250	84,000 84,000	245,700 132,300	51,800 51,800	157,430 84,770	331,100 331,100	699,790 376,810	331,100 331,100	883,610 475,790	266,700 266,700	681,590 367,010
Interest during Construction (Debt & Equity)	14% 11%	16% 11%	14% 11%	16% 11%	14% 11%	16% 11%	14% 11%	16% 11%	14% 11%	16% 11%	14% 11%	16% 11%
Estimated O&M Costs (% of Capex)	2	2	2	2	2	2	2	2	2	2	2	2
Plant Load Factor (%)	85.6	85.6	85.6	85.6	85.6	85.6	85.6	85.6	85.6	85.6	85.6	85.6
Estimated Economic Life of the plant (years)	15	15	15	15	15	15	15	15	15	15	15	15

3.2.4 Electricity production costs

The electricity production costs result from economy factors, specific investment costs and factors of annuity which are outlined above. It should be noticed, that the specific investment costs and annuity factors like insurance, costs for maintenance and inspection are benchmarks with validity for Germany, without any differentiation concerning local conditions and circumstances. Furthermore the whole calculation is simplified referring to costs for substrates, transport, consumables, revenues for disposal and heat sale due to missing information. Hence the resulting specific production costs are an estimation which will differ from production costs under real conditions. The production costs for each model plant are listed in Table 3-6.

Table 3-6 Electricity production costs in USD ct (Own calculations)

Model plant	Specific production costs [USD ct/kWh$_{el}$]
D50min – D50max.	10.95 – 24.33
W50min – W50max	11.18 – 28.65
U50min – U50max	7.46 – 19.43
D250min – D250max	7.58 – 15.24
W250min – W250max	7.74 – 18.90
U250min – U250max	6.14 – 14.81

For the proposed basic tariffs as shown in Table 4-1 of 19.86 and 13.77 USD ct/kWh$_{el}$ for 50 and 250 kW$_{el}$ respectively, the calculated specific production costs and estimated frame parameters result in minimum payback periods as shown in Table 3-7. It has to be noticed that realistic paypack periods strongly depend on the FiT in relation to real production costs of each plant.

Table 3-7 Minimum Payback periods for the considered model biogas plants at a specific FiT of 10 %

Model plant	Payback period [a]
D50min	4.1
W50min	4.3
U50min	2.2
D250min	4.5
W250min	4.7
U250min	3.3

4 RECOMMENDATIONS FOR AN ELECTRICITY TARIFF SYSTEM

4.1 Development in Germany

For almost a decade, Feed-in-Tariffs for Renewable Energies (RE) have become an important instrument to fulfil the agreements given by the Kyoto-Protocol in 1997. Beyond that, numerous energy experts deem the RE to be a key technology for decentralisation and for a sustainable energy supply. In Germany, biogas – especially from agriculture - plays a major role among the RE, the number of plants installed exceeded 4,000 in 2008 and is growing by approx. 400 p.a. for the coming years. Besides a dozen large scale applications for upgrading and feeding biogas (biomethane) to the natural gas grid, all plants have a CHP-device for cogeneration. The installed capacity of such a single plant varies from 30 kW_{el} up to ~5 MW_{el} on an average of ~350 kW_{el}. The total installed electrical capacity from biogas stands currently at ~1,500 MW, with an annual output of ~11.5 billion kWh in 2009. The strong development of the past 5-8 years in the german biogas-sector can be ascribed to a consequently broadened, attractive legislative framework. One of the major components is the Renewable-Energy-Act (EEG) which was enacted in 2000 and then amended twice (2004 & 2009) to draw back possible misguided developments and to further extend the growing share of RE in the production of electricity. In the beginning of 2009 a Renewable-Energy-Act for heat supply (EEWärmeG) was enacted.

Most of the german biogas plants are situated in the agricultural sector, they often digest a combination of liquid manure and energy crops due to the given potentials and the economic preconditions set by the EEG. In addition to the digestion of energy crops, the source separated organic waste fraction from household is of growing interest instead of composting which is state-of-the-art for source separated organic waste until now.

A growing number of rural settlements (with up to 500 habitants) become a so called bioenergy-village, which is primarily characterized through a possible complete independence from external energy supply. The combination of district heat and power supply is quite advantageous for the whole village, because new added value is created and kept inside the municipality.

4.2 Framework

It is important to note that for this study, the client and the authors did not simply transfer the German model. The general approach of promoting renewable energy-based electricity generation through Feed-In Tariffs is proved beyond the German context. This study was based on data collected on the ground, and the recommendations provided here, while building on a number of experiences from the German context, have been tailored to suit the specific requirements of Kenya.

Biogas has unique characteristics as a cross-sectional RE-technology, giving the opportunity to manage several tasks with just one application. The potential and economic studies done before combine residue and wastewater disposal with the production of renewable energy. As described, the calculations include only revenues for the production of electric energy. Since it is a political decision whether or not the enhancement of hygiene and the reduction of environmental problems arising from anaerobic degradable wastes and wastewater by promoting its use in biogas plants or by implementing and monitoring regulations for waste and wastewater disposal are considered worth promoting, no revenues were calculated for the excess heat at this point. The disposal of the nutrient rich residues from biogas production which could be used as a valuable fertiliser, was not taken into consideration either.

To achieve high energy efficiencies it seems to be promising to adopt both strategies. The promotion of the use of organic wastes in biogas plants by feed-in-tariffs and the implementation of complementary regulations is an effective way to ensure a regulated waste disposal. Additionally a strict control of disposal regulations is necessary. In this case costs of organic waste disposal would not be passed completely to the energy consumers.

The feed-in-tariff system for small-scale plants (up to 50 kW_{el}) suggested in the following, is based on minimum cost scenarios of energy production. With this rather low remuneration, an illegal substitution of biogas through diesel fuel at the power station of a biogas plant shall be prevented. For this reason, the replacement of diesel through gas engines which do not need any complementary fuel will be beneficial[3].

As described before, no extra cost or revenues are calculated for the by-products of biogas production (e.g. heat and fertiliser). Value creation from these by-products will depend strongly on the location of the plants, their integration into e.g. farming systems and the general acceptance of the digestate as fertiliser. Sites with the possibility for a creation of added value have to be worked out in a particular study.

Costs for logistics and pre-treatment of the residues are not calculated either. They will have to be paid mainly by the originator. Storage costs depend on the variable availability of the residues throughout the year. The costs may be lower if different residues with alternating seasonal availability could be treated in one plant. For example storage capacity could be saved, if substrates with a short period of formation (e.g. coffee pulp) can be combined with other substrates in other periods.

Thus, for detailed cost calculations and estimations of feed-in-tariffs, detailed information about geographical distribution and seasonal availability of the residues as well as specific logistic and transport costs and site-connected revenues from heat and fertiliser production would be necessary. More detailed feasibility studies will address these issues on a case to case basis.

[3] if diesel engines are used, approx. 10 % of energy from diesel is necessary

4.3 Basic tariff

4.3.1 Economic considerations

To ensure reliability for operators and investors it will be essential not to change the basic tariff annually. We propose to create three static basic tariffs, depending on the installed electric capacity of the CHP, since the specific costs of small plants are higher than the costs of larger plants (Table 4-1).

Remuneration of the energy producers should be attractive enough to promote the decentralised digestion of considerable amounts of residues but not create additional or high costs for the energy consumers. In some cases investors might try to excessively benefit from differentiated feed-in-tariffs, as it was observed in Germany. The splitting of one large-scale application into several small–sized applications at the same location has to be prevented through appropriate formulations in the regulative framework.

