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Sweet Fuel

Sweet Sorghum
an alternative energy Crop

SWEETFUEL / Grant Agreement n° 227422

WP6

Deliverable 6.4:

Report on economic assessment

Composition of the consortium

CIRAD
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SWEETFUEL:
Sweet Sorghum: an alternative energy crop

Deliverable 6.3:
Report on economic assessment

Authors:

G. Basavaraj

P.Parthasarathy Rao

Co-authors:

M. Lagesh

Organisation:

International Crops Research Institute For The Semi-Arid Tropics

Patancheru 502324
Andhra Pradesh, India
Tel: +91 40 30713071
Fax: +91 40 30713074
Fax: p.partha@cgiar.org
www.icrisat.org

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1 Executive summary

By 2035, global energy consumption is projected to grow by 41% and consumption of liquid fuels is expected to rise by 20% - almost 15 million more barrels per day. With the world's population projected to reach 8.3 billion by then, an additional 1.3 billion people will need energy. To meet this demand a diverse energy mix is needed. This is where biofuels like ethanol, biodiesel and bioenergy can help; (BP Outlook 2030, published in Jan 2013).

To promote use of biofuels several countries have mandated blending of biofuels with gasoline / diesel. Brazil has the highest blending target of 20%in 2013. Most other countries have 10-15% targets by 2020.The major feed stocks presently utilized for bio ethanol production are sugarcane, corn, wheat and sugarcane molasses but these are not sufficient to meet the mandatory requirements for bioethanol blending programs. Also, there are food security concerns with biofuel feed stocks competing for land growing foodgrains. Under this background sweet sorghum (*Sorghum bicolor* (L.) Moench) is an alternative feed stock that has several advantages due to its efficiency in both, water use and nutrient uptake. Furthermore, the production of food, feed and fuel can be combined in one crop as the stalks can be used for ethanol production, bagasse (left over stalk after juice is extracted) for animal feed and grain for food or feed. This is an important asset on the background of the currently increasing discussion on energy production and food security. Sorghum biomass is another important feed stock particularly in temperate climatic regions and this report also looks at use of biomass sorghum for production of biogas/ biomethene for energy, 2nd generation ethanol and FT diesel (Fisher Trospsch synthesis through gasification) under temperate climatic conditions.

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As the more widespread use of energy sorghum for bioethanol production is primarily limited by the lack of variants specifically bred for this purpose, a project funded by the European Commission with the title “SWEETFUEL: Sweet Sorghum: an alternative energy crop” was launched (Grant agreement no. 227422). The SWEETFUEL project aims at developing sweet sorghum and biomass sorghum variants for tropical, semi-arid and temperate environments.

This project is split in seven work packages (WPs). WP 6 “Integrated Sustainability Assessment” of the SWEETFUEL project provides a multi-criteria evaluation of the sorghum produc-

tion and use pathways taking into account technological, environmental, economic and social aspects.

This report is the outcome of Task 6.3 “Economic assessment” as part of WP 6 “Integrated Sustainability Assessment” of the SWEETFUEL project. It was composed by ICRISAT with contributions from all SWEETFUEL partners, namely IFEU ARC, CIRAD, EMBRAPA, KWS, UANL, UCSC, UNIBO and WIP.

The report on economic assessment provides answers tothe following core question:

- Which are the best ways to produce and use sweet and biomass sorghum for energy from an economic point of view?
- Economic competitiveness of sweet and biomass sorghum as a feedstock for different energy pathways under varying parameters of crop production, conversion efficiencies, and output of ethanol / energy.

The report defines general specifications and settings and definitions for this study followed by a short description of sweet and biomass sorghum scenarios considered under the sweet-fuel project for which economic assessment is carried out. Broadly three sets of scenarios are considered: 1. Sweet sorghum to ethanol; 2. Biomass sorghum to biogas; 3. Biomass sorghum to alternative products (2^{nd} generation ethanol, FT diesel etc.). For each of the scenarios the key parameters like crop productivity, sugar content of stalk, recovery rate from feedstock to end product etc., are varied within a given bandwidth where the *typical* case is the closest to reality while the *low* and *high* cases are two extremes but still within the realm of feasibility.

For the economic assessment itsel four levels of cost categories are distinguished in the current study for all the sweet and biomass sorghum scenarios that includes:Production costs of sweet sorghum and biomass sorghum; transport costs; processing costs which include cost of converting sweet and biomass sorghum to different use pathways; and cost of acquisition, operations and maintenance. Besides estimating variable cost of prodcution the cost model used for economic assessment takes into account indicators of commercial viability viz., NPV (Net Present Value) & IRR (Internal Rate of Return) of capital investment and operational costsof procesing unit.

The key findings indicate that the economic assessment of the sweet sorghum to ethanol scenarios though positive throws up mixed results. Stalk+grain to ethanol (cane fallow 2020) and grain to food scenarios are economically most viable compared to stalk only to ethanol scenario. For the stalk+grain scenario, IRRs of 70% and 148% are obtained under the typi-

cal and high scenarios respectively. For the grain to food scenario the IRRs are marginally lower under the typical and highcases. The stalk only to ethanol scenario (cane fallow) is viable only under the high case with IRR of 25%.The syrup route to ethanol is the most unviable scenario where syrup is produced at the village level and transported to the distillery for conversion to ethanol. This is because the syrup production at village level is on small scale leading to higher costs of production

By-products during crop production and processing stage make an important contribution to economic returns. Among the by-products from sweet sorghumprocessing for ethanol the value of surplus bagasse used to generate electricity is the highest followed by excess power, calcium carbonate, vinasse. Leaves stripped from sweet sorghum stalk before processing are used either as fertilizer or feed but the value of leaves is found to be low. For the grain to food scenario grain value is the highest followed by others. Surplus bagasse can also used as feed. Our findings indicate that the use of surplus bagasse for feed has a lower value and thus economically less efficient compared to its use to generate electricity.

For biomass sorghum to biogas the return on investment is positive with IRR of 24%, 44% and 57% under the three cases, low, typical and highrespectively. Economic feasibility analysis of producing 2nd generation ethanol from sorghum biomass indicatesthat processing cost of second generation ethanol determines its profitability which in turn depends on the enzyme price.Bringing down enzyme price holds the key for the economic viability of 2nd generation ethanol. Likewise the production of FT dieselisfound to be uneconomical. Consequently the indicator of returns to investment i.e, net present value is negative. The break even prices (price at which NPv is zero) ranges from 1.2 to 1.5 euro / liter as we move from high to low case that are significantly higher than global bio diesel prices of 0.85 euro / liter.

Sweet sorghum is thus a viable alternative feedstock for ethanol production provided the whole plant is utilized, i.e., both stalk and grain besides the by-products particularly bagasse. There are however a number of issues that need to be resolved at the ground level for this to become a reality.

2 Introduction, goal and scope

Bioethanol is one part in the increasing use of biofuels. Worldwide, sugar cane is the main source of bioethanol. However, the cultivation of this crop cannot be realised in water-limited or temperate regions. On this background, sweet sorghum (*Sorghum bicolor* (L.) Moench) has several advantages due to its efficiency in both, high water use and nutrient uptake. Furthermore, the production of food, feed and fuel can be combined in one crop. This is an important asset on the background of the currently increasing discussion on fuel production and food security.

As the more widespread use of energy sorghum for bioethanol production is primarily limited by the lack of variants specifically bred for this purpose, a project funded by the European Commission with the title “SWEETFUEL: Sweet Sorghum: an alternative energy crop” was launched (Grant agreement no. 227422). The SWEETFUEL project aims at developing sweet sorghum and biomass sorghum variants for tropical, semi-arid and temperate environments. The focus lies on tolerance to cold, drought and acid soil as well as on a high production of stalk sugars, easily digestible biomass and grains – depending on the environmental region the crop shall be cultivated in and the purpose it shall be used for. This project is split in seven work packages (WPs). WPs 1-5 focus on breeding aspects as well as cultivation and harvest practices. Based on the results of WPs 1-5, WP 6 performs a global assessment while WP 7 transfers project results to the stakeholders.

WP 6 “Integrated sustainability Assessment” of the SWEETFUEL project provides a multi-criteria evaluation of the sorghum production and use pathways taking into account technological, environmental, economic and social aspects. The outcome of the integrated assessment will be a set of optimised, sustainable sorghum production and use systems.

This report is the outcome of Task 6.3 “Economic assessment” as part of WP 6 “Integrated assessment” of the SWEETFUEL project. It was composed by ICRISAT with contributions from all SWEETFUEL partners, namely IFEU,ARC, CIRAD, EMBRAPA, KWS, UANL, UCSC, UNIBO and WIP. Itdelivers results of economic assessment of all sweet sorghum and biomass sorghum scenarios based on definitions and settings outlined in D 6.2 “Report on technological assessment” /Braconnier et al. 2013.

The report on economic assessment provides answers tothe following core question:

- Which are the best ways to produce and use sweet and biomass sorghum for energy from an economic point of view?

- Economic competitiveness of sweet and biomass sorghum as a feedstock for different energy pathways under varying parameters of production,conversion efficiency and output of ethanol / energy. .

To address the above mentioned core questions, the following issues were assessed:

- Cost structure of production, processing and other costs
- Cost of production of ethanol and alternative products from sweet and biomass sorghumby varying values of key parameters
- Influence of different usage pathways from the by-products on the overall results and which usage shall be preferred from an economic point of view?
- Net Cash flows of distillery/industry over a fifteenyears' time period and overall economic assessment

The following sub-chapter of the report defines general specifications and settings and definitions of economic assessment. In Chapter 3, short descriptions of sweet and biomass sorghum scenarios considered under the sweetfuel project are presented. Economic assessment methodology is presented in Chapter 4. The results ofthe economic assessment are described in Chapter 5. The report is concluded in chapter 6, with recommendations and outlook. Chapter 7 lists references and Chapter 8 contains the glossary and abbreviations. In Chapter 9, supplementary material can be found as appendices.

2.1 General specifications, definitions and settings

For the analysis of the investigated scenarios, general definitions and settings are necessary. They are used to assess environmental, economic and social implications and guarantee their consistency. The general settings have been described within the report for task 6.1 (Report on technological assessment) /Braconnier et al. 2013/ and are quoted below.

Definition of sorghum variants

Sorghum is a crop which has quite a large diversity in phenotypic variability and composition. In the SWEETFUEL project the following terminologies are used:

Sweet sorghum: Sorghum cultivars with juicy stems and high juice sugar content in their stalks; potentially used as an energy and / or food crop.

Biomass sorghum: Sorghum cultivars with high lignocellulosic biomass yield, potentially used as energy crop.

Energy sorghum: Sweet and biomass sorghum cultivars used in this project.

Grain sorghum: Sorghum cultivars with high grain yield established as food and feed crop.

Fibre sorghum: Sorghum cultivars with a high content of fibre; potentially used as fibre or energy crop.

This project mainly focuses on sweet and biomass sorghum, whereas grain sorghum is treated as reference system. Fibre sorghum is not investigated in this project.

Time frame

In this project the use of sweet and biomass sorghum for both, 1st generation as well as 2nd generation fuel technologies is assessed. The former, i. e. the production of bioethanol is already well-established. In contrast, second generation technologies such as the production of ethanol from lignocellulose or the biomass gasification for so-called BtL (Biomass-to-Liquid) fuels are not yet commercially available, however, pilot and demonstration plants are operated in some countries (e. g. Europe, USA, Brazil, China, India). In this project prospective conditions given in the year 2020 are considered as main scenario since it is expected that the technology described will be mature then and thus comparable with other 1st generation ethanol production technologies. Additionally, the situation in 2015 is described for some scenarios since this reflects the state of the art at the end of the project which is currently existent in Brazil for instance.

Geographical coverage

Sweet sorghum: In general, sweet sorghum is a manifold plant which can be cultivated in many parts of the world. Due to its high efficiency in water use and light exploitation it is particularly suitable for semi-arid and subtropical areas. Additionally, however, it is also thoroughly suitable for tropical regions. Thus, the following scenarios are defined for sweet sorghum cultivation:

- Subtropical / semi-arid climate with around 700 mm rainfall
- Tropical climate with around 1,200 mm rainfall per year.

Biomass sorghum: In future, biomass sorghum will be mainly cultivated to obtain high biomass yields for biogas production. This requires protruding growing conditions. Coming along with the recent discussion on fuel versus food as well as political regulations, biomass

sorghum has a high potential to be cultivated especially in temperate regions. Thus, for this investigation biomass sorghum scenarios are only settled in those areas.

Within the regions investigated in this project, there might be great differences due to differences in environmental conditions as well as due to varying production practices and conditions in different countries. These differences are captured by sub-scenarios and sensitivity analyses taking into account different yields, uses of the by- products or production costs etc. It is outside the scope of the project to analyse every single country where sweet or biomass sorghum could be produced. However, if country specific conditions have a significant influence on the results, single countries may be chosen to show these dependencies. This might be the case for labour costs or emissions from electricity generation.

Functional unit

The functional unit has to be chosen depending on the questions to be answered. As the project aims at increasing the output of the crop by developing improved cultivars and since land usually is the limiting factor, the use of sorghum cultivars from 1 hectare of land is assessed.

Technical reference

The technical reference describes the technology to be assessed in terms of plant capacity and development status / maturity. As the investigated scenarios cover both, “central” and “decentralised production at village level” two main technical references were defined:

- 25,000 – 120,000 t ethanol per year production capacity in the case of centralised production.
- 3 t syrup per day in the case of decentralised production.
- For all plant capacities, mature, full industrial plants will be assessed.

3 Description of scenarios and sensitivity analyses

This project investigates several sweet and biomass sorghum cultivations and use pathways to determine optimized and sustainable sweet and biomass sorghum production and use systems. The systems under investigation are described in subchapters 3.1 and 3.2. Further details can be found in the report on technological assessment /Braconnier et al. 2013.

3.1 Sweet sorghum scenarios

Generally, sweet sorghum cultivation and use is described in three different scenarios: cane fallow, grain to food and syrup production. In all scenarios the main product is ethanol. However, the scenarios differ with respect to the processing of the sugar juice and the use of the by-products. In the cane fallow and syrup scenarios (see subchapters 3.1.1and 3.1.3) grains are either used as fertiliser, for ethanol production or as feed. In the syrup production scenario the sugar juice in a first processing step is boiled down to syrup which is used to produce ethanol in a proceeding conversion process. The focus of the grain to food scenario (see subchapter 3.1.2) lies on the use of sweet sorghum as multi-purpose crop to limit food / fuel trade-offs. This means that the grains are used as food whereas juice is used for energy production. In the following subchapters all scenarios are described in detail.