To make a rough estimate for an average basic Feed-In-Tariff, the minimum and maximum production costs of the AD-technologies considered before are taken into account for the calculation of a mean value for 50 and 250 kW_{el}.

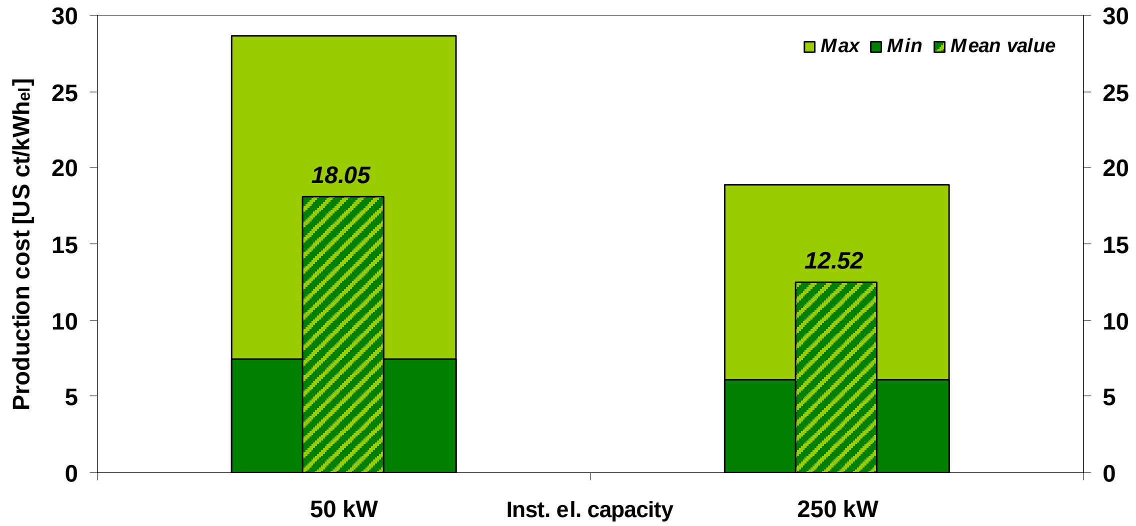

Figure 4-1 Comparison of minimum and maximum production costs depending from plant scale

Based on this calculations average production costs of 12.52 and 18.05 USD ct/kWh_{el} can be estimated respectively.

4.3.2 Proposal for a basic Feed-in-Tariff

Due to different cost levels as shown in Table 3-5, it is likely that not all biogas technologies will be promoted successfully by one basic tariff. For this reason the remuneration suggested has to be considered as a minimum-level-payment.
In order to achieve an effective and attractive FiT offering actual incentives for rapid investment, additional percentages should be considered on top of the average production costs. The following table presents the production costs per plant size, and the implications of additional incentives through percentage increases in three steps of 5%, 10% and 15%. Speed and extent of realizing the potential for biogas in Kenya stand in correlation with the chosen percentage.

Table 4-1 Proposal for basic tariffs for electric power from biogas in Kenya; therefore production costs for 50 and 250 kWel according to the mean values shown in figure 5-1 and estimates for 500 and 1,000 kWel are taken

Installed capacity of examplary plant	Production costs (USD ct/kWh$_{el}$)	Basic-FiT (USD ct/kWh$_{el}$)			**Suggested tariff share**
		+ 5%	+ 10%	+ 15%	
50 kW$_{el}$	18.05	18.96	19.86	20.76	**0 - 50 kW$_{el}$**
250 kW$_{el}$	12.52	13.15	13.77	14.40	**50 – 250 kW$_{el}$**
500 kW$_{el}$	10.00 [1]	10.50	11.00	11.50	**250 – 500 kW$_{el}$**
1,000 kW$_{el}$	9.00 [1]	9.45	9.90	10.35	**> 500 kW$_{el}$**

[1] Production costs for 500 and 1,000 kW$_{el}$ are estimates

With regards to actual payments and to the negotiation of the power purchase agreements, the monthly payment should be 1/12 of the *estimated* payment of the year. At the end of the year, the operator needs to declare the effective amount of power produced and settle the difference and corresponding payments with the grid operator / offtaker of the electricity.

4.3.3 Plant-size related degression

The degression of the Feed-In-Tariff should provide a better economic framework for small-size biogas plants. With this strategy it is more likely that even low biomass potentials can be energetically used and long distance transports may be avoided.
As shown in Table 4-2, the tariffs should be paid in steps of production for each plant. This means that each plant gets the higher tariff for the first amount of produced electric power. That avoids discrepancies of payments between the plants at the frontiers of tariff differences.

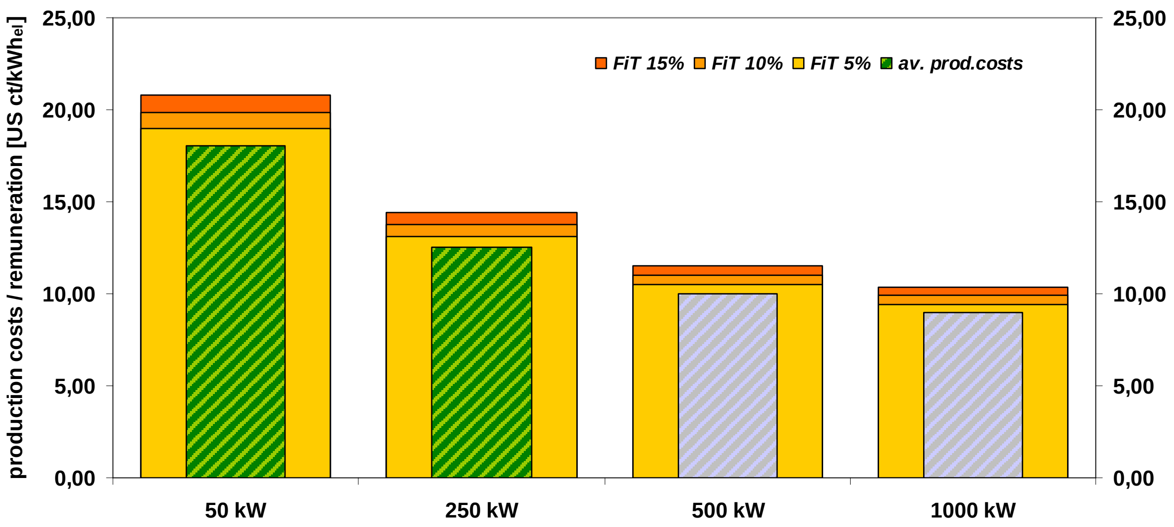

Figure 4-2 Capacity-related decrease of the plant-specific remuneration at different FiT-suggestions. Production cost levels at 500 and 1,000 kW_{el} are rough estimates.

The plant-size–related degression does not mean that a 500 kW_{el} plant gets 11.00 USD ct/kWh_{el} for the whole production. The payments are divided into four capacity-bond steps, so that any biogas plant gets a share of its production with remuneration at 50 kW, 250 kW, 500 kW and 1,000 kW, depending on the production of the plant. To demonstrate this, an exemplary calculation is shown in the following chapter.

4.3.4 Exemplary calculations for different plant scales

The theoretical production of a 50 kW_{el} biogas plant running at full load for one year (8,760 h) can be 438,000 kWh_{el}. This is the first tariff step which any biogas plant should be paid. The following steps for bigger plant scales are build up in the same way.

Table 4-2 Theoretical and realistic amount of electricity produced by one biogas plant per year.

Tariff step	Share considered for calculation	Max. production share per step [kWh_{el}/a]	Theor. max. production at 8,760 hours p.a. [kWh_{el}/a]
50 kW_{el}	0-50 kW_{el}	438,000	438,000
250 kW_{el}	50-250 kW_{el}	1,752,000	2,190,000
500 kW_{el}	250-500 kW_{el}	2,190,000	4,380,000
> 500 kW_{el}	>500 kW_{el}	unlimited	unlimited

To give an idea of the payments for the different plant scales considered above, the average amount of production is calculated for 6 plant scales ranging from 100 to 1,500 kW_{el}. The results are shown in the following table.

Table 4-3 Example for annual production rates and their shares for each FiT step. Theoretical calculation based on 7,500 full-load hours p.a.

Plant capacity	Total production at 7,500 h/a	50 kW Step 0-50 kW_{el} Share	250 kW Step 50-250 kW_{el} Share	500 kW Step 250-500 kW_{el} Share	> 500 kW Step
100 kW_{el}	750,000	438,000	312,000	0	0
300 kW_{el}	2,250,000	438,000	1,752,000	60,000	0
500 kW_{el}	3,750,000	438,000	1,752,000	1,560,000	0
700 kW_{el}	5,250,000	438,000	1,752,000	2,190,000	870,000
1,000 kW_{el}	7,500,000	438,000	1,752,000	2,190,000	3,120,000
1,500 kW_{el}	11,250,000	438,000	1,752,000	2,190,000	6,870,000

A 100 kW_{el} biogas plant will produce in average 750,000 kWh of electricity per year. The major share of its production is situated inside the 50 kW step (438 MWh_{el}), the minor share is situated in the 250 kW_{el} step (312 MWh_{el}). Using an examplary FiT at 10 % above production costs the remuneration is calculated as follows: In regard to table 5-1 the major share of 438 MWh_{el} is refunded with 19.86 USD ct/kWh_{el} and the minor share is refunded with 13.77 USD ct/kWh_{el}. Accordingly, the remuneration for a bigger plant, e.g. with a capacity of 1,500 kW_{el}, is a combination of four capacity steps, as it is shown in the following figure.

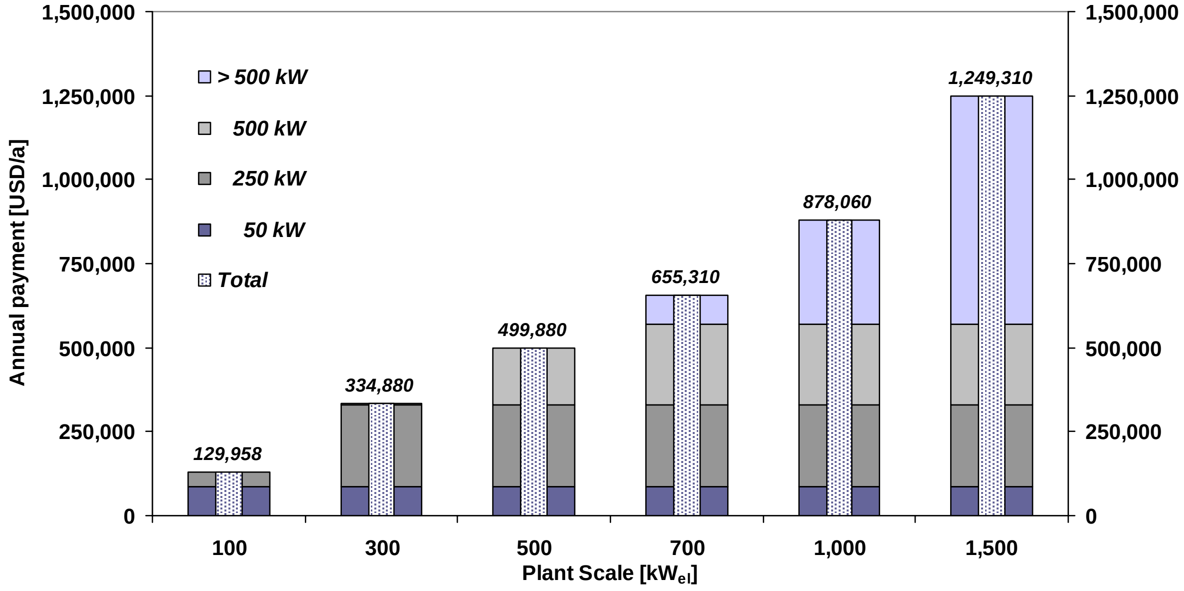

Figure 4-3 Total annual payments for model plants in a range from 100 to 1,500 kW_{el} installed electric capacity.

Finally, the average specific FiT for a given plant size depends on its size and workload. It can be calculated by division of the total annual payment through the total annual production. For example, as it is shown in the following figure the average Feed-in-Tariff paid for a 500 kW_{el} biogas plant is 13.33 USD ct/kWh_{el} with an annual production of 7,500 full-load hours per year.

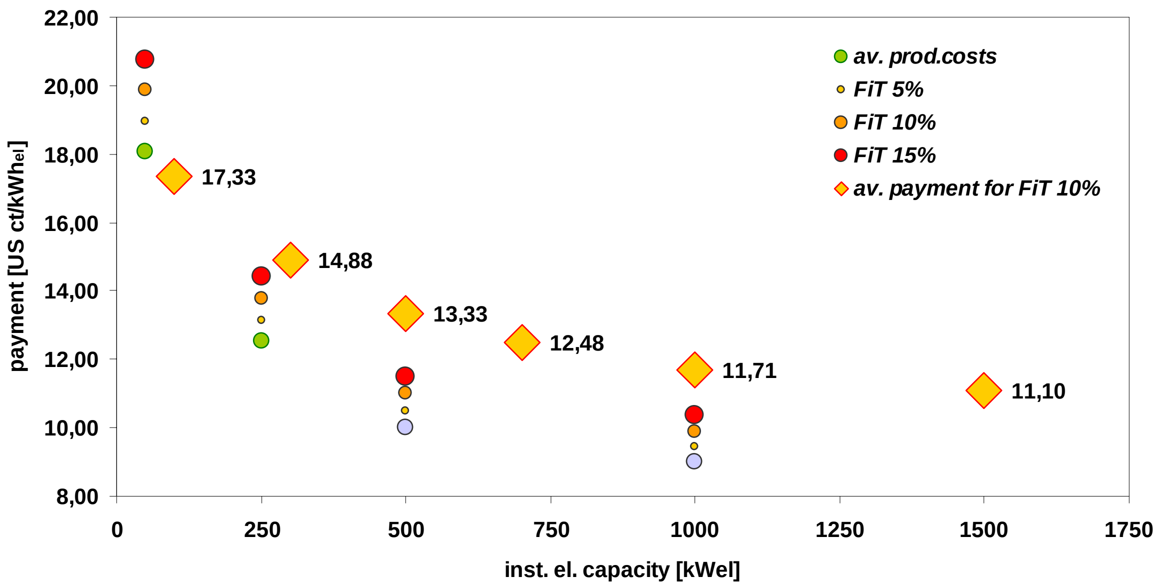

Figure 4-4 Demonstration of the specific FiT paid for different plants at 100 – 1,500 kW_{el} (orange). The calculated production costs for 50 and 250 kW_{el} (green) and the estimated production costs for 500 and 1000 kW_{el} (light grey) as well as the suggested FiT at three different levels (5, 10 and 15 %) are also shown.

It can be shown that a relatively high specific tariff for the first step of production, does not increase the remuneration significantly, but ensure smaller plants to cover production costs.