3.1.1 Cane fallow scenarios

In this project prospective conditions imaginable for the year 2020 are considered as main cane fallow scenario. Additionally, the situation in 2015 is described since this reflects the state of the art at the end of the project. Both scenarios are almost identical except the use of grains. In 2020, it is expected that the grains of sweet sorghum are used for ethanol production; however, in 2015 grains of sweet sorghum remain on the field, replacing mineral fertiliser.

Cane fallow

An overview of the cane fallow scenariois given in Fig. 3-1. After harvest, the sweet sorghum stalks are transported from the villages to centralised ethanol facilities. The leaves either remain on the field (1 a), replacing mineral fertiliser or are used for energy production together with bagasse to gain enough process energy for converting juice and grains into ethanol (1 b).

In the central ethanol production units, the sweet sorghum stalks are crushed and the juice is pressed out, leaving bagasse. The juice is fermented into ethanol which is used as transport fuel, for blending with conventional gasoline.

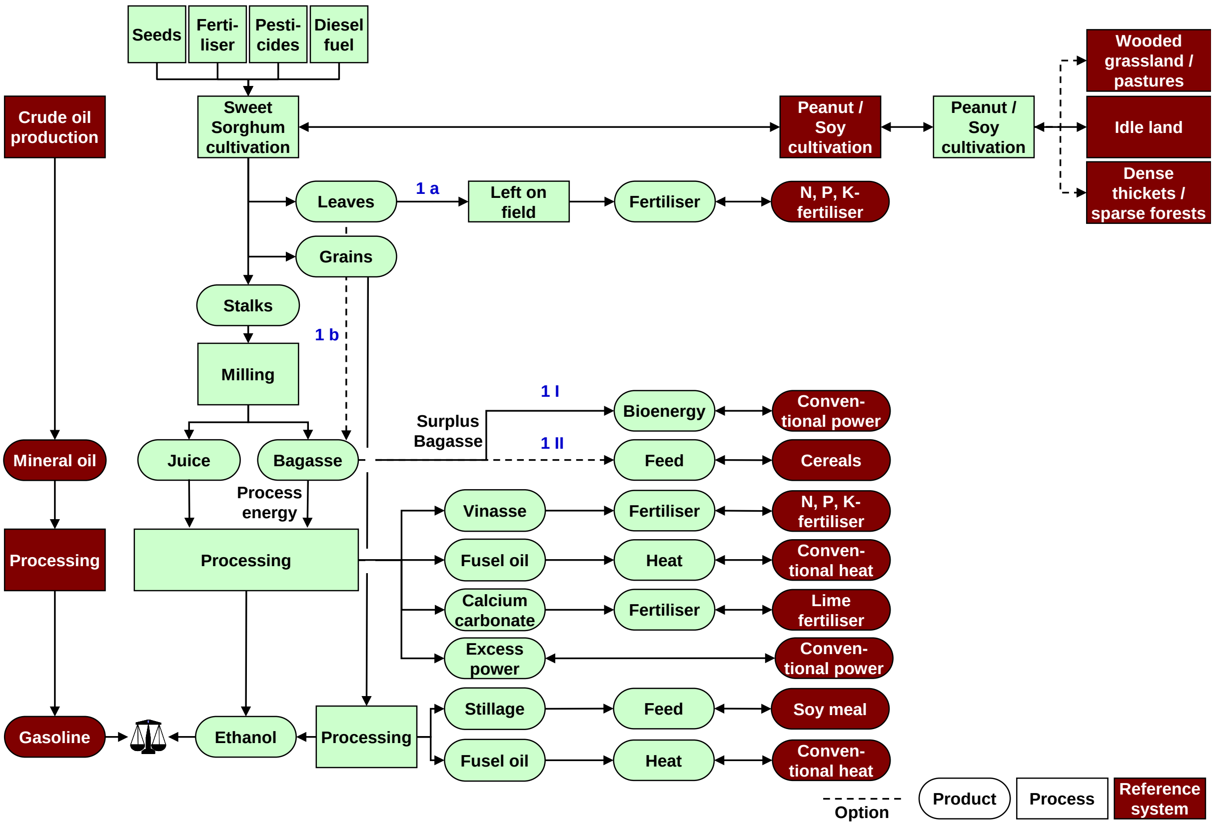


Fig. 3-1 Schematic overview of the cane fallow scenario (scenario 1); numbers indicate scenario numbers (for a summary, see Table 3-1)

From the bagasse process energy is generated which is used internally in the ethanol production process. Surplus bagasse is either used for generating green power that is fed into the power grid, replacing conventionally produced electricity (1 I) or as animal feed, replacing cereals (1 II). In certain regions, bagasse is a very popular animal feed. For example in India, feed traders travel up to 100 km in order to buy the bagasse.

Other by-products derived during ethanol production are vinasse, stillage, excess power, fusel oils and carbonation lime. Vinasse is obtained as by-product if sugar juice is processed and can be used as fertiliser, replacing mineral fertiliser. Stillage is a by-product which occurs if grains are processed to ethanol and can be used as feed, replacing soy meal. Excess power occurs while process energy is generated from the bagasse, replacing conventional power. Fusel oils are converted into heat, replacing conventional heat. For fusel oils, the use in the aroma industry has been indicated as one use option. However, the extraction of fusel oils for a use in industry requires a lot of energy. Up to now, there is no evidence that this is realisable at acceptable efforts and costs. Thus, this option is not analysed within this project. In case of ethanol production from juice, carbonation lime is also derived as a by-product. Carbonation lime is used as fertiliser, replacing lime fertiliser.

Cane fallow 2015

An overview of the cane fallow scenario 2015 is given in Fig. 3-2. Cane fallow 2015 is almost identical to the cane fallow scenario (see subchapter “cane fallow”), except that nowadays sugarcane or forage harvesters are used for harvesting sweet sorghum. This technology works fine for stalks but grains and leaves are cut and left on field, thus a usage of both is not pursued. Consequently, by-products derived from ethanol production out of grains are not considered in the cane fallow 2015 scenario. By-products derived from ethanol production out of juice are identical to those of the cane fallow scenario. Surplus bagasse can either be used for generating green power, replacing conventional power (2 I) or as animal feed, replacing cereals (2 II).

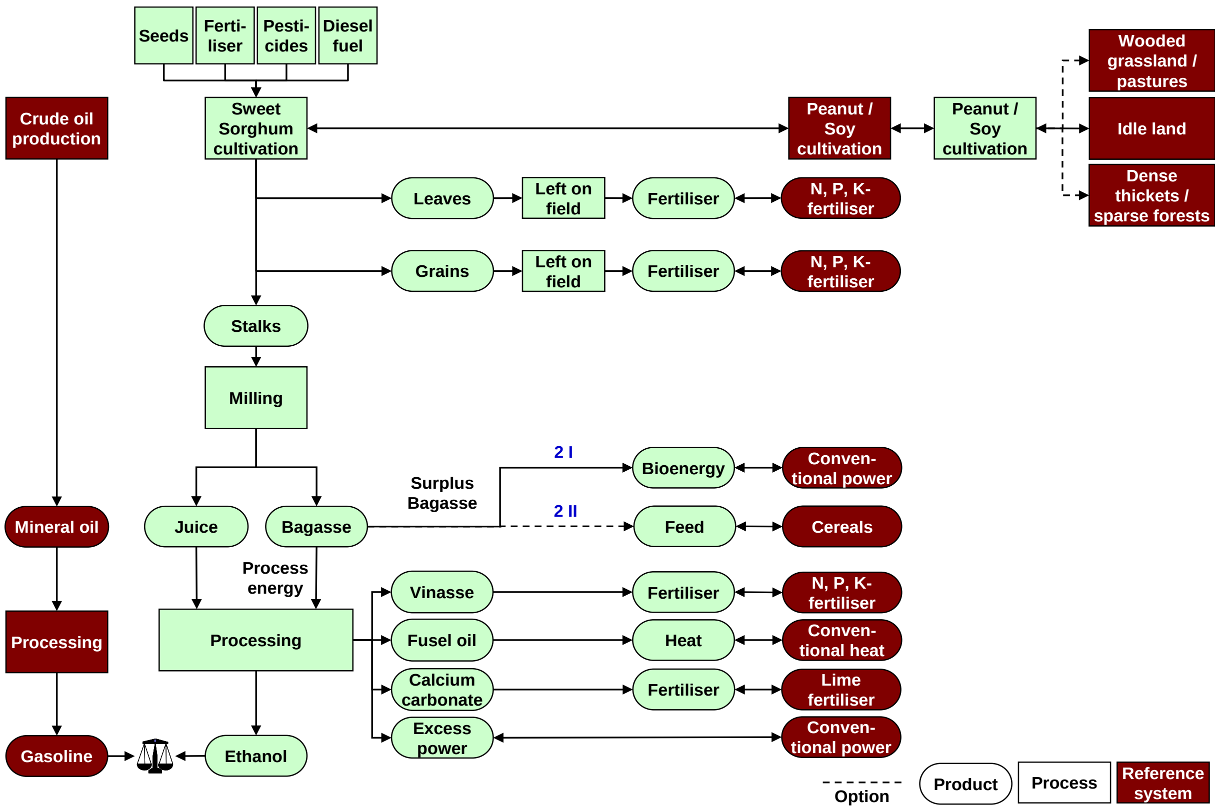


Fig. 3-2 Schematic overview of the cane fallow scenario 2015; numbers indicate scenario umbers (for a summary, see Table 3-1)

3.1.2 Grain to food scenarios

In some regions sweet sorghum might not be grown as intermediate crop but replace grain sorghum cultivation. This has not been current practice so far but is conceivable in the future e. g. in semi-arid regions such as Southern Africa or North-eastern Mexico. We assume that sweet sorghum cultivars grown in those areas produce less grain than grain sorghum. Since the grains of grain sorghum are used in some countries for food and in others for feed, replacing grain sorghum with sweet sorghum might jeopardise food / feed security in those areas (Fig. 3-3**,** “Initial situation”). To further guarantee food / feed security, differences in grain yield need to be balanced by cultivating additional grain sorghum. This requires an additional area which is e. g. in Southern Africa, transformed out of idle land that becomes free due to the intensification of existing land use or that is not used at present (see Fig. 3-3, “Grain to food”). For example: If the grain yield of sweet sorghum is 2.5 t / (ha*year) and of grain sorghum 3 t / (ha*year) an additional area of 0.17 ha is needed to balance the difference of 0.5 t of grain yield (see Fig. 3-3). Some people argue that there are sweet sorghum hybrids which produce more grains than grain sorghum if cultivated on the same ground and under similar cultivation and climate conditions. However, this is far of today’s reality and there is still a lot of research and breeding necessary to be able to use such hybrids commercially. Thus, as it cannot be foreseen whether those breeding efforts can be successful, especially since also grain sorghum can be further developed, this scenario is not considered in this report.

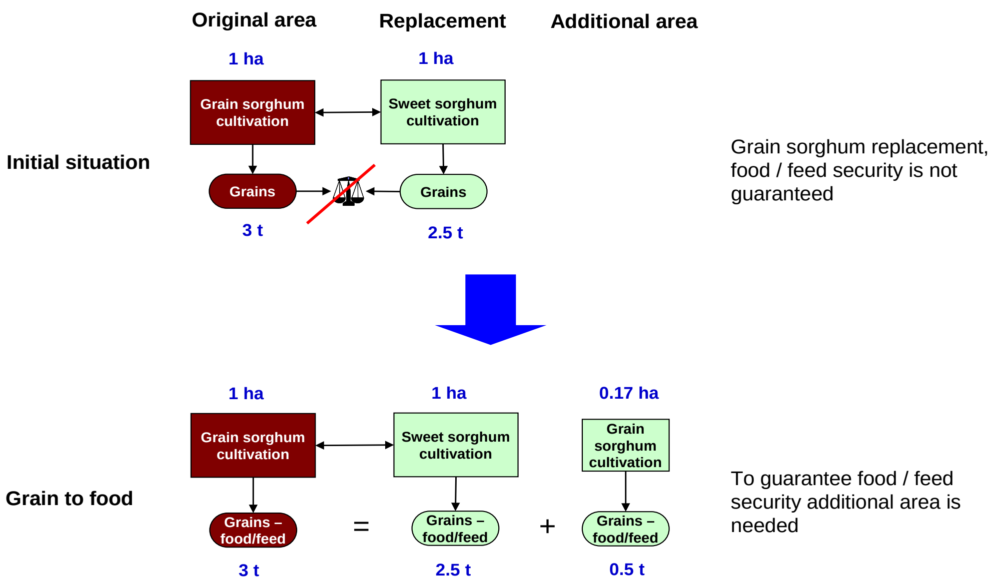


Fig. 3-3 Schematic overview of the grain to food scenario. Blue numbers are examples for illustration, see text

An overview of the grain to food scenariois given in Fig. 3-3.As described above, in this scenario grains of sweet sorghum are used as food to guarantee food security. Leaves are separated during harvest and remain on the field, replacing mineral fertilizer. Since also the use of leaves as animal feed is promoted and might be an option in some regions, also this use is assessed. In this case, cereals are replaced as feed. Stalks are processed in a central ethanol production unit which corresponds to the processing (including all by-products) described in the cane fallow scenario (see Fig. 3-1 and corresponding descriptions).