4.3.5 Difference costs

The overall investment for 100 MW_{el} at average specific investment costs of 4,000 USD/kW_{el} will be 400 Mio USD. Once the regulation is enacted, a detailed monitoring of the development of the plant number and size and the payments in the biogas sector is strongly recommended. With the available information about the cost for power production from biogas and actual production costs for electricity in Kenya, difference costs can be calculated. In this case a hypothetical installed capacity of 100 MW_{el} is given and distributed according to three scenarios considering different shares of small-, medium- and large-scale plants. Due to the unknown future spreading of biogas in Kenya, the first scenarios focuses on small scale agricultural plants, the second scenario emphasized medium sized plants, whilst the third scenario takes industrial biogas production into account.

Table 4-4 Approximation of installed biogas plants for three scenarios.

Biogas plants at	Scenario 1 installed [MW_{el}]	count [-]	Scenario 2 installed [MW_{el}]	count [-]	Scenario 3 installed [MW_{el}]	count [-]
100 kW_{el}	50	500	25	250	25	250
500 kW_{el}	25	50	50	100	25	50
1,000 kW_{el}	25	25	25	25	50	50
Total	100	575	100	375	100	350
Mean Remuneration (USD/kWh_{el})	**0,1492**		**0,1392**		**0,1352**	

In case of using residues or crops which were not considered in this study, the potential investments for anaerobic digestion may rise significantly. On the other hand any FiT for biogas will be more expensive when compared with actual Kenyan generation costs, which are strongly influenced by very cheap hydro power generation. If average generation costs for electricity are set to 10.00 USD ct/kWh_{el}, difference costs of 26.3 to 36.9 Mio USD/a may arise. The costs for three different scenarios mentioned above, are presented in the following table.

Table 4-5 Annual payments and difference costs for three scenarios with a installed capacity of 100 MWel,

Scenario	1	2	2
Installed capacity [MW]	100	100	100
Annual Production [MWh/a]	750,000	750,000	750,000
Total biogas remuneration [USD]	111,924,734	104,429,143	101,386,635
Case A: current generation mix			
Generation cost [0.08 USD / kWh)	60,000,000	60,000,000	60,000,000
Difference costs [USD]	**51,924,734**	**44,429,143**	**41,386,635**
Case B: Least Cost Power Development Plan			
Average expected generation cost [0.11 USD USD / kWh]	**82,500,000**	**82,500,000**	**82,500,000**
Difference costs [USD]	**29,424,734**	**21,929,143**	**18,886,635**
Case C: 100 MW thermal power			
Generation cost [0.17 USD USD / kWh]	**127,500,000**	**127,500,000**	**127,500,000**
Difference costs [USD]	**-15,575,266**	**-23,070,857**	**-26,113,365**

It is important to note, however, that the share of the relatively cheap hydropower in the future energy mix. According to the Least Cost Power Development Plan update 2009, of the candidate sources of the future power mix, only geothermal and imports are cheaper than 0.13 US$ / kWh (load factor of 90%). The proposals presented here for medium – sized and large biogas plants are very close to the GoK cost projections of the future energy mix.

We have compared the generation costs of the three scenarious for biogas sector development with three cases in order to assess the estimated difference costs:

- Case A: based on the KPLC Annual Report, we calculated the average generation costs of the current generation mix at approx. 0.8 US$ / kWh. Unsurprisignly, for the reasons mentioned above, the generation costs for 750,000 MW/a from biogas are higher than those of the current generation mix.
- Case B: based on the figures provided by the Least Cost Power Development Plan update 2009, we calculated the average generation costs of the planned capacity investments at approx. 0.11 US$ / kWh. The costs of biogas power production are still higher, but the difference is considerably smaller as in Case A.
- Case C: for a hypothetical thermal generation mix of 100 MW (LSD 34%, GT 3%, coal 30%, MSD 34%; oil price 100 US$ / barrel, coal price 90 US% per metric ton), we calculated generation costs of 0,17 US$ / kWh. This is

significantly higher than the biogas generation costs, which demonstrates clearly that biogas is an economically more viable source of firm or peak power.

For the market segment and tariff category of the very small and relatively expensive plants, it is equally important to consider that the cross cutting nature of biogas has its strongest relevance in this segment. This is due to the structure of the agricultural sector in Kenya and the large projected number of sites in this category. Whereby the larger plant sizes are directly competitive against most of the conventional alternatives, the consideration here extends to questions of promotion of jobs and asset creation in medium-sized agricultural enterprises, of rural and peri-urban development and business development for the manufacturing sector. In this segment, the share of local manufacture and thus the impact on local employment generation will be overproportionally high.

4.4 Bonus schemes

The german bonus system is highly differentiated according, with specific tariffs for specific substrates, and a elaborate system of bonuses for heat usage, innovative technologies and for the reduction of emissions from the CHP. Many countries adopted the model of a basic tariff but avoided to invent further bonuses in order to keep regulations as simple and transparent as possible.
However, bonus offer relatively simple options to channel investment towards specific purposed and policy objectives. The following proposals are mere examples for possible options drawn from the Kenyan context.

4.4.1 Early Mover bonus

To initiate fast changes and to consider a decrease in investment costs, a simple *early-mover-bonus* for plants taking up operation not later than 3 years after enacting regulations is suggested. The bonus could start at 2.0 USD ct/kWh$_{el}$ and shall decrease by 50% per annum. For example, if the regulation is enacted in 2010 the plant owner gets 2.0 USD ct/kWh$_{el}$ in addition to the basic FiT. If the same plant is set to operation in 2011 or 2012 the remuneration has lowered to 1.0 and 0.5 USD ct/kWh$_{el}$ respectively.

4.4.2 Peak Load supply

Biogas is able to meet daytime variability of energy demand with additional costs. Thus, electricity production from biogas is a good option to stabilise the grid. If production of electricity from biogas plants should be concentrated on a small number of hours with high demand (e.g. high demand in Kenya for 2 hours per day between 8 and 10 a.m.) more gas storage, installed engine power, capacity of transformer and grid connection needs to be installed. Depending on the demand and supply of electricity a bonus of up to 8.0 USD ct/kWh$_{el}$ might be paid to reward the supply of peak-load. If the period of high electricity demand exceeds 12 h/d, the bonus should not exceed 2.0 USD ct/kWh$_{el}$ In this case an exact billing to claim the extra payment is essential.

4.4.3 Rural electrification

In absence of the national grid maintained by KPLC and especially in rural areas, electricity has to be produced by cost-expensive diesel engines. Furthermore some sensitive sectors also strongly depend on a secure energy supply. In both cases generation costs exceed the suggested FiT mentioned above, so that a bonus that brings the FiT (basic + bonus) to the level of diesel-powered generation costs can be seen as an effective instrument for a cheap and sustainable supply in remote areas and for emergency current systems.

4.4.4 Energy efficiency

Modern CHP devices show electrical efficiencies of up to 40 %. Another 45 % appear as heat (exhaust gas and coolant) while approx. 15-20 % of the fuel energy gets lost. In the case of solely usage of the electricity almost 60 % of the input energy is wasted. In the past five years many strategies have been developed to increase the overall efficiency by using the heat. In the following several opportunities for heat usage will be suggested in order of their technical complexity (and costs):

- Heating of private homes
- Provision of heat for technical processes
- Provision of cooling energy through absorption refrigeration
- Generation of electricity from waste heat by Organic Rankine Cycle modules

Due to the fact, that the demand of heating in private homes is deemed to be low and the economic efforts for the supply cooling energy and power generation make it even more complex to realise a project, only the provision of technical heat is recommended. For this application a bonus payment of 2-5 USD ct/kWh$_{el}$ is recommended, if the degree of heat usage exceeds 50 % of the net heat production.