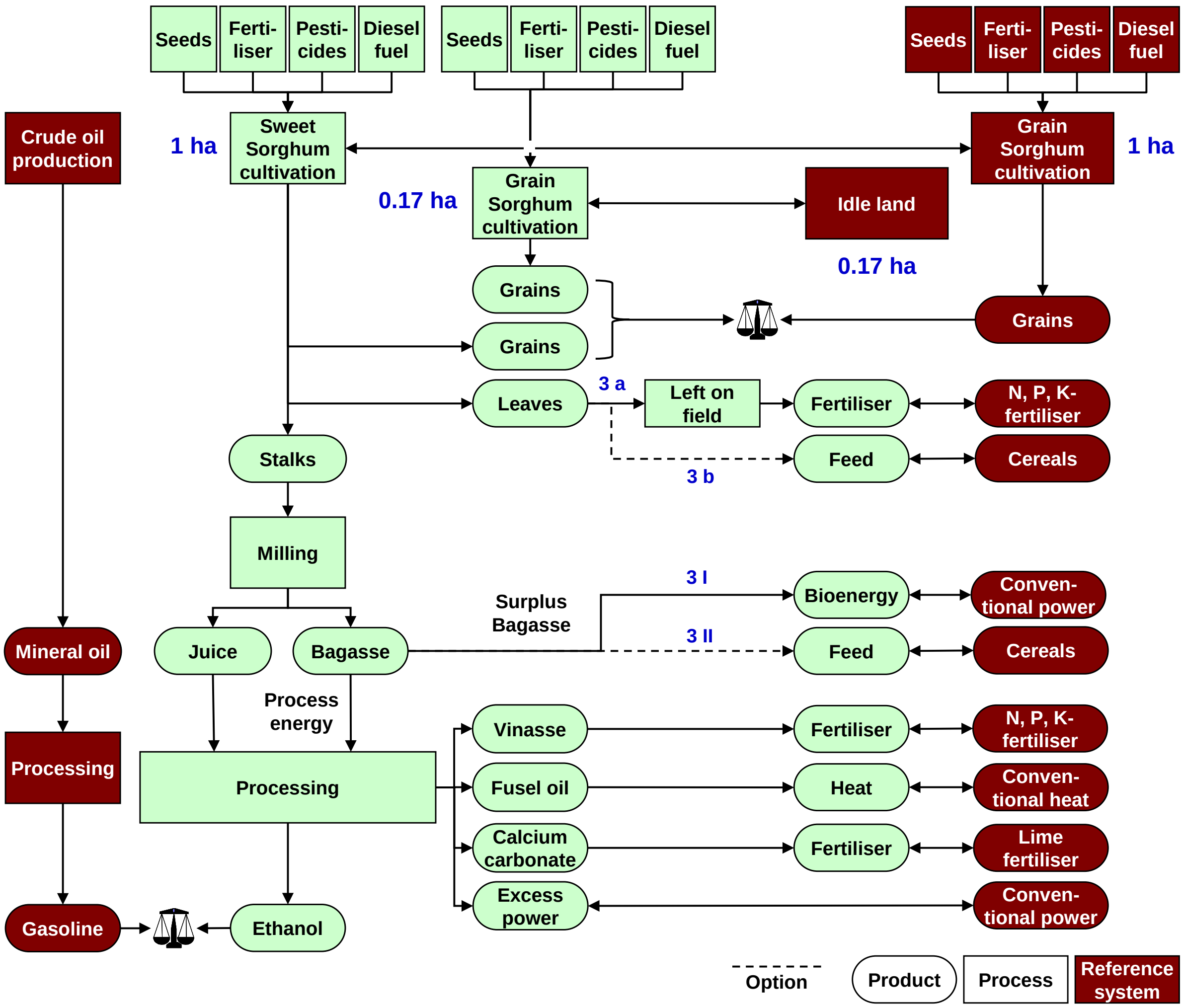


Fig. 3-4 Schematic overview of the grain to food scenario; numbers indicate scenario numbers(for a summary, see Table3-1). Large blue numbers are examples for illustration, see text.

Extra high yield scenarios

Besides semi-arid regions grain sorghum is also cultivated in regions such as Central-western Mexico with conditions preferable for extra high yield. Three land use options are conceivable in those regions as described in the following paragraphs (Fig. 3-5).

Option I

This option is identical to the grain to food scenario described before (see Fig. 3-3 and Fig. 3-4 and corresponding explanations); however regions such as Central-western Mexico are characterised by preferable environmental conditions (e. g. high annual precipitation) which allow high grain yields of about 10 t per hectare per year. Since in those regions sweet sorghum yield might also be higher than in semi-arid regions grain sorghum is here replaced by high-yield sweet sorghum.

However, since there is no idle land in Central-western Mexico anymore, the additional area needs to be recruited in other regions where yields are expected to be lower. For example: If the grain yield of sweet sorghum is 7 t / (ha*year) and of grain sorghum 5 t / (ha*year) an additional area of 0.6 ha is needed to balance the difference of 3 t of grain yield if grain sorghum is cultivated (Fig. 3-3).

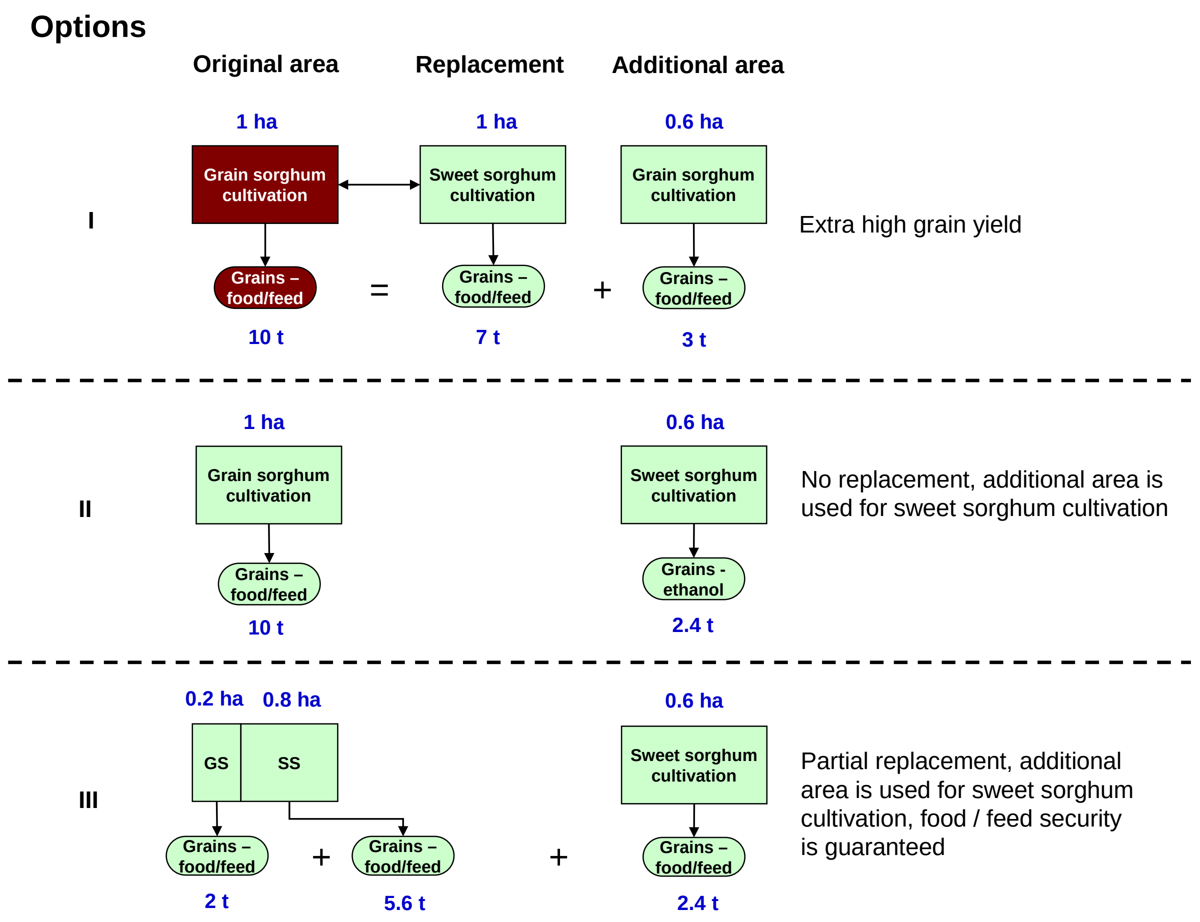


Fig. 3-4 Schematic overview of the two land use options of the extra high scenario.Blue numbers are examples for illustration, see text.

Option II

The same production area as in option I is assumed (Fig. 3-5,option II). Grain sorghum is not replaced and sweet sorghum is only grown on the additional area. Grains of grain sorghum are used as food / feed to guarantee food / feed security, whereas grains and juice of sweet sorghum are processed to ethanol in a central ethanol production unit which corresponds to the processing described in the cane fallow scenario (see Fig. 3-1 and corresponding descriptions). For example: High grain yield of grain sorghum cultivation is about 10 t and grain yield of sweet sorghum cultivation on the additional area is about 2.4 t, if high case sweet sorghum cultivation as described in the grain to food scenario (grain yield: 4 t / (ha*year)) is taken as a basis.

Option III

Another option, assuming again the same production area as in option I, contains a partial replacement of grain sorghum (Fig. 3-5, option III). Thus, sweet sorghum is cultivated on parts of the original grain sorghum cultivation area and on the additional area. The proportion was thereby chosen in the way that grains out of sweet and grain sorghum cultivation still guarantee food / feed security. Thus, grains from grain and sweet sorghum are used as food or feed and the juice of sweet sorghum is processed in a central ethanol production unit which correspond to the processing described in the cane fallow scenario 2015 (see Fig. 3-2 and corresponding descriptions). For example: If grain yield of sweet sorghum which is cultivated on the additional area is about 2.4 t, sweet sorghum can be grown on 0.8 ha (if high yield sweet sorghum as described in option I is taken as a basis) and grain sorghum on 0.2 ha (if extra high yield grain sorghum as described in option I is taken as a basis) of the original area to gain still a grain yield of 10 t in total.

3.1.3 Syrup production scenario

In some cases, infrastructure for biomass transportation to large centralised production units may be insufficient or not existent. Therefore, partially decentralised processing might be another option to grow and use sweet sorghum. Additionally, central ethanol producers often face the difficulty of a rather narrow production window where large amounts of sweet sorghum need to be processed. In such cases the syrup production from sweet sorghum juice might be an advantage. Since the syrup can be stored longer than the sweet sorghum juice, the ethanol production facility can ease production and expand the production window. In this scenario the sweet sorghum stalks are milled at village level and the juice is further processed into syrup which is transported to central ethanol units. The grains are separated be-

fore harvest and used as feed or food, replacing cereals. The leaves are used as feed, replacing cereals. The bagasse which is obtained during stalk milling is used at village level for heat production that is needed to concentrate the juice into syrup. If there is surplus bagasse, it is used as animal feed, replacing cereals. The syrup is transported to a centralised ethanol production unit and it is treated just as the juice in the cane fallow scenario. For the central ethanol unit, external energy carriers need to be used since the bagasse from syrup production is left in the villages. External energy carriers can either be fossil energy carriers such as coal or oil or bagasse that is left over from joined processes.

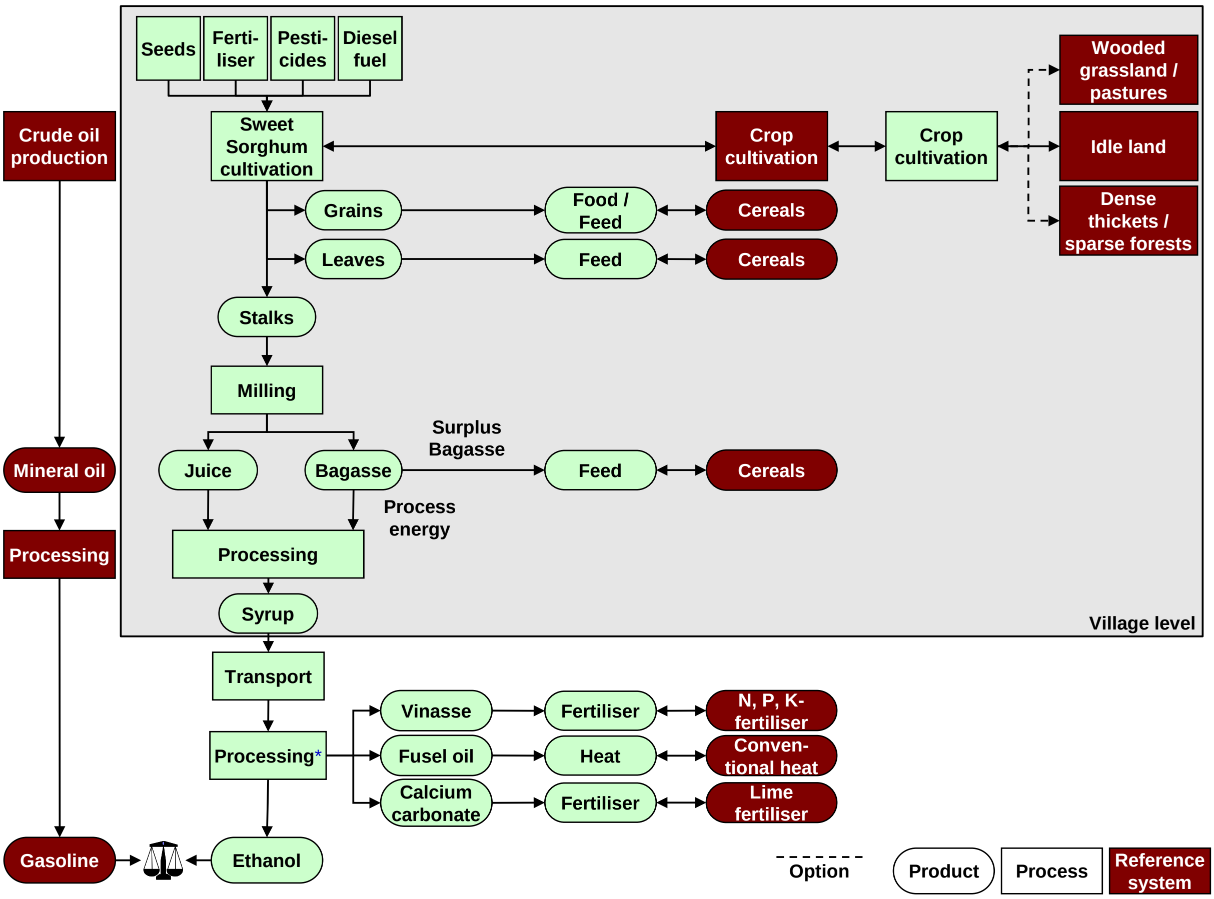


Fig. 3-5 Schematic overview of the syrup production scenario for a decentralised productionnumbers indicate scenario numbers *For the ethanol production unit in the syrup scenario external energy carriers are neededwhichcan either be fossil energy carriers (3 I) or bagasse from joint processes (4 II).

3.1.4 Sensitivity analyses

As already specified in the general settings, sweet sorghum is cultivated in various regions covering multiple climatic conditions and cultivation practices (e. g. the amount of fertiliser as well as harvesting expenditures) which can result in strong variations in yield. The influence

of those yield differences are assessed via sensitivity analyses. Thus, *low, typical and high* case values were defined to cover the bandwidths of such parameters. Since there are also variations in the juice content of stalks and the sugar content of juice, also, low, typical and high datasets were determined to cover a certain bandwidth.

Furthermore, due to various process technologies used in multiple regions different conversion efficiencies may occur. Thus, also for this parameter, low, typical and high datasets were defined to cover a bandwidth of the parameter.