4.4.5 Price indexing of FiT

In the case of strong changes in the energy market (oil prices) as well as inflation, an index will be crucial to ensure the plant operators assets and to bring further projects to the market. The following equation used in the german biogas sector to adjust heat-prices, is even suitable to adjust the FiT annually.

$$Z_t = Z_0 * \left(a + b\frac{X_t}{X_0}\right)$$

Z_0 FiT (basic and further bonuses) at t = 0
Z_t adjusted FiT at a defined date
a, b factors for weighting, a + b = 1
X_0 Reference at t = 0
X_t Reference at a defined date
The reference can be: electricity, fuel, consumer price index, generation costs etc

5 RECOMMENDATIONS ON COMPLEMENTARY REGULATIONS

Complementary regulations are as important as the FiT for a successful implementation of biogas production.

5.1 Regulations of waste management

An effective control of disposal is also necessary for an enhancement of hygiene and the reduction of environmental problems from organic residues and waste water. Transparent and effective regulations for residues and waste water management with a clear schedule for the requirements in the following years are important for digestible residues and waste-water to be used for biogas production.

Biogas production from waste is characterised by relatively high investment costs, but once installed, plants produce energy for a long term period. Using residues as substrates for digestion, the consumption-related costs can be moderate but will depend on the characteristics and the requirements of the residues. Considering the high investment costs a secure supply of biomass residues for several years is very important for the economic feasibility of a plant. Planning security of waste supply depends on both, the market situation and legal preconditions. Such planning security is not only important for the implementation of biogas plants but also for the calculation of moderate costs (lower risks – lower costs).

5.2 Grid access

5.2.1 Standard regulations with guaranteed remuneration

Power generation from biogas is an effectual way to supply base-load and is highly recommended under the aspect of decentralisation. Grid access regulations are of central importance, if biogas energy should be fed into grid at any suitable plant site in Kenya. Since biogas producers and grid owners are not identical, the following aspects should be regulated:

- Technical requirements of a grid connection;
- Technical requirements to use parts of the grid for local transportation of electric power for example to a neighbour;
- Cost distribution between plant owner and grid owners.
- Feed-in at times with low demand on electricity. In this case power generation from fossil sources is suggested to be cut off first.

5.2.2 Supplementary regulations in case of power wheeling

As an efficient instrument for the unbundling of electricity supply, biogas plant owners should be able to sell electric power directly to customers, e.g. industry. In this case the grid operator gets a fee for wheeling of electricity. This fee could be geared to the market price or to the theoretical remuneration when alternatively joining the guaranteed FiT.

5.3 Regulatory approval and constructive regulations

In Europe many biogas projects stagnate due to the complexity of regulations and a great variety of engaged authorities. Often the approval to build up and operate a plant takes much time. Clear and transparent general regulations for the realisation of bioenergy projects are necessary for:

- Generation of reliability for planning and investment by clear rules (prevention of expensive modifications or retrofitting)
- Prevention of negative ecological effects of bioenergy usage

5.4 Granting of loans

In relation Problems for biogas implementation in Kenya may arise from the high demand of private capital contribution and the high loans. Main parts of a biogas plant work for 20 years and more. In case of high loans like in Kenya the break even point of recapitalisation has to be in a very short time. This would restrict the implementation of biogas plants to plants with very high profitability. It could be important to provide credit institutions in Kenya with a guideline for evaluation of biogas projects. Such a guideline for the evaluation of biogas projects, including the aspects of regularly information can enhance security of credit institutions. It has to be investigated, if an extra credit programme could be provided by regional or international financing institutions (e.g. The World Bank, African Development Bank).

For recommendations on the interest during construction, it should be considered that the construction time of a biogas plant can easily cover one year. Furthermore a ramp-up time is needed to achieve full load conditions and stable process. In addition the project must be financed for the first two years without any reflux of capital.

5.5 Monitoring

Many countries invented a detailed monitoring of the developments in the RE-Sector, in Germany this is done partially by the DBFZ. The assessment estimates the proportion of electricity generation from biomass, gives detailed information about the distribution of biomass plants and discusses misguided developments as well as positive effects. The annual reports were considered by the amendment of the EEG (2009).

A basic monitoring should cover following topics:

- Number of biogas plants in operation
- type of substrates used
- amount of electricity generated, RE-Quota
- level of utilization for the most important potentials
- experiences with regulative framework

5.6 Further Aspects

For the implementation of biogas in Kenya, following aspects should be kept in mind:

- Organization of a biogas association to represent special interests and to obtain knowledge-transfer from foreign countries
- Training/education of technical specialists: Development and integration of special courses for operation and maintenance of biogas plants
- Training/education of scientists: Integration of special modules in universities and academies
- A need for more detailed bottom-up potential studies with focus on the economic aspects
- A cooperation with the administration in Kenya: Networking and exchange of experiences with regional administrations (and national ministries) for simplification and pinpoint focusing of administrative regulations (approvals etc.) for bio – energy plants in Kenya
- Cooperation of companies: Concerted installation of pilot projects at high potential sites (based on bottom-up studies), efficient market development by cooperation of companies with scientific, educational and administrative institutions

6 KENYAN ELECTRICITY SECTOR AND INVESTMENT RECOMMENDATIONS

6.1 Renewable energy policies and energy infrastructure in Kenya

6.1.1 Policies for renewable energies

The Kenyan Energy Act as of 2006 empowered the Energy Minister to "promote the development and use of renewable energy technologies, including but not limited to biomass, biodiesel, bioethanol, charcoal, fuelwood, solar, wind, tidal waves, hydropower, biogas and municipal waste" (Energy Act 2006, Art. 103). The Energy Act 2006 does not define specific policies for the promotion of renewable policies but sets the policy framework for the energy sector (e.g. petroleum and electricity) and consolidates regulations of the Electric Power Act from 1997 and the Petroleum Act from 2000. Prior to the Energy Act and the Sessional Paper No. 4 of 2004 on Energy, there was no comprehensive Kenyan energy policy. In this paper, the government committed itself to promote co-generation in the sugar industry with a target of 300 MW installed capacity by 2015, to provide pre-feasibility and feasibility studies on the potential for renewable energy sources and to propose feed-in-tariffs for electricity generated from renewable energy sources [64]

6.1.2 Feed-in-tariffs for electricity from renewable energy sources

In May 2008, a feed-in-tariffs policy on wind, biomass and small-hydro resource generated electricity was implemented by the Ministry of Energy. The feed-in-tariffs were specified for the electricity generation from wind energy, small hydro power and biomass energy. The current policy framework does not specify differentiated feed-in-tariffs for electricity generation depending on the type of biomass sources (solid, liquid biomass; energy crops, municipal waste) or the conversion technologies (combustion, anaerobic fermentation, etc.). Feed-in-tariffs include the grid connection and are higher for firm power (power which is guaranteed by the supplier to be available at all times during a period covered by a commitment) than for non-firm power. The government guarantees access to the grid (transmission and distribution) and the duration of support of each technology will be determined by the economic life of the plant. The tariffs (see A cooperation with the administration) shall apply to the first 150 MW of installed capacity of each technology and be valid for 15 years from the date of the first commissioning of the plant in order to enhance planning security.