Cane fallow and grain to food scenarios

The typical dataset can be described as follows:

- Average stalk / biomass yield
- Average juice content in stalks and sugar content in juice
- Medium conversion efficiency

For the low dataset of cane fallow and grain to food scenarios, yield variable parameters are set assuming low biomass yields as well as a low juice and sugar content. The conversion efficiency parameter is set in the way that the lowest possible expenditure savings are achieved:

- Low stalk / biomass yield and sugar content
- Low juice content in stalks and sugar content in juice
- Low conversion efficiency

For the high dataset of cane fallow and grain to food scenarios, yield variable parameters are set assuming high biomass yields as well as a high juice and sugar content. The conversion efficiency parameter is set in the way that the highest possible expenditure savings are achieved:

- High stalk / biomass yield and sugar content
- High juice content in stalks and sugar content in juice
- High conversion efficiency

Syrup scenario

For the syrup scenario the same sensitivity analysis are conducted as for the cane fallow and grain to food scenarios. However, in the syrup scenario the extraction efficiency differs, since it is not expected that in a decentralised production system the extraction efficiency is 95 %

as it is assumed for the processing in a centralised production unit. Thus, low, typical and high datasets are defined to assess the influence of extraction efficiency differences in the syrup scenario. Furthermore, in the syrup scenarios, external energy carriers are needed for the ethanol processing in the central ethanol unit since the bagasse from syrup production is left in the villages. Thus, a sensitivity analyses is conducted for different external energy carriers such as coal, oil or bagasse from joint processes. For the economic assessment however, (only one i.e., external power is considered and not coal or bagasse.

Grain sorghum as reference system

Since the yield of grains produced by grain sorghum is also dependent on climate conditions low, typical and high datasets of grain yield were defined for grain sorghum as reference system as well.

3.2 Biomass sorghum scenarios

Besides sweet sorghum, biomass sorghum is also considered as a viable energy option under this project particularly in temperate climatic conditions. Biomass sorghum is cultivated mainly to gain high biomass yields for biogas production besides alternative products whose technologies are still being tested or refined.

The target systems are centralised, mechanised systems in industrialised settings. The focus lies on high biomass yields, whereas sugar content and grain yields are of less importance. Accordingly, the crop is used as a whole. Several options of energy production from biomass sorghum are assessed in order to give a bandwidth on different use options and to include both first and second generation technologies. The main focus is laid on biogas and biomethane production. Alternatively, the combustion of the biomass and the production of fuel is analysed with the focus on second generation technologies. Two options are assessed here: first, second generation ethanol produced from lignocellulose and second, biomass gasification with the synthesis of the gas into diesel.

Biomass sorghum in the temperate climate, e. g. in Germany, is grown analogous to maize used as energy crop. It is mainly cultivated on land which becomes free due to the intensification of existing land use. In other places also idle land can be used to grow biomass sorghum. In the further course of the report all these land use options are referred to as “idle land”. Forest conversion is forbidden in all countries within Europe. Also a conversion of grassland is undesired from a nature protection point of view and forbidden throughout Eu-

rope. Therefore, forest and grassland will not be assessed as agricultural reference systems. Thus, no sensitivity analyses for alternative land use options are conducted.

The yield differences due to multiple climatic conditions in the temperate zone are assessed via sensitivity analyses.

3.2.1 Biogas andbiomethane production

An overview of biogas and biomethane production is given in Fig. 3-7. For the biogas production, the biomass sorghum is chopped and ensilaged after harvest. Subsequently, the silage is fermented into biogas. Biomass sorghum can be fermented together with co-substrates such as manure or corn. However, the main objective is to assess the use of biomass sorghum from a certain area. Therefore, biomass sorghum digestion will be assessed without any co-substrate. The biogas is either used for heat and power (5 I A) or only for power production (5 I B), replacing conventionally produced heat and power or power only, respectively.

Alternatively, the biogas can be further processed into biomethane and used

1. for heat and power production which replaces conventional heat and power (5 II A), or
2. as a transport fuel replacing conventional gasoline (5 II B) and natural gas (5 II C), respectively.

In all processes, digestate is produced as a by-product. It is used as fertiliser replacing mineral fertilisers.

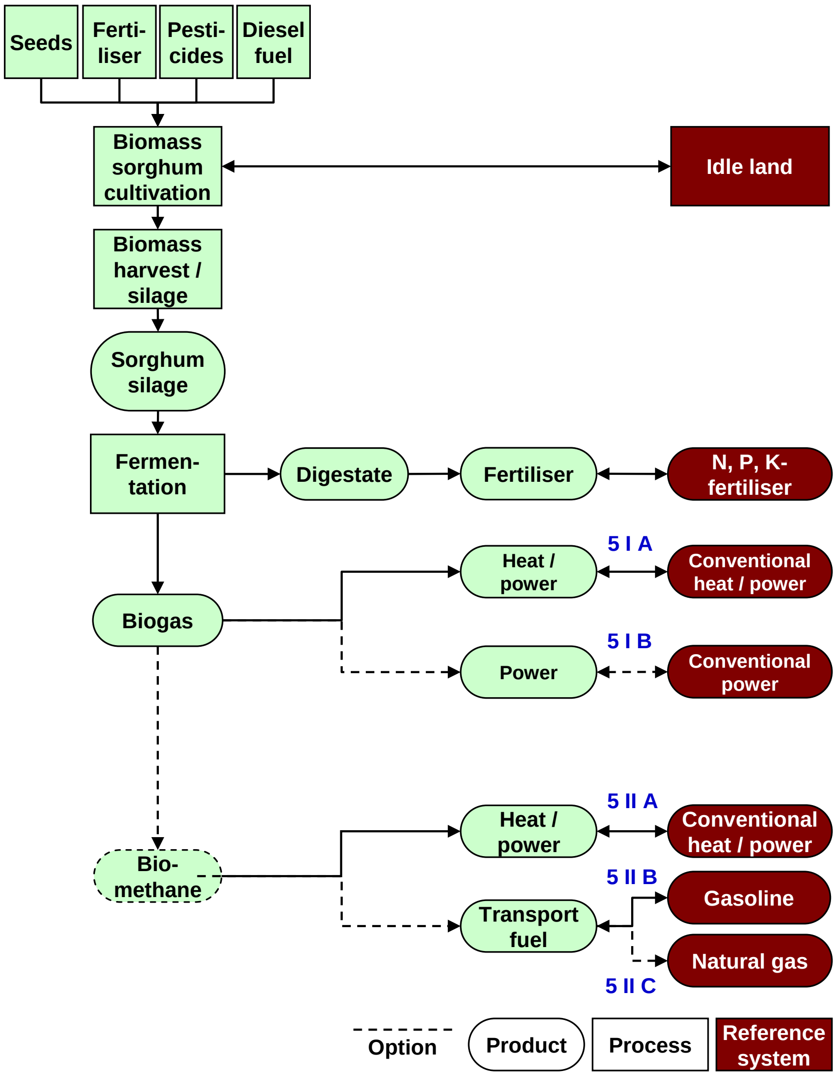


Fig. 3-6 Schematic overview of biogas production from biomass sorghum for the temperate climate; numbers indicate scenario numbers(for a summary, see Table 3-2)

3.2.2 Second generation ethanol

An alternative to the conversion of biomass sorghum into biogas or biomethane is the production of ethanol from the lignocellulose fraction of biomass sorghum (5 a). An overview of this scenario is given in Fig. 3-8. The biomass is harvested and pre-treated in order to render the cellulose and hemicellulose accessible for a subsequent hydrolysis step. After the hydrolysis of the cellulose and hemicellulose for breaking down the long chains into C6 sugars (e. g. glucose) and C5 sugars (e. g. xylose), the substrate is fermented. In order to maximise the efficiency of the overall process, the fermentation of both glucose and xylose is desirable, however fermentation efficiency of C5 sugars still needs to be improved. The ethanol is used as transport fuel, replacing conventional gasoline. Digestate is obtained as by-product and

used as fertiliser, replacing mineral fertiliser. If there is surplus bioenergy from the process, it is fed into the grid and replaces conventional power production.

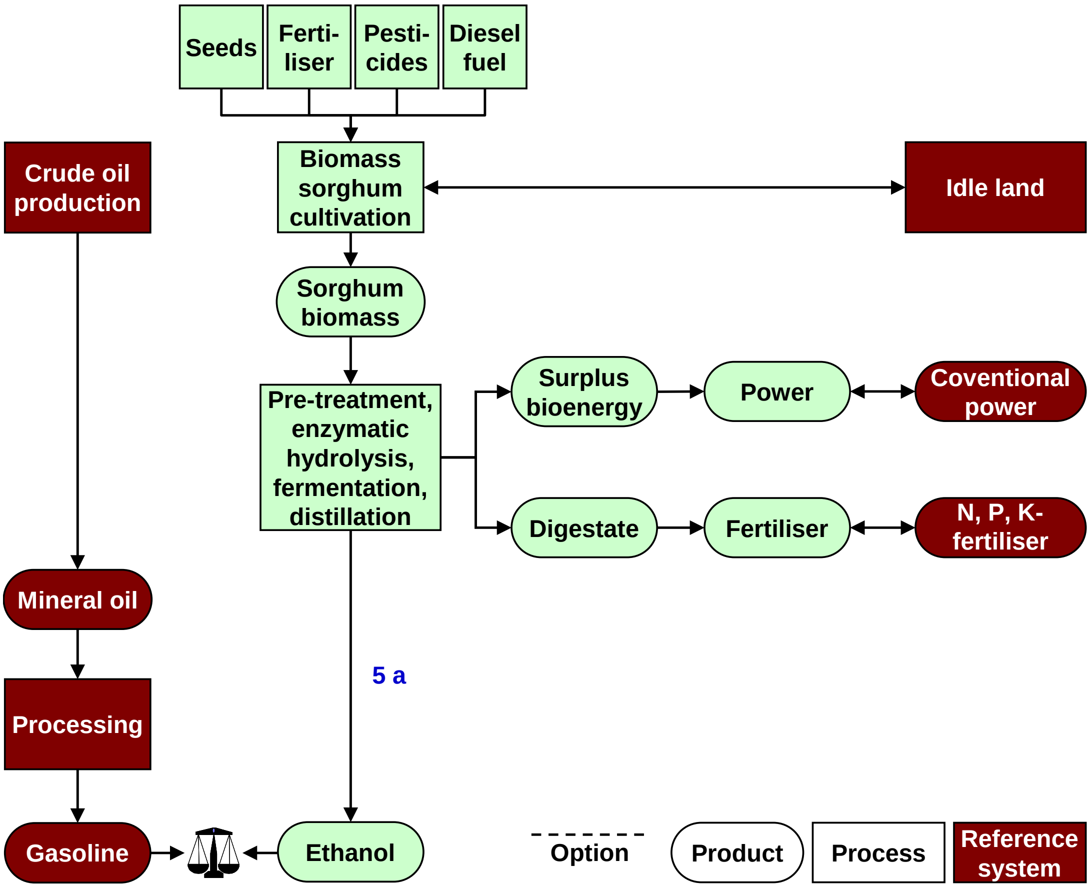


Fig. 3-7 Schematic overview of second generation ethanol production from biomass sorghum lignocellulose for the temperate climate; numbers indicate scenario numbers (for a summary, see Table 3-2)

3.2.3 Direct combustion

Another option to convert biomass sorghum into energy is direct combustion (Fig. 3-9). Since this process requires comparatively dry biomass, direct combustion is especially feasible in the southern regions of Europe such as in the southern part of Spain, Italy or Greece. Here, the stalks remain on the field after harvest for drying. After collection, they can be directly used for combustion in the direct combustion process.

During the combustion process, heat and power are produced that replace conventionally produced heat and power (5 b I). Furthermore, either power or heat could be produced separately. Power production replaces conventional power (5 b II) while heat production either replaces natural gas (5 b III A) or fuel oil (5 b III B).

In all processes ash is produced as by-product which has to be disposed in landfills.

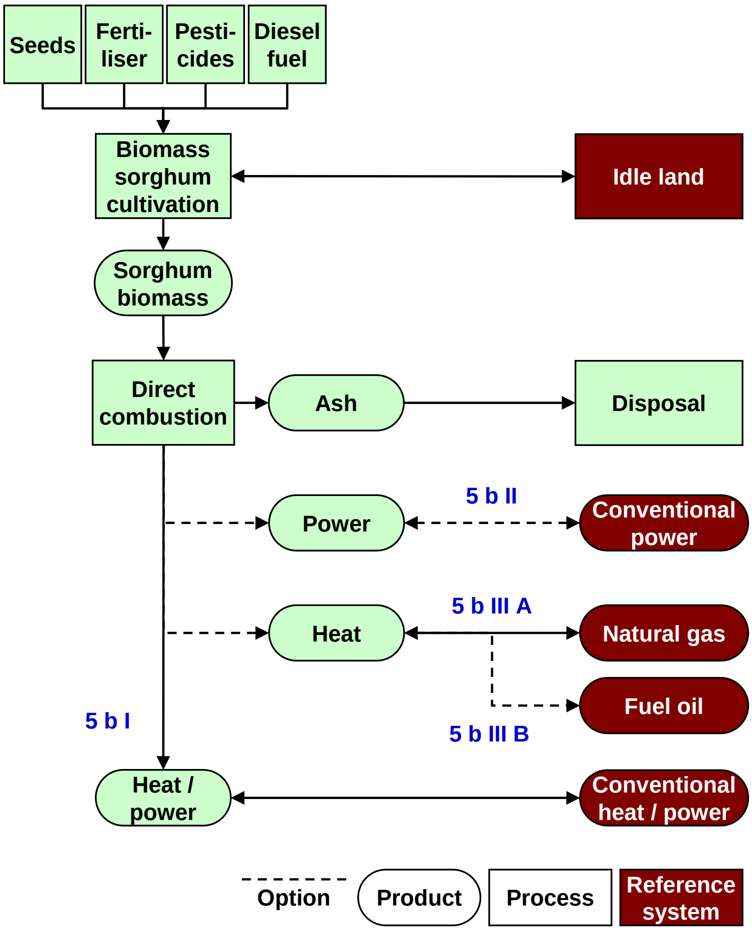


Fig. 3-8 Schematic overview of direct combustion of biomass sorghum for the temperate climate; numbers indicate scenario numbers (for a summary, see Table 3-2)

3.2.4 Gasification

Besides direct combustion, dry biomass is also needed for biomass sorghum gasification (Fig. 3-10).

For biomass gasification, two options are analysed: first the direct gasification (5 c I), second the gasification with a prior pyrolysis of the biomass (5 c II).