Table 6-1 Feed-in-tariffs for renewable energy resource generated electricity; [65]

Technology type	Plant capacity (MW)	Maximum firm power tariff (USD/kWh) at the interconnection point	Maximum non firm power tariff (USD/kWh) at the interconnection point
Wind power (single farm)	0 – 50	0.09	0.09
Any individual capacity greater than 50 MW	51 and above	Tariff to be negotiated on commercial basis	Tariff to be negotiated on commercial basis
Biomass derived electricity	0 – 40	0.07	0.045
Any individual capacity greater than 40 MW	41 and above	Tariff to be negotiated on commercial basis	Tariff to be negotiated on commercial basis
Small hydro power	0.5 – 0.99	0.12	0.10
	1 – 5	0.10	0.08
	5.1. – 10	0.08	0.06
Any individual capacity greater than 10 MW	11 and above	Tariff to be negotiated on commercial basis	Tariff to be negotiated on commercial basis

The feed-in-tariff policy will be reviewed every three years from the date of publication; any changes shall only apply to power plants developed after the publication of the revised guidelines [64].

6.1.3 Electricity generation and distribution

Kenya is very dependent on hydropower which provides 50 % of electricity (see Figure 6-1). Eleven hydropower plants are operating in Kenya with five major stations in the Tana River: Kindaruma (44 MW), Gitaru (225 MW), Kamburu (94.2 MW), Masinga (40 MW) and Kiambere (144 MW). There are also several small hydro stations with a combined generation output of 40 MW. All hydropower facilities are operated by the Kenya Power and Lighting Company (KPLC) and sum up to a total installed capacity of 737 MW [66].

Geothermal energy is generated using natural steam tapped from volcanic-active zones in the Rift Valley. Some 127 MW is fed into the national grid from three plants located at Olkaria. Thermal (fuel-generated) energy is generated in power stations at Mombasa and Nairobi [67]. Thermal installed capacity of KPLC amounted to 154 MW in 2008. The electricity purchased by KPLC and independent power producers amounted to 6;360 GWh in 2007/08 [66]. The leading electric power generation company in Kenya is *Kenya Electricity Generating Company Limited* (KenGen), which produces about 80 % of electricity consumed in the country. There are four

Independent Power Producers (IPPs) which produce about 18 % of the country's electric power.

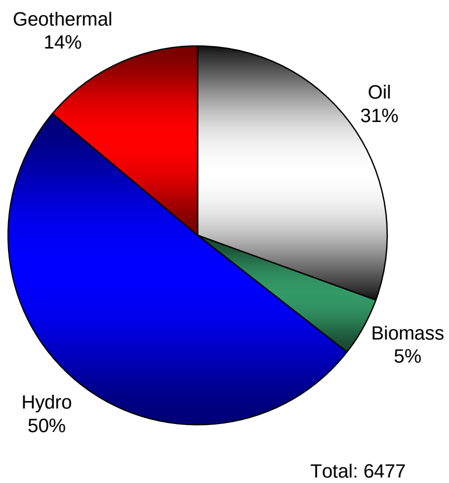

Figure 6-1 Electricity generation in Kenya 2006; [68]

Since the implementation of the feed-in-tariff policy framework, only one biomass power plant with based on sugarcane bagasse and an installed capacity of 35 MW (26 MW sold to the grid) has been realised by Mumias Sugar Company [69]. The slow implementation of other co-generation projects is attributed to the relatively low feed-in-tariff which amounted to 6.0 USD ct/kWh in the case of the contract between the company and the grid operator KPLC. Electricity generation by biogas plants has not been implemented yet, since the feed-in-tariff for biomass does not offer specific tariffs for biogas. Only one pilot plant with an installed capacity of 150 kW_{el} has been financed by a local investor and constructed by two German biogas companies with the support of German GTZ (Source: GTZ Target Market Analysis).
Key player in the transmission, distribution and retail of electricity throughout Kenya is the Kenya Power and Lighting Company (KPLC). The company is 48.4 % state-owned and is the only licensed public electricity transmitter and distributor [70]. It owns and operates the national transmission and distribution grid, and is responsible for the scheduling and dispatch of electricity to almost 900 000 customers throughout Kenya. Another 160,000 customers are attended by the Rural Electrification Programme (REP). KPLC is responsible for the interconnected network of transmission and distribution lines, which are being extended continuously and grew from about 23,000 km in 2003 to 40,000 km in 2008 [66]. The national grid is operated as an integral network, linked by a 220 kV and 132 kV transmission network, which shall be further enhanced.

6.1.4 Energy prices

Since implementation of the Energy Act of 2006, tariffs for the supply of electrical energy from the Interconnected System and also from the off-grid systems in Kenya are set by the Energy Regulatory Commission (ERC).

The tariff structure consists of four main charges (not considering VAT, etc.): a fixed charge, an energy charge, a demand charge and a fuel cost charge. The fixed charge varies between 120 KES per month (DC) and 11,000 (CI provided at 132 kV). The energy charge has three different steps for domestic consumers not exceeding 15,000 units/month (2.00 KES for 0-50 units, 8.10 KES for 51-1,500 units, 18.57 for units consumed above 1,500 units) and amounts to 4.10 KES/unit for commercial and industrial consumers provided at 132 kV [71]. The demand charge only applies to the commercial users and varies between 170 and 600 KES/kVA. The fuel cost charge is determined by a formula considering the cost of all the fuel used to generate electricity in a given month divided by all the units consumed in that month. Since fuel for electricity generation is imported, fuel costs accompany global fuel prices and provoke oscillating electricity prices.

Additionally, a foreign exchange rate fluctuation adjustment and an inflation adjustment are calculated every six months and charged for the subsequent half year. In addition to a VAT of 16 % charged over four types of charges, the government levies 5 % of revenue from unit sales for the Rural Electrification Programme (REP) and 0.03 KES/kWh for the Energy Regulatory Commission (ERC).

All these tariffs and levies sum up to quite high effective electricity prices, which amounted from 10 to 15 KES/kWh (0.14 to 0.21 USD/kWh) in September 2008 for industrial consumers for instance [72][1] [2]. Due to frequent power blackouts, the companies must provide emergency power aggregates whose electricity costs amount from 0.25 to 0.35 EUR/kWh [73] [74].

6.2 Biogas investment recommendations

6.2.1 Identified promising biogas subsectors in Kenya

As described in chapter 3.4, the biogas potential of the analysed case studies sums up to a considerable potential that could be exploited economically/technically since large parts of the substrates are concentrated at few locations. Unfortunately, the utilisation of the substrate with the highest potential analysed in this study – municipal solid waste from the city of Nairobi – seems rather unlikely since there is a lack of administrative capacity of the institutions (e.g. City Council) responsible for enforcement of waste management regulations [72].

But especially the sisal sector (9 to 31 MW_{el}, based on pulp, wastewater and balls from replanting) and the coffee sector with a potential installed capacity between 2 and 18 MW_{el} are sectors with high biogas potential and professional structures.

Production in the sisal sector is concentrated on large estates, which account for more than 80 % of total sisal production [21]. At four of the seven largest sisal estates, biogas plants with a capacity about 1 MW_{el} or more could be installed. There are two pilot biogas plants for biogas production from sisal waste, one located in Tanzania (Hale, Katani Estate) and one in Kenya (Biogas Power Ltd; Kilifi), showing the technical feasibility and economic viability of biogas plants using sisal pulp and wastewater.

In the coffee sector, almost half of the production comes from cooperatives of small farmers and the other half from larger coffee estates. Thus, in the case of the cooperatives, several small scale biogas plants (< 50 kW_{el}) would be feasible while in the case of the coffee estates, few medium scale biogas plants (250 kW_{el}) could be realised. Different digester designs (e.g. CSTR, plug-flow and two stage systems with CSTR for hydrolysis and UASB for methanogenesis) could be adapted for the anaerobic digestion of solid coffee wastes and high performance reactor systems could be interesting for wastewater treatment with the immobilisation of microorganisms.

6.2.2 Offering adjusted biogas technologies

It should be considered that the calculations for the electricity production costs and the feed-in-tariffs were based not only on lower operational (personal) costs but also on lower specific investment costs than in Germany. This can be justified by lower costs for construction works, heating installations, insulation and biogas non-specific equipment like pumps and pipes, which is available on the local market. Further potential savings are costs for process control and redundant parts, because biogas plants in Germany contain technical equipment which is not essential, but comfortable (e.g. computer visualization and control). It is recommended to use a rugged design for the equipment.

6.2.3 Joint-ventures with Kenyan partners

With regard to the local financing conditions and expectations of cooperation partners, German investors should be aware of the fact that minimum equity ratio (35 – 50 %) has to be higher than in Germany and that interest on equity is expected to be higher in Kenya in order to reduce payback time of the investment. German companies, which are interested to entry into the promising Kenyan biogas market, need a long-term strategy and should base their activities in Kenya on the cooperation with experienced and well connected local cooperation partners. Joint-ventures with Kenyan partners would facilitate the implementation of the projects due to the familiarity with national and local licensing procedures (e.g. plant construction, environmental licences). This cooperation would also facilitate the transfer of biogas technology and knowledge and help spread biogas production and utilisation in Kenya, since local companies would be involved into the project implementation and local engineers and technicians would be trained for maintenance works.

6.2.4 Offering solutions for substitution of electricity demand of local agro-industries

According to the current legislation, the grid system operators are bound to connect plants generating renewable electricity to the grid and guarantee purchase priority ("The grid system operators shall connect plants generating electricity from renewable energy sources and guarantee priority purchase, transmission and distribution of all electricity from renewable energy sources specified in this document.") [62]. As in Germany, costs of the plant connection to the closest grid connection point have to be bared completely by the power producer. However, due to the limited electricity infrastructure, costs for the grid extension – which would have to be bared by the grid operator – could be high and conflicts between the power producer and the grid operator could arise. Thus, for companies with agricultural residues, the installation of biogas plants could help satisfy the own energy demand as a first step. Thus, alternative energy provision and biogas production and electricity generation could be one interesting and economic option, even without feeding into the national electricity grid. Another option is the direct sale of biogas electricity to bulk consumers (e.g. cement industry) whereas the national grid is only used for the transmission of electricity.

6.2.5 Biogas framework in Kenya

Since the need for action due to electricity shortages, high consumer prices and waste disposal problems matches with a considerable biogas potential from agricultural residues, the Kenyan biogas market offers promising perspectives. Since the realisation of this potential depends also upon the political and regulatory framework conditions, German investors, plant manufacturers and technology providers should follow closely the reformulation and implementation process of the feed-in-tariffs for biogas energy. If the feed-in-tariffs would be implemented as recommended within this study, framework conditions for biogas projects would be favourable. However, the technological, economical and social challenges and opportunities for the implementation of biogas projects should be evaluated carefully. Experiences in Germany show that support from local communities for biogas technologies is very important (e.g. odour nuisance). The provision of electricity in remote rural communities could guarantee this support and be decisive for the biogas market development in Kenya and even in neighbouring East African countries, where similar regulations could be adopted.

6.2.6 Implementation of renewable energy plants in Kenya

Private investors who want to produce renewable energy have to send an expression of interest (EOI) to the Ministry of Energy. This expression of interest has to contain information about

- the particulars of the applicant
- the project site location
- the site and land ownership and control
- the technology
- a preliminary project feasibility assessment
- the project sponsors and developers
- the technical advisors, experts or contractors
- the project financing
- the project development and implementation plan

6.3 SWOT-Analysis for investments in Kenyan biogas sector

In the following table, the results of a SWOT-analysis are summarised:

Table 6-2: SWOT Analysis for investments in Kenyan biogas sector

STRENGTHS	Coffee and sisal sector as well as municipal solid waste present large potential for biogas production General regulative framework for promotion of renewable energies already implemented (grid connection), specific feed-in-tariffs will be regulated in the near future Specific production costs (0.06-0.19 USD/kWh) for biogas electricity (250 kW_{el}) calculated within this study are in the range of electricity production costs based on diesel oil (100 USD/bbl) which contributes 1/3 of electricity generated in Kenya
WEAKNESSES	Current feed-in-tariffs for electricity from biomass are low (0.07 USD/kWh), no incentive for biogas production For the majority of the calculated sub-sectors, the biogas potential is below 1 MW_{el} Little experience in biogas production in Kenya, only one realised biogas plant (150 kW_{el}) so far, all components had to be imported Mono-fermentation of substrates may reduce economic feasibility, mix of different substrates would have to be analysed based for the specific plant locations Lack of skilled technicians and engineers, maintenance costs may be higher respective full load hours lower than expected
OPPORTUNITIES	Effective electricity costs for agricultural consumers are high, production of biogas electricity for own demand could be interesting for several agricultural producers, even without attractive feed-in and grid access regulations Pressure on government to promote attractive feed-in regulations is high due to electricity shortage and frequent power blackouts Waste disposal problems could be solved with utilisation of agricultural residues and municipal solid waste for biogas production Successful implementation of biogas plants in Kenya could open access to nascent biogas markets in other East-African countries, similar regulations (FIT) are expected for neighbouring countries
THREATS	Values for methane production of some agricultural residues (tea waste, cut flowers) are not well known, due to little practical experience, efficiency and economic viability may be lower than previously calculated Utilisation of the substrate with the highest potential (MSW) may be cost-intensive because of collection and handling or even not feasible due to administrative, regulative and logistical problems Sustainability of political stability after violent conflict following 2007 election in Kenya is unclear, political upheaval may threat investments

7 ANNEX

7.1 List of figures

7.2 List of tables

7.3 Bibliography

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7.4 Data on biogas potentials from solid substrates