For both options, the biomass needs to be comparatively dry as a pre-treatment. Concerning energy supply for drying waste heat from the gasification process can be used in the case of direct gasification. For the pyrolysis, however, external energy supply is needed. As a next step, the biomass or the pyrolysis oil is gasified into a synthesis gas. It is a mixture of hydro-gen and carbon monoxide. After cleaning the gas, it is synthesised into the so-called BtL

(Biomass-to-Liquid) fuels. The standard synthesis is the Fischer-Tropsch synthesis where FT diesel is produced as a main product. If there is surplus bioenergy from the process, it is fed into the grid and replaces conventional energy.

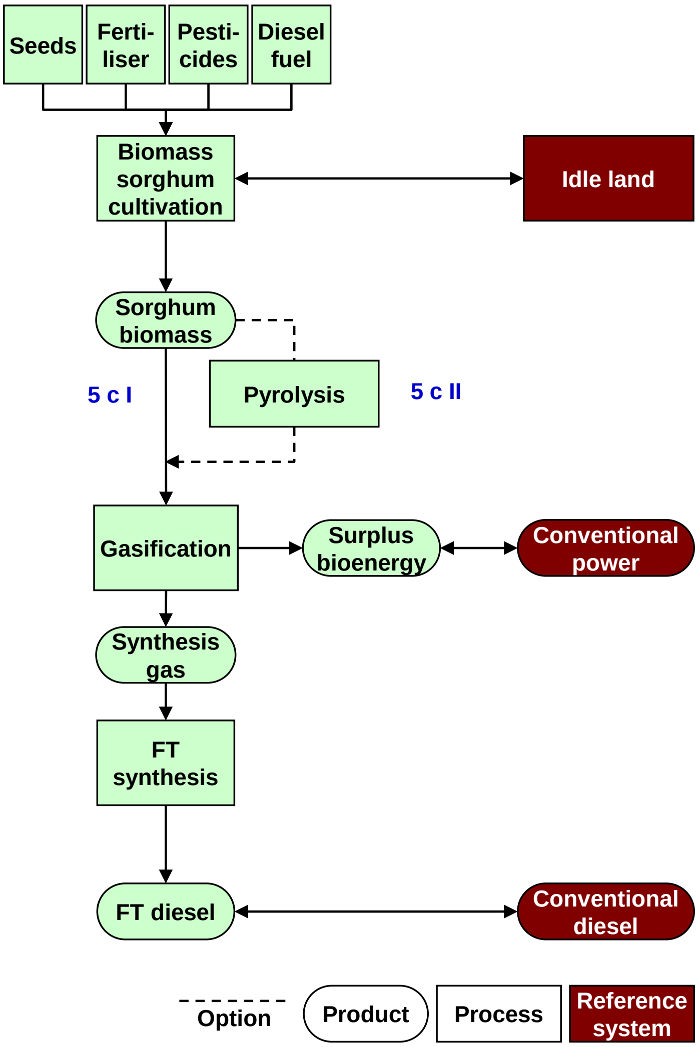


Fig. 3-9 Schematic overview ofFT diesel production from biomass sorghum gasification for the temperate climate; numbers indicate scenario numbers (for a summary, see Table 3-2)

3.2.5 Sensitivity analyses

Similar as for sweet sorghum, biomass sorghum is also cultivated in various regions covering different climate and soil conditions as well as cultivation practices. The influence of those yield differences are assessed via sensitivity analyses. Thus, low, typical and high cases were defined to cover the bandwidths of such parameters.

For the biogas scenarios also different conversion efficiencies and plant sizes (including differences in the storage of the digestate) are considered. Thus, also for this parameter, low, typical and high datasets were defined to cover a certain bandwidth.

Thus, the typical dataset for thebiogas scenarios can be described as follows:

- Average biomass yield
- Medium conversion efficiency

The low dataset of the biogas scenarios contain:

- Low biomass yield
- Low conversion efficiency

The high dataset of the biogas scenarios can be described as follows:

- High biomass yield
- High conversion efficiency

3.3 Summary: scenario overview

Tables 3-1, 3-2 and 3-3 summarise all scenarios under investigation and sensitivity analyses.

Table 3-1 Summary of all sweet sorghum scenarios

	Sweet sorghum				
	Scenario	**Option**	**Use of surplus bagasse**	**Option****	**Use of leaves**
1	**Cane fallow**	**1 I**	Bioenergy	**1 I a**	Fertiliser (left on field)
				1 I b	Together with bagasse
		1 II	Feed	**1 II a**	Fertiliser (left on field)
				1 II b	Together with bagasse
2	**Cane fallow 2015**	**2 I**	Bioenergy		Fertiliser (left on field)
		2 II	Feed		
3	**Grain to food**	**3 I**	Bioenergy	**3 I a**	Fertiliser (left on field)
				3 I b	Feed
		3 II	Feed	**3 II a**	Fertiliser (left on field)
				3 II b	Feed
4	**Syrup**	**4 I***	Feed		Feed
		4 II*	Feed		

* For the ethanol production unit in the syrup scenario external energy carriers are needed which can either be fossil energy carriers (4 I) or bagasse from joint processes (4 II).

** The option numbers listed here are combinations of the alternative use pathways of surplus bagasse and of leaves.

Table 3-2 Summary of all biomass sorghum scenarios

2	**Biomass sorghum**				
	Conversion process	**Option**	**Main product / method**	**Option**	**Use of main product**
5	**Biogas production**	**5 I**	Biogas	**5 I A**	Heat and power
				5 I B	Power
		5 II	Biomethane	**5 II A**	Heat and power
				5 II B	Transport fuel replacing gasoline
				5 II C	Transport fuel replacing natural gas
			Alternatives		
5 a	**LCF-ethanol production**	**5 a**	Ethanol		Transport fuel
5 b	**Direct combustion**	**5 b I**	Heat & power		Heat and power
		5 b II	Power		Power
		5 b III	Heat	**5 b III A**	Natural gas
				5 b III B	Fuel oil
5 c	**Gasification**	**5 c I**	Direct gasification		FT diesel
		5 c II	Gasification with prior pyrolysis		FT diesel

* The option numbers listed here are combinations of the alternative methods of biomass conversion and of the use pathways of the main product.

Table 3-3 Summary of all sensitivity analyses for sweet and biomass sorghum scenarios

Sensitivity analyses		
	Varied parameters	**Scenarios**
Cultivation*	Yield, fertilisers, diesel consumption	Sweet sorghum scenarios, biomass sorghum scenarios, grain sorghum reference scenario
	Juice content, sugar content	Sweet sorghum scenarios
	Juice extraction efficiency	Syrup scenario
Conversion	Conversion efficiency*	Sweet sorghum scenarios, biogas scenarios, direct combustion scenario
	External energy carriers	Syrup scenario
Digestate storage*	Cover	Biogas scenarios
Land use	Alternative land use	Cane fallow, syrup production, grain to food scenarios

* Bandwidth of these parameters is covered by low, typical and high datasets.

4 Methodology

4.1 Economic assessment

In the following paragraphs the system boundaries for economic assessment are presented in section4.1.1 andorigin of the data is considered in 4.1.2. A general introduction on the methodology of economic assessment and conceptual framework is described in sub-chapter 4.2. All other aspects related to economic assessment are presented in sections 4.2.1 to 4.2.9.

4.1.1 System boundaries

The economic assessment for this project covers the entire value chain from feedstock production to the distribution and usage of the final products and byproducts (Figure 4.1). Further description of the various scenarios using sweet and biomass sorghum are already described and presented in Chapter 3.

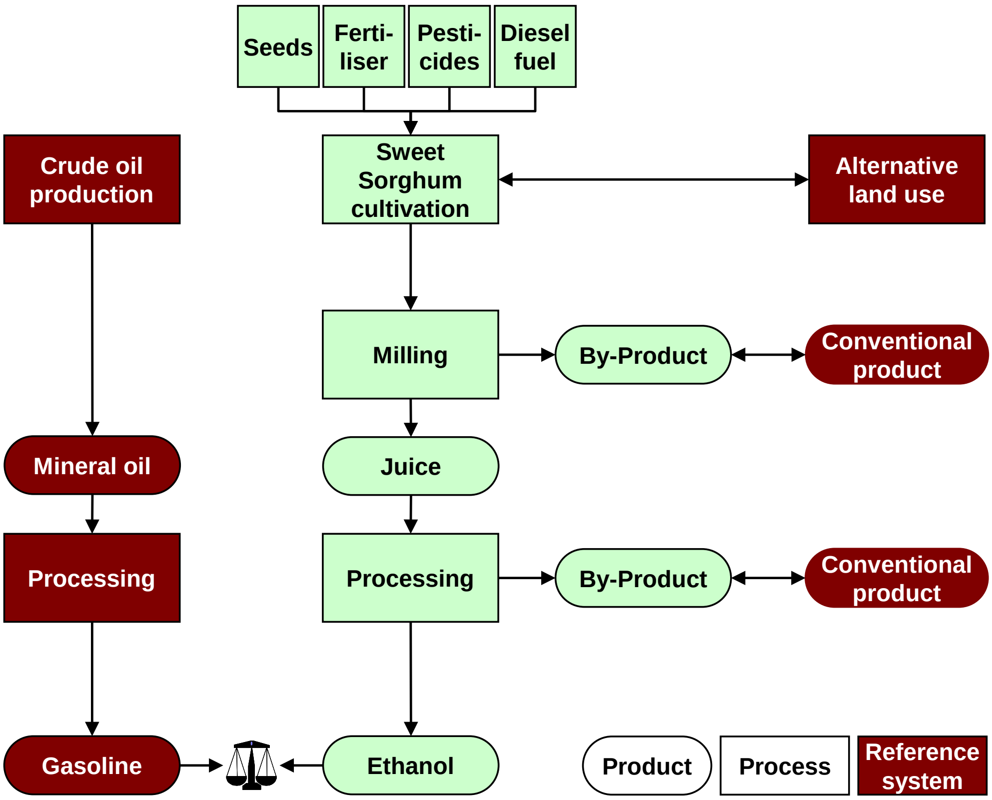


Fig. 4-1 System boundaries for economic assessment of ethanol from sweet sorghum

4.1.2 Data origin and data quality

Since Sweet sorghum is cultivated in many different regions, for the SWEETFUEL project a multitude of data and information with respect to agricultural production and reference systems are needed. There was no generic data format concerning economic assessment. Data requirement are strongly dependent on the goal and scope of the study, and the cost differences are the main concern rather than absolute figures. Concerning the cultivation of sweet sorghum across geographical reference systems, data on production of sweet and biomass sorghum for the study is obtained from WP 5 compiled across geographical settings and is used for economic assessment. Data has been compiled for all the sweet sorghum and biomass sorghum scenarios as described in Chapter 3.The price data for inputs utilized in production of sweet and biomass sorghum and conversion is described in sub-chapter 4.2.3

4.2 Methodology of Economic assessment

Within this sub-chapter, primarily the dimensions of costing are examined. Each of the dimensions indicated will address to a set of questions that may arise when one is involved in data collection & compilation, estimating the costs, inclusion & exclusion of cost categories, how the costs are modelled and how the costsare aggregated. The analysis also demonstrateswhich cost categories, co-products and energy pricing have the greatest impact on economic viability.

4.2.1 Conceptual framework for economic assessment

The conceptual framework of economic assessment is based on the life cycle discerning production, processing, use and maintenance costs. A steady state cost model (meaning all technologies remain constant in time) is employed in the current study and thus it cannot be used to model the dynamic effect in the real markets. The cost model assumed is linear homogeneous or homogeneous to degree 1 implying that as inputsare doubled the output is also doubled. The present study concerns the comparison of production of the end products (as described in sweet and biomass sorghum scenarios) on one hectare of land.

4.2.2 Cost categories

Four levels of cost categories are distinguished in the current study for all the sweet and biomass sorghum scenarios to conduct economic assessment. These include;

a. Production costs of sweet sorghum and biomass sorghum which include all production activities starting with land preparation till harvest.

b. Transport cost which includes cost of transporting sweet sorghum and biomass sorghum to the centralized ethanol processing units.

c. Processing costs which include cost of converting sweet and biomass sorghum to different use pathways

d. Cost of acquisition, operations and maintenance

An overview of the above mentioned cost categories along with units are described in Table 4.2.1. The costs include for all the generic sweet and biomass scenarios and does not distinguish based on use pathways.

Table 4.2.1. Overview of cost categories

Cost category	**Cost type with units**
Production cost	Seed cost (Kg/ha/year) Fertilizer cost (Kg/ha/year) Pesticide cost (Kg/ha/year) Diesel cost for field preparation, sowing, fertilizing, spraying and harvesting (liters/ ha/year)
Transport cost	Diesel cost (liters/ ha/year)
Processing cost	Yeast (gram/litre of ethanol) CaO (Kg/ha/year) H2SO4 (Kg/ha/year) NH3 (Kg/ha/year) Enzymes (gram/litre of ethanol) NH3 (Kg/ha/year) Chemicals for water treatment (Kg/ha/year) Power (kWh / (ha/year)
Acquisition, operation and maintenance	Capital costs of machinery (euros) Rent (euros) Personnel costs (euros/day) Interest cost on investment (loan) and working capital (%) Depreciation costs (euros)

4.2.3 Cost and Revenue estimation

Cost estimation implies an assessment of the value or price something has (Huppes et al, 2008). A parametric type of cost estimation (cost per unit[1]) is used in the current study. The costs per complete process (either production or processing) of the reference flows (sweet and biomass sorghum scenarios) have been calculated by multiplying the costs per reference unit with the absolute amount of inputs required for the process output.

In case of capital costs on machinery/equipment, interest cost on investment and working capital, depreciation and personnel costs (wages and salary), the information is gathered from available literature wherever relevant for cost estimation . These costs are then scaled to match the production output required for each standardised processing plant. The revenues derived from the co-products for each of the sweet and biomass sorghum scenarios described are subtracted in the total cost of producing the process outputs.

For cost estimation, the world average price of inputs used to generate outputs of sweet and biomass sorghum are obtained from "pink sheets" of world bank and FAO statisticsand relevent websites(www.alibaba.com, www.amazon.com). In case of non-availability of information, prices for inputs are obtained from literature.