	Unit		Coffee pulp	Cut flowers wastes	Tea wastes	Sisal pulp	Old sisal plants	Sugar filter cake	Pineapple solid wastes	MSW Nairobi	Pig manure	Chicken manure	Vegetable waste
Amount of fresh waste	[tons/a]		110,295	27,358	9,640	615,050	120,000	192,705	75,000	996,450	10,920	82,125	798
		min	16.23%	21.84%	65.00%	9.00%	25.00%	20.00%	14.00%	30.00%	20.00%	18.00%	5.00%
		max	22.90%	32.76%	91.80%	14.30%	33.00%	30.00%	16.00%	60.00%	25.00%	32.00%	20.00%
DM content	[%FM]	average	19.57%	27.30%	78.40%	11.65%	29.00%	25.00%	15.00%	45.00%	22.50%	25.00%	12.50%
		min	92.80%	90.45%	95.00%	82.30%	90.00%	70.00%	95.00%	50.00%	75.00%	63.00%	76.00%
		max	92.80%	94.15%	98.00%	87.50%	96.00%	70.00%	97.00%	70.00%	90.00%	83.00%	90.00%
VS content	[%DM]	average	92.80%	92.30%	96.50%	84.90%	93.00%	70.00%	96.00%	60.00%	82.50%	73.00%	83.00%
		min	16,612	5,405	5,953	45,557	27,000	26,979	9,975	149,468	1,638	12,935	30
		max	23,439	8,438	8,672	76,958	38,016	40,468	11,640	418,509	2,457	17,041	144
Amount of VS	[tons/a]	average	20,026	6,894	7,313	61,257	32,364	33,723	10,808	283,988	2,048	14,988	87
		min	380	300	300	360	600	460	550	310	414	250	400
		max	400	420	417	686	623	490	669	486	613	620	650
Biogas potential	[m^3/ton VS]	average	390	360	358	523	611	475	610	398	514	435	525
		min	60%	50%	50%	50%	50%	50%	51%	58%	58%	60%	50%
		max	65%	60%	60%	70%	70%	60%	65%	70%	70%	65%	60%
Methane content	[%]	average	63%	55%	55%	60%	60%	55%	58%	64%	64%	63%	55%
		min	228	150	150	180	300	230	281	180	240	150	200
		max	260	252	250	480	436	294	435	340	429	403	390
Methane potential	[m^3/ton VS]	average	244	201	200	330	368	262	358	260	335	277	295
		min	34	30	93	13	68	32	37	27	36	24	8
		max	55	78	225	60	138	62	68	143	97	84	70
Methane potential	[m^3/ton FM]	average	45	54	159	37	103	47	52	85	66	54	39
		min	3,787,539	810,689	892,891	8,200,216	8,100,000	6,205,101	2,797,988	26,874,257	393,120	1,940,203	6,065
		max	6,094,143	2,126,322	2,168,098	36,939,903	16,574,976	11,897,607	5,063,400	142,376,762	1,054,872	6,867,498	56,020
Methane yield	[m^3]	average	4,940,841	1,468,506	1,530,495	22,570,059	12,337,488	9,051,354	3,930,694	84,625,509	723,996	4,403,850	31,042

	Unit		Coffee pulp	Cut flowers wastes	Tea wastes	Sisal pulp	Old sisal plants	Sugar filter cake	Pineapple solid wastes	MSW Nairobi	Pig manure	Chicken manure	Vegetable waste
		min	37,875,395	8,106,893	8,928,910	82,002,156	81,000,000	62,051,010	27,979,875	268,742,565	3,931,200	19,402,031	60,648
		max	60,941,429	21,263,222	21,680,984	369,399,030	165,749,760	118,976,067	50,634,000	1,423,767,618	10,548,720	68,674,978	560,196
Total energy	[kWh/a]	average	49,408,412	14,685,057	15,304,947	225,700,593	123,374,880	90,513,539	39,306,938	846,255,092	7,239,960	44,038,505	310,422
		min	14,392,650	3,080,619	3,392,986	31,160,819	30,780,000	23,579,384	10,632,353	102,122,175	1,493,856	7,372,772	23,046
		max	25,595,400	8,930,553	9,106,013	155,147,593	69,614,899	49,969,948	21,266,280	597,982,400	4,430,462	28,843,491	235,282
Electricity production	[$kWh_{therm.}$/a]	average	19,994,025	6,005,586	6,249,499	93,154,206	50,197,450	36,774,666	15,949,316	350,052,287	2,962,159	18,108,131	129,164
		min	11,362,618	2,432,068	2,678,673	24,600,647	24,300,000	18,615,303	8,393,963	80,622,770	1,179,360	5,820,609	18,194
		max	21,938,914	7,654,760	7,805,154	132,983,651	59,669,914	42,831,384	18,228,240	512,556,342	3,797,539	24,722,992	201,671
Heat generation	[kWh_{el}/a]	average	16,650,766	5,043,414	5,241,914	78,792,149	41,984,957	30,723,344	13,311,101	296,589,556	2,488,450	15,271,801	109,932
		min	1.62	0.35	0.38	3.51	3.47	2.66	1.20	11.52	0.17	0.83	0.003
		max	2.74	0.96	0.98	16.62	7.46	5.35	2.28	64.07	0.47	3.09	0.025
Installed capacity	[MW_{el}]	average	2.18	0.65	0.68	10.07	5.47	4.01	1.74	37.79	0.32	1.96	0.014

7.5 Data on biogas potentials from wastewaters

	Unit		Coffee processing wastewater	Dairy wastewater	Slaughterhouse wastewater	Distillery stillage	Nut processing wastewater	Pineapple processing wastewater	Sisal decortications wastewater
Amount of wastewater	[m³/a]		4,104,000	1,083,000	60,000	108,000	9,216	840,000	2,460,200
Ammount of COD in wastewater	[g/l]	min	1	2	5	55	4	3	8
		max	28	6	11	125	4	8	15
		average	14	4	8	90	4	6	12
Amount of COD	[tons/a]	min	2,462	2,166	300	5,940	37	2,520	19,682
		max	114,912	6,498	660	13,500	40	6,720	36,903
		average	58,687	4,332	480	9,720	38	4,620	28,292
COD degradability	[%]	min	85%	85%	55%	52%	65%	80%	80%
		max	95%	90%	98%	80%	75%	90%	93%
		average	90%	88%	77%	66%	70%	85%	87%
Biogas potential	[m³/ton $COD_{rem.}$]	min	350	333	320	330	308	300	427
		max	400	400	360	450	353	450	523
		average	375	367	340	390	330	375	475
Methane content	[%]	min	60%	75%	60%	60%	65%	65%	82%
		max	80%	85%	78%	85%	85%	85%	86%
		average	70%	80%	69%	73%	75%	75%	84%
Methane potential	[m³/ton $COD_{rem.}$]	min	210	250	192	198	200	195	350
		max	320	340	280	383	300	383	450
		average	265	295	236	290	250	289	400
Methane potential	[m³/ton FM]	min	0	0	1	6	1	0	2
		max	9	2	3	38	1	3	6
		average	4	1	2	22	1	2	4
Methane yield	[m³]	min	439,538	460,275	31,680	611,582	4,792	393,120	5,510,848
		max	34,933,248	1,988,388	181,156	4,131,000	8,999	2,313,360	15,443,906
		average	17,686,393	1,224,332	106,418	2,371,291	6,896	1,353,240	10,477,377

	Unit		Coffee processing wastewater	Dairy wastewater	Slaughterhouse wastewater	Distillery stillage	Nut processing wastewater	Pineapple processing wastewater	Sisal decortications wastewater
		min	4,395,384	4,602,750	316,800	6,115,824	47,923	3,931,200	55,108,480
		max	349,332,480	19,883,880	1,811,557	41,310,000	89,994	23,133,600	154,439,055
Total energy	[kWh/a]	average	176,863,932	12,243,315	1,064,179	23,712,912	68,959	13,532,400	104,773,768
		min	1,670,246	1,749,045	120,384	2,324,013	18,211	1,493,856	20,941,222
		max	146,719,642	8,351,230	760,854	17,350,200	37,798	9,716,112	64,864,403
Electricity production	[$kWh_{therm.}$/a]	average	74,194,944	5,050,137	440,619	9,837,107	28,004	5,604,984	42,902,813
		min	1,318,615	1,380,825	95,040	1,834,747	14,377	1,179,360	16,532,544
		max	125,759,693	7,158,197	652,161	14,871,600	32,398	8,328,096	55,598,060
Heat generation	[kWh_{el}/a]	average	63,539,154	4,269,511	373,600	8,353,174	23,387	4,753,728	36,065,302
		min	0.19	0.20	0.01	0.26	0.002	0.17	2.36
		max	15.72	0.89	0.08	1.86	0.004	1.04	6.95
Installed capacity	[MW_{el}]	average	7.95	0.55	0.05	1.06	0.003	0.60	4.66