4.2.4 Geographical differences and Exchange Rates

The inputs used to generate outputs of sweet and biomass sorghum differ based on geographical reference considered. For example, inputs for production and processing of sweet sorghum to ethanol under cane fallows are obtained under Brazilian conditions as geographical reference. Due to these geographical differences, world average prices **(in dollars)** obtained from "pink sheets" of World Bank, FAO statistics and relevent websites(www.alibaba.com, www.amazon.com) for the inputs used are converted to **Euros** at 2012 exchange rates. The data on absolute quantities of input used were compiled for the year 2012 by WP5. Hence, 2012 is used as reference year for exchange rate conversion from dollars to euros and cost estimation.

[1]In this study hectare is used as unit for production cost and for other cost categories unit of measurement are described in table 1.

4.2.5 Cost aggregation

To aggregate costs over the different phases of the life cycle of sweet and biomass sorghum for different use pathways, the steps involved were;

1. Identification of the subsystems that could result in different cost and revenues
2. Assignment of costs or prices to the respective subsystems identified in step 1
3. Calculation of costs per unit of subsystem by multiplying the cost per reference unit with the absolute quantities of the process outputs
4. Aggregation of all the costs and prices of all the subsystems over the complete life cycle.

This stepwise calculation allows one to provide costs for certain cost categories (production, processing, co-products) and costs over a certain period of time.

4.2.6 Discounting

Discounting in the present study is applied for two reasons. To understand whether profit can be made from the technology choice of sweet and biomass sorghums for different use pathways and the other to deal with cost of borrowings. Typically, the discount rate for private investments is between 5% and 20%, to be decided by the private decision maker (Huppes et al, 2008). For long-term projects in the public sector, the discount rates can be as low as 2%.

In the study, discounting wherever relevant is integrated into the calculations. The discount rates for different installations vary based on how they depreciate. For example, much of the major equipment installation has a useful life of 15 years and would be depreciated at 10% per annum. Hence, instead of computing separately for each of the investment processes (example capital equipment, plant, building) estimates available from Asia Pacific Economic Cooperation (APEC,) Energy Working Group reports 2010 which have similar product outflows were used for analysis wherever relevant. .

4.2.7 Uncertainty in cost data and sensitivity analysis

As already specified in the general settings, sweet sorghum is cultivated in various regions covering multiple climatic conditions and cultivation practices (e. g. the amount of fertiliser as well as harvesting expenditures) which can result in strong variations in yield. The influence of those yield differences are assessed via sensitivity analyses. Thus, low, typical and high case values were defined to cover the bandwidths of such parameters.

Furthermore, due to various process technologies used in multiple regions different conversion efficiencies may occur. Thus, also for this parameter, low, typical and high datasets were defined to cover a bandwidth of the parameter.
Additionally, inconsistencies in the costs used in the economic assesemnet can relate to the definition of the cost, collection methods, costing method and type, cost considerations, geographical differences, exchange rates, among others. To overcome such uncertainties, data on absolute quantities used in the process were defined for low, typical and high cases. Accordingly, the results are presented for low, typical and high cases for each of the use pathwaysof sweet and biomass sorghum.

4.2.8 Capital and Operational cost and assumptions for economic assessment

The cost model used for economic assessment takes into account indicators of commercial viability viz., Net variable cost, NPV (Net Present Value) & IRR (Internal Rate of Return) (for definition of the terms used see Appendix 9.1). Most of the assumptions on finacing (site development costs, procurement & construction costs, equity and debt capital and crushing capacity) for this study are directly taken from APEC report,2010 andinvestment costs for use of biomass sorghum to biogas and biomethane (typical for European conditions)wereprovided by KWS (a plant breeding company in Germany named after Kleinwanzlebener Saatzucht) partner in sweetfuel project. Operational expenditure (OPEX) is arrived at taking all cost on per litre basis and scaling it up using plant capacity. The financial analysis further assumes an amortiztion period of 15 years. It is generally found that both processing and labour costs have greater impact on scale economies of the plant.. Hence, sensitivity analysis is carried out by assuming 10 and 15 per cent decline in processing and labour cost for typical and high scenarios respectively. Further, the interest costs, rent, other payment on working capital are assumed to remain constant as the scale increases. A nominal interest rate of 10% is assumed for financial analysis in all the scenarios.

Table 4.2.2. Value of capital and operational expenditure for economic assessment for different scenarios

Scenario	CAPEX (Capital expenditure)	OPEX(Operational expenditure) (million euros)	Crushing Capacity
	(million euros)	Low scenario	(million tonne per annum)
Sweet sorghum Juice to Ethanol	57.53	82.10	1 million tonne of stalk
Sweet sorghum Juice+ Grain to Ethanol	57.53	89.43	1 million tonne stalk+ 0.1 million ton of grain
Grain to food Scenario	57.53	83.79	1 million tonne of stalk
Sweet sorghum Syrup to Ethanol	57.53	88.17	1 million tonne stalk
Biomass sorghum to Biogas	2.00	0.75	11500 tonne biomass
Biomass sorghum 2nd Gen. Ethanol	112.22	1413.14	0.5 million tonne
Biomass sorghum FT diesel	56.19	210.77	1 million tonne

source: APEC Report, 2010 and KWS, Germany

4.2.9 Systematic exclusions in the study foreconomic assessment

Though a life cycle frame work is used in the present study for economic assessment, it does not take into consideration certain of the costs in life cycle phase due to; non availability of data in some cases and in others due to complexities involved in their calculations and linearity assumption of cost model as in the present study.

The costs not considered in the assessment include;

a. Research and development costs
b. Transfer payments (subsidies)
c. External costs (Taxes and tariffs)
d. Externality costs
e. End of life costs/disposal cost and
f. Profit margin

5 Results: Economic assessment

In the following subchapters, the results of the economic assessment of the sweetsorghum and biomass sorghum scenarios are presented. Subchapter 5.1focuseson sweet sorghum scenarios, subchapter 5.2 on biomass sorghum: biogas and bio-methane andscenario 5.3 on biomass sorghum to alternative products: 2nd generation ethanol and FT diesel.

5.1 Sweet sorghum scenarios

In this subchapter an overview of the economic influence of the sweet sorghum scenarios i.e., cane fallow2015, cane fallow 2020, grain to food and syrup production at village level are discussed. For description of all scenarios under sweet sorghum see subchapter 3.1and sub-sub chapters under it. As described in the methodology section, the economic assessment looks at net variable cost (after allowing credits for by-products)for producing one unit of the product followed by economic feasibility analysis taking the capital cost of production unitand operational expenses per annum. A life span of fifteen years for the production unit is assumed. Break even prices of the end product are worked out, i.e., the price at which the unit would break even meeting its operational and fixed expenditure.

5.1.1 Cane fallow scenarios 2015 and 2020

In this subchapter, the results of the cane fallow scenarios are presented. These include cane fallow 2015, cane fallow 2020. For a detailed scenario description see subchapter 3.1.1 and Figures 3.1 and 3.2.

Production costs of producing sweet sorghum, processing costs and by-product values following processing to ethanol are calculated on a per hectare basis. Using the conversion factor of sweet sorghum stalk to ethanol on per hectare basis,variable costs per liter of ethanol are calculated (for details see appendix table 9.2.1.1 and 9.2.1.2). For our purposes net variable costs are considered where by-productvalues are given credits and deducted from total variable cost. The pathway considered here is use of surplus bagasse for generation of electricity. Under this pathway net variable cost is highest (0.63 euro / liter) for the cane fallow 2015 (scenario 1)where only the stalk is crushed for ethanol. However, the cost declines as we move from low to typical and high cases. It is only 0.35 in the high case implying a

significant decline with costs that are less than with the world prices of ethanol at 0.49 euro / liter (Table 5.1.1).

Under the cane fallow 2020 scenario where grain is also crushed for ethanol there is a dramatic fall in the net variable cost which is only 0.42 under the low case. This further reduces to 0.24 in the high case. It is 0.26 under typical case. Thus, under this scenario where both grain and stalk are used for processing to ethanol the costs are economically viable under the typical and high cases. The decline in variable cost as we move from low to high scenarios is mainly due to decline in feedstock costs due to higher stalk yields(see table 5.1.1 and appendix table 9.2.1.2).

Fertilizer costs account for a major share of sweet sorghum feed stock cost followed by seed and tractor costs (Figure 5.1.1). For processing costs CaO accounts for bulk of the cost followed by H_2SO_4 (Figure 5.1.3).

Variable costs were also worked out for different use pathways of the by-products, i.e., use of surplus bagasse for feed. Results indicate that there is a significant increase in the variable cost under the low case when surplus bagasse is used for feed under both the cane fallow 2015 and 2020 scenarios(for e.g. 0.78 Euro/liter under cane fallow 2015 and 0.51 under cane fallow 2020 scenarios).However in the typical and high cases the decline is much less due to reduction in the availability of surplus bagasse (Table 5.1.2). Thus among the two usage pathways for surplus bagasse its use to generate electricity is more economical than its use for feed.

As indicated the value of by-product from processing stalk and stalk+grain to ethanol are treated as credits and their value subtracted from the variable cost of ethanol production. From Table 5.1.3 we find that electricity from surplus bagasse, calcium carbonate excess power account for a major share of by-product value per hectare followed by vinasse under both the scenarios i.e., stalk to ethanol and stalk+ grain to ethanol. Under stalk+grain to ethanol stillage is obtained as additional by-product from grain that is used for animal feed. Sensitivity analysis across cases indicates that the values of the by-products / ha increase as we move from low to high case since larger quantities of ethanol are produced under high case compared to low case except electricity from surplus bagasse whose value declines since not much surplus bagasse is left as we move to the high case. Under the use pathway where surplus bagasse is used as feed the values of feed as by-product are significantly lower than those for generating electricity (Table 5.1.4).

The capital expenditure cost (CAPEX) of ethanol plant using sweet sorghum with crushing capacity of 1 million tonne of stalk per annum and operational expenditure (OPEX) are

shown in Table 5.1.5. In the same table the operational expenditure for a plant using both 1 million tonne stalk and 0.1 million tonne grain for ethanol production are given.

A break up of the operational expenditure into its different cost items indicates that feed stock cost accounts for bulk of the cost under the typical case,followed by processing cost. Labor cost and other working capital costs are next most important operational costs (Figure 5.1.4 and 5.1.5). The total cost per tonne of ethanol is given in Table 5.1.6. Under the typical scenario the cost works out to 649 euro / tonne for stalk to ethanol and 422 euros/ tonne under stalk +grain scenario. As expected the cost declines quite significantly as we move from low to typical to high cases. .

Economic assessment indicates that under the stalk to ethanol scenario (2015) net present value of cash flow from production and sale of ethanol is negative in the low and typical case. and becomes positive only under the high case (Table 5.1.7). The break-even price where the NPV would be zero is 0.86 euro / liter under the low case and 0.59 euro / liter under the typical case which are higher than the world market prices of ethanol. For the scenario with stalk + grain to ethanol (2020) the NPV is negative under the low case but becomes positive under the typical and high cases with 70% and 148% internal rates of return (IRR). The break-even price under the low case is 0.0.61euro / liter and as expected the break-even price is below world market price of ethanol under the typical and high cases.

Under the use pathway where surplus bagasse is used as feed the economic assessment results are not different except that the negative NPV's are larger than when surplus bagasse is used for electricity generation. Similarly the positive NPVs and IRR are lower under this use pathway (Table 5.1.8).

5.1.2. Grain to food scenarios

In this subchapter, the results of the grain to food scenario is described. For a detailed scenario description see subchapter 3.1.2

Under the grain to food scenario the variable cost net of by-product credits is highest (0.42 euro / liter) under the low case. The cost further declines as we move from low to typical and high cases. It is only 0.14 in the high case implying a significantdecline (Table 5.1.1) and highly economical cost of production.

Variable costs were also worked out for different use pathways of the by-products i.e., use of surplus bagasse for feed. The Results indicate that use of surplus bagasse for feed does not make any significant difference on variable cost for ethanol productionexcept under the low

case where the costs increase to 0.58 euro / liter compared to 0.42, where surplus bagasse is used to generate electricity (Table 5.1.2).

Regarding value of by-product from Table 5.1.4,we find that the use of grain as food has the highest value among the by –products and this increases significantly as we move from low to high case. Electricity from surplus bagasse, excess power and calcium carbonate are other important by–products but dwarfed by the value of grain.

Under the use pathway where surplus bagasse is used as feed the values of feed are significantly lower than those for generating electricity (Table 5.1.4).

The capital cost (CAPEX) of ethanol plant using sweet sorghum with crushing capacity of 1 million tonne of stalk per annum and 0.1 million tonne of grain and the operational expenditure cost (OPEX) are shown in Table 5.1.5.

Break up of operational costs indicate that feed stock cost accounts for bulk of the cost under the typical case. Processing cost is the next most important cost followed by labor cost and other working capital costs(Figure 5.1.6). The cost per tonne of ethanol is 688 under the low case Table 5.1.6. However, the cost declines very significantly under the typical case.

For the scenario with grain to food the NPV is negative under the low case but becomes positive under the typical and high cases with 67% and 120%internal rates of return (IRR) (Table 5.1.7). The NPV and internal rates of return are marginally lower than those obtained under the stalk + grain to ethanol scenario.

Under the use path way where surplus bagasse is used for feed the positive IRR under typical and high cases is lower implyinglower returns under this use path way(Table 5.1.8).

5.1.3. Syrup production scenario

In this subchapter, the results of the syrup production scenario are described. For a detailed scenario description see subchapter 3.1.3

Under the syrup scenario the variable cost net of by-product credits is highest (1.19 euro / liter) under the low case. The cost however, declines as we move from low to typical and high cases. It is 0.59 in the high case which is still above the world market prices of ethanol (Table 5.1.2).

Regarding value of by–product from Table 5.1.4 we find that the use of grain as food has the highest value among the by–products and this increases significantly as we move from low to high case. Calcium carbonate, vinasse and use of surplus bagasse as feed are other by–products whose values however are small in comparison to grain value.

The capital expenditure cost (CAPEX) of ethanol plant using sweet sorghum with crushing capacity of 1 million tonne of stalk per annum and the operational expenditure cost (OPEX) are shown in Table 5.1.5. It is more or less similar to the plant where stalks are crushed for ethanol.

Break up of operational costs like for other scenarios indicate that feed stock cost accounts for bulk of the cost under the typical case. Processing cost, Labor cost and other working capital costs are next most important operational costs (Figure 5.1.7). The cost per tonne of ethanol is higher under this scenario than those from other scenarios. For example, it is 850 under the typical case under this scenario compared to 649 under the stalk to ethanol scenario implying higher costs involved in syrup production and its subsequent conversion to ethanol (Table 5.1.6).The non-viability of ethanol from syrup is due to higher production cost of syrup at village level which is 58% of total processing cost. This could be because the village level processing to syrup is not on commercial lines. As expected the cost declines as we move from low to high scenarios although the costs under these cases are still relatively higher than for those from other scenarios and still economically unviable.

Thus, for the syrup scenario the NPV is negative under all cases. The break-even price works out to 1.43 under the low case and 0.77 and 0.63 under the typical and high cases (Table 5.1.8). Clearly the syrup scenario is not economical under all cases.

Table 5.1.1 Summary of Variable Cost for Sweet Sorghum to ethanol Scenarios (Production and Processing)

Cases/ Scenarios	Output	Variable Cost (€/liter)		
		Low	Typical	High
Cane Fallow: Stalk (Scenario 1)	Ethanol	0.63	0.44	0.35
Cane Fallow: stalk + Grains (2020)	Ethanol	0.42	0.26	0.24
Grain to food (Scenario 3)	Ethanol	0.42	0.22	0.14

Note: World ethanol price 0.49€/liter (2012)

Table 5.1.2 Summary of Variable Cost for Sweet Sorghum to ethanol Scenarios (Production and Processing), surplus bagasse for feed

Cases/ Scenarios	Output	Variable Cost (€/liter)		
		Low	Typical	High
Cane Fallow: Stalk (Scenario 1)	Ethanol	0.78	0.49	0.36
Cane Fallow: stalk + Grains (2020)	Ethanol	0.51	0.28	0.24
Sweet Sorghum: Grain to food (Scenario 3)	Ethanol	0.58	0.30	0.19
Syrup to Ethanol (Scenario 4)	Ethanol	1.19	0.65	0.59

Fig. 5.1.1 Breakup of Production cost Sweet Sorghum Stalk, stalk+grain & grain to food Scenarios Typical Case (Euro/ha)

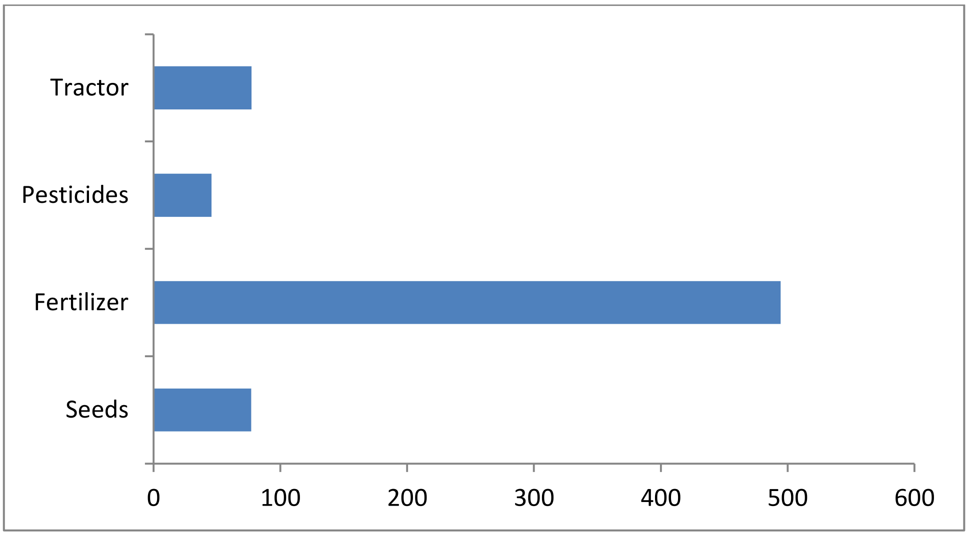


Fig. 5.1.2 Breakup of Production cost Sweet Sorghum Syrup to ethanol Scenario Typical Case(Euro/ha)

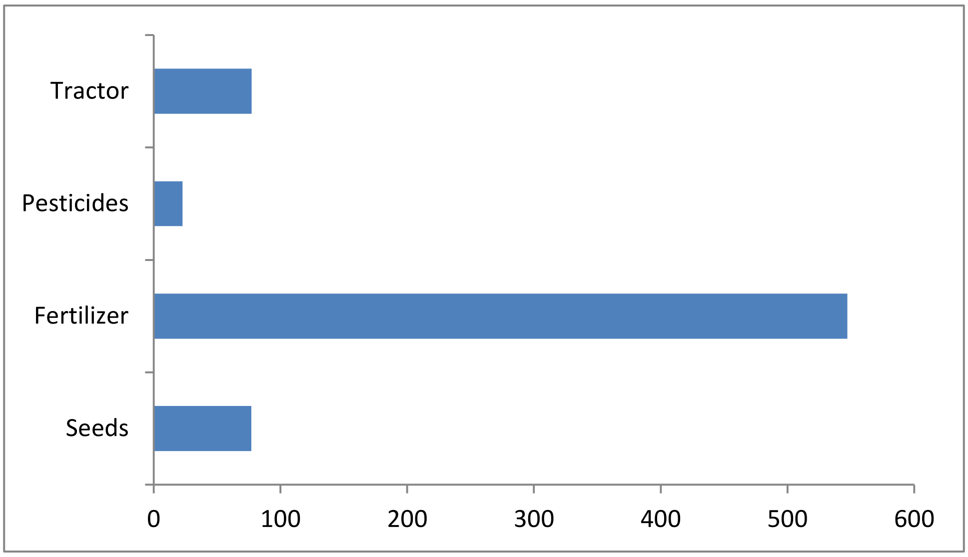


Fig. 5.1.3 Breakup of Processing cost of Sweet Sorghum Scenarios: Typical Case

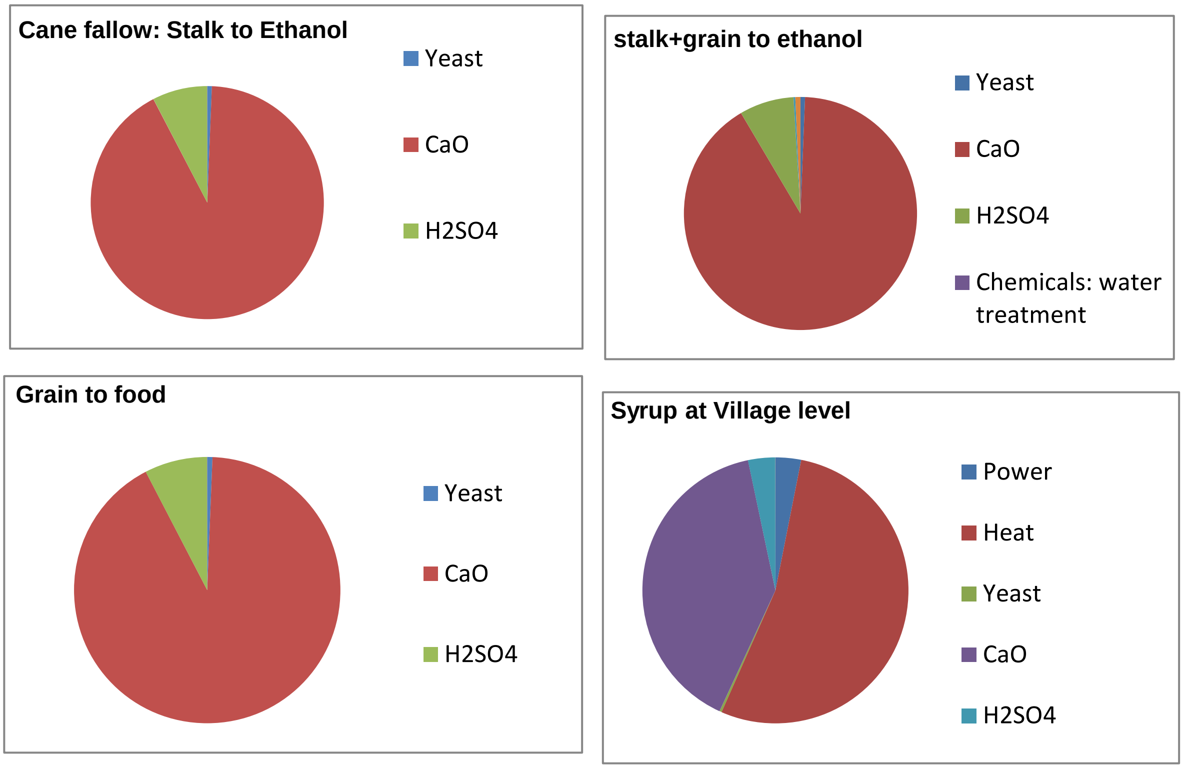


Table 5.1.3 Value of byproduct for sweet sorghum to ethanol scenarios (Euro/ha)

Scenarios→	**Cane Fallow: Stalk to ethanol (Scenario 1)**			**Cane Fallow: stalk+Grains to Ethanol (2020)**			**Grain to food (Scenario 3)**		
Option→	**1Ia**			**1Ia**			**3Ia**		
Cases/ Items	**Low**	**Typical**	**High**	**Low**	**Typical**	**High**	**Low**	**Typical**	**High**
Leaves (NPK)	7	13	23	7	13	23	7	10	13
Excess power	26	106	311	17	75	261	26	68	118
Electricity from surplus bagasse	137	143	43	131	118	1	137	143	143
Fusel oil (EtOH juice)	7	20	53	7	20	53	7	13	21
Vinasse (EtOH juice)	12	34	92	12	34	92	12	22	36
Calcium carbonate (EtOH juice)	34	95	247	34	95	247	34	63	95
Fusel oil (EtOH Grain)	---	---	---	0	1	2	---	---	---
Stillage (EtOH grains)	---	---	---	15	59	104	---	---	---
Grains (food)- DM	---	---	---	---	---	---	156	389	622

Table 5.1.4 Value of byproduct for sweet sorghum to ethanol scenarios, surplus bagasse for feed (Euro/ha)

Scenarios→	**Cane Fallow: Stalk to ethanol (Scenario 1)**			**Cane Fallow: stalk+Grains to Ethanol (2020)**			**Grain to food (Scenario 3)**			**Syrup to Ethanol (Scenario 4)**		
Option→	**1Ia**			**1Ia**			**3Ia**			**4I**		
Cases/ Items	**Low**	**Typical**	**High**	**Low**	**Typical**	**High**	**Low**	**Typical**	**High**	**Low**	**Typical**	**High**
Leaves (NPK)	7	13	23	7	13	23	7	10	13	---	---	---
Excess power	26	106	311	17	75	261	26	68	118	---	---	---
Fusel oil (EtOH juice)	7	20	53	7	20	53	7	13	21	5	15	43
Vinasse (EtOH juice)	12	34	92	12	34	92	12	22	36	8	26	75
Calcium carbonate (E-tOH juice)	34	95	247	34	95	247	34	63	95	23	73	210
Fusel oil (EtOH Grain)	---	---	---	0	1	2	---	---	---	---	---	---
Stillage (EtOH grains)	---	---	---	15	59	104	---	---	---	---	---	---
Grains (food)- DM	---	---	---	---	---	---	156	389	622	156	622	1089
Surplus bagasse (feed)-DM	31	29	0	31	29	0	33	35	34	34	43	43

Table 5.1.5 Capital (CAPEX) and Operational (OPEX) expenditure costs of the plant under Sweet sorghum Scenario

Cases/ Scenario	CAPEX (Capital expenditure)	OPEX[a] (Operational expenditure) (in million euros)			Crushing Capacity
	(million Euros)	Low	Typ	High	(million tonne per annum)
Cane Fallow: Stalk (Scenario 1)	57.53	73.15	71.52	83.05	1 million tonne of stalk
Cane Fallow: stalk + Grains (2020)	57.53	80.49	115.30	166.31	1 million tonne stalk+0.1 million ton of grain
Grain to food (Scenario 3)	57.53	74.85	51.21	34.81	1 million tonne of stalk
Sweet sorghum Syrup to Ethanol(Scenario 4)	57.53	81.94	89.29	113.28	1 million tonne of stalk

Note: 1. Assuming economies of scale, processing and Labour cost in OPEX moving from Low to Typical and Typical to High cases are reduced by 10% and 15% respectively

Fig. 5.1.4 Breakup of Operational Cost, Typical Case

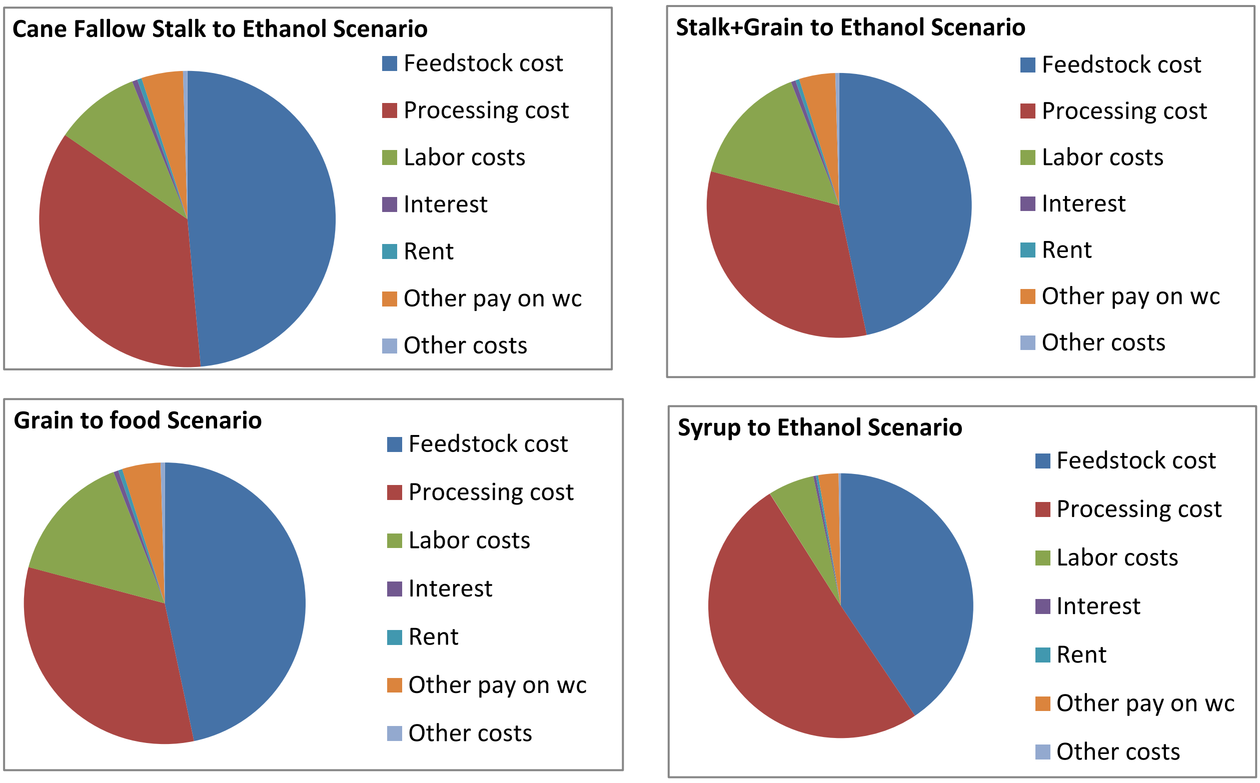


Table 5.1.6 Cost of ethanol from sweet sorghum, Euro/ton

Total cost per ton of Ethanol			
Cases/Scenario	**OPEX ***		
	Low	**Typ**	**High**
Cane Fallow: Stalk (Scenario 1)	944	649	500
Cane Fallow: stalk + Grains (2020)	687	422	369
Grain to food (Scenario 3)	688	58	---
Sweet sorghum Syrup to Ethanol (Scenario 4)	1608	850	724

*costs are after accounting for by-product credit

Table 5.1.7 Economic Assessment of Sweet Sorghum Scenarios

Cases/ Scenarios	**Low**		**Typical**		**High**	
	NPV € (millions)	**IRR (%)**	**NPV € (millions)**	**IRR (%)**	**NPV € (millions)**	**IRR (%)**
Cane Fallow: Stalk (Scenario 1)	-173	---	-68	---	49	25%
Cane Fallow: stalk + Grains (2020)	-91	---	225	70%	536	148%
Sweet Sorghum: Grain to food (Scenario 3)	-78	---	214	67%	423	120%
Break-even price analysis[1]						
Cases/ Scenarios	**Low**		**Typical**		**High**	
	Break-even price		**Break-even price**		**Break-even price**	
Cane Fallow: Stalk (Scenario 1)	0.86		0.59		0.44	
Cane Fallow: stalk + Grains (2020)	0.61		0.36		0.31	
Sweet Sorghum: Grain to food (Scenario 3)	0.65		0.13		-0.10	

Note: 1.breakeven is the price at which NPV=0; World ethanol price 0.49€/liter (2012)

Table 5.1.8 Economic Assessment of Sweet Sorghum Scenarios, Surplus bagasse for feed pathway

Cases/ Scenarios	Low		Typical		High	
	NPV € (millions)	IRR (%)	NPV € (millions)	IRR (%)	NPV € (millions)	IRR (%)
Cane Fallow: Stalk (Scenario 1)	- 246	---	- 107	---	41	22%
Cane Fallow: stalk + Grains (2020)	-160	---	181	59%	535	148%
Sweet Sorghum: Grain to food (Scenario 3)	-149	---	164	54%	386	110%
Syrup to Ethanol(Scenario 4)	-305	---	-147	---	-123	---

Break-even price analysis

Cases/ Scenarios	Low	Typical	High
	Break-even price	Break-even price	Break-even price
Cane Fallow: Stalk (Scenario 1)	1.01	0.65	0.45
Cane Fallow: stalk + Grains (2020)	0.70	0.39	0.31
Sweet Sorghum: Grain to food (Scenario 3)	0.81	0.22	-0.04
Syrup to Ethanol(Scenario 4)	1.43	0.77	0.63

Note: Note: 1.breakeven is the price at which NPV=0; World ethanol price 0.49€/liter (2012)

5.2 Biomass sorghumBiogas and Biomethane scenarios

In this subchapter an overview of the economic influence of the biomass sorghum sub-scenarios, i.e.,biogas and biomethane scenarios are discussed. For a description of these scenarios under biomass Sorghum see subchapter 3.2.1. The economic assessment looks at variable costs after allowing credits for by-products and economic feasibility based on capital cost, plant capacity and operational expenses assuming a life span of fifteen years for the production unit.

Under the biomass sorghum to biogas scenario the variable cost net of by-product credits is highest 0.10 euro / Kwh) under the low case. It declines marginally under the typical and high scenarios to 0.09 euro / Kwh (Table 5.2.1). The variable costs are marginally higher for production of biomethane.The variable costs at 0.10are below the world market price of power at 0.2 euro / Kwh implying significant economic returns due to power from biogas produced from sorghum biomass.

For biomass sorghum break up of production costs indicates highest share for fertilizer costs followed by seed cost. This is somewhat similar to those for sweet sorghum (Figure 5.2.1).For production costs of biomass sorghum per hectare see Appendix 9.2.2.1 and 9.2.2.2.

Break up of processing cost indicates, power for conversion as the major cost component followed by power for compression (Figure 5.2.2).Digestate is the main by product under this process that is used as fertilizer. Its value however is not very significant (Table 5.2.2)

The capital expenditure cost (CAPEX) of biogas plant using sorghum biomass as feedstock with crushing capacity of 11500 tonne of biomass per annum and the operational cost (OPEX) are shown in Table 5.2.3.

Break up of operational costs like for other scenarios indicates that feed stock and processing costs accountfor bulk of the cost under all cases. Rent and other working capital costs are next most important operational costs (Figure 5.2.3).

Given the low variable cost of biogas production from biomass sorghum we observe positive NPV’s for all cases with IRR ranging from 24% to 57%.(Table 5.2.4).

Table 5.2.1 Summary of Variable cost of Biomass Sorghum for biogas and biomethane (Production and Processing)

Biomass Sorghum Scenarios (Scenario 5)	Output	Variable Cost (€/Kwh)		
		Low	Typical	High
Biogas	Killo Watt Hour	0.10	0.09	0.09
Bio methane	Killo Watt Hour	0.12	0.11	0.11
Bio methane (instead of natural gas)	Mega Jule	0.03	0.03	0.03

Note: world power price 0.2€ /kwh (2012). World biomethane price 0.012 € /mj

Fig. 5.2.1 Breakup of production cost of Biomass Sorghum for biogas and biomethaneTypical Case (Euro/ha)

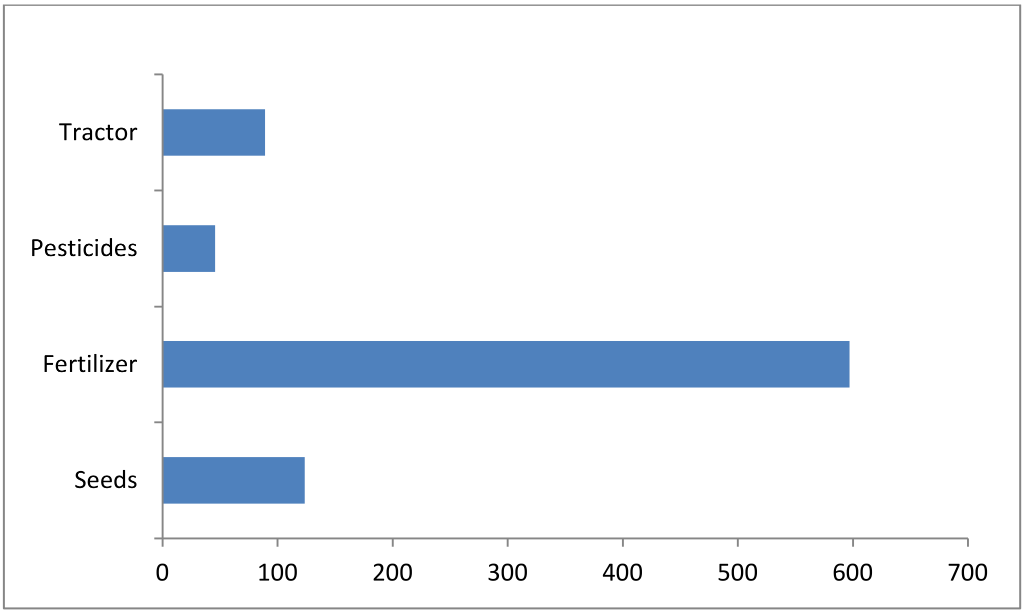


Fig. 5.2.2 Break-up of Processing cost of Biomass Sorghum to biogas Scenario: Typical case

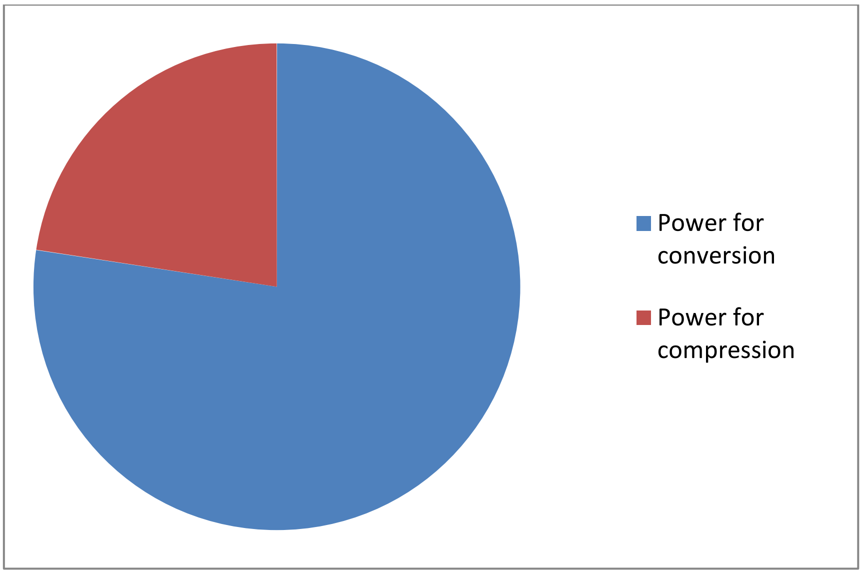


Table 5.2.2 Value of byproduct for Biomass Sorghum Scenarios (in Euro/ha)

Scenarios→	**Biomass to Biogas**			**Biomass to Biomethane**		
Option→	**5IB**			**5IIA**		
Items	**Low**	**Typical**	**High**	**Low**	**Typical**	**High**
Digestate (for biogas/biomethane)	7.60	11.88	14.25	7.60	11.88	14.25

Table 5.2.3 Capital (CAPEX) and Operational (OPEX) expenditure costs of the plant under Biomass Sorghum Scenario

Scenario	**CAPEX (Capital expenditure)**	**OPEX[a] (Operational expenditure) (in million euros)**			**Crushing Capacity**
	(million Euros)	**Low**	**Typical**	**High**	**(million tonne per annum)**
Biomass sorghum to Biogas	2.00	0.75	0.98	1.11	11500 tonne biomass

Fig. 5.2.3 Breakup of Operational Cost: Biomass to Biogas

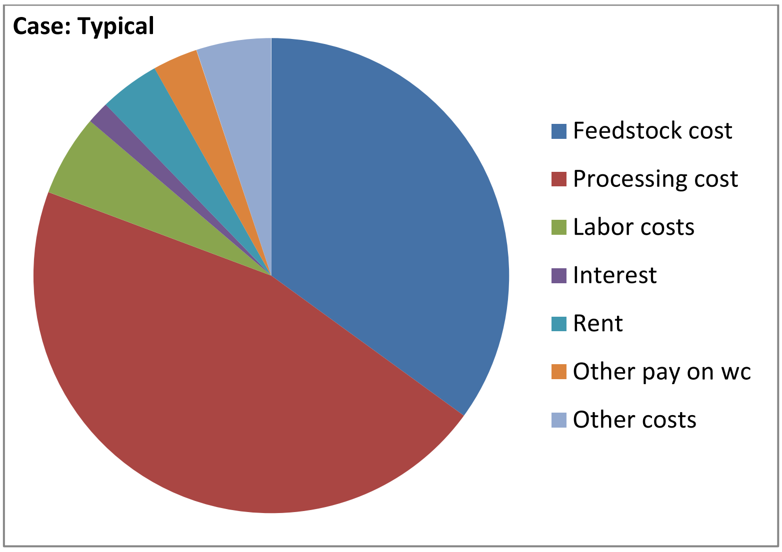


Table 5.2.4 Economic Assessment of Biomass Sorghum Scenarios

Cases/ Scenarios	Low		Typical		High	
	NPV € (millions)	IRR (%)	NPV € (millions)	IRR (%)	NPV € (millions)	IRR (%)
Biomass: Biogas	1.60	24	4.34	44	6.05	57
Biomass: Biomethane	0.60	16	3.00	34	4.48	45
Break-even Price Analysis[1]						
	Break-even price		**Break-even price**		**Break-even price**	
Biomass: Biogas	0.16		0.13		0.12	
Biomass: Biomethane	0.17		0.14		0.13	

5.3 Biomass sorghum for Alternative Product Scenarios

In this subchapter an overview of the economic influence of the biomass sorghum on alternative product scenarios, i.e., second generation ethanol, direct combustion and gasification scenarios are presented. For a description of these scenarios under Biomass Sorghum see-subchapter 3.2.2 to 3.2.4. The economic assessment looks at variable cost after allowing credits for by-products and economic feasibility based on capital cost, plant capacity and operational expenses assuming a life span of fifteen years for the production unit.

5.3.1 Second generation ethanol

An alternative to biomass conversion of biomass sorghum into biogas or biomethane is the production of ethanol from lignocellulose fraction of biomass sorghum i.e., second generation technology that is still to be produced on a commercial scale. Hence relevant data on processing costs are not readily available i.e., the price of enzyme used for processing second generation ethanol. Based on information from literature and personal communications a price band ranging from 200 euros per tonne of enzyme to 500 euros / tonne are considered for the economic asessment. Under the lowe price range of enzyme biomass sorghum to second generation ethanol the variable cost is 0.40 euro / liter under the low case with only marginal decline under the typical and high cases. Under the higher price of enzyme the variable cost is 0.78 under the low case again with marginal decline in other cases. (Table

5.3.1). Thus, If we expect the price of enzyme to be closer to the lower price in the price band second generation ethanol could be viable in the medium to long term.

The capital expenditure cost (CAPEX) of second generation ethanol plant using sorghum biomass as feedstock with crushing capacity of 0.5 million tonnes of biomass per annum and the operational expenditure cost (OPEX) are shown in Table 5.3.3.

Break up of operational costs unlike for other scenarios with ethanol as end product indicates that feed stock cost and processing costs accountfor bulk of the cost under all cases. Labor interest and other working cost costs account for the rest(Figure 5.3.2).

The cost of ethanol from biomass sorghum is 625 euros / tonne under the typical case with lower price band for the enzyme. Under the higher price band it is 1065 euros / tonne. Presently even under the lower price band of the enzyme the NPVs are negative under all cases (Table 5.3.5). As expected they are more negative under the higher price band of the enzyme. Break-even price is around 0.61 / liter of ethanol under the typical case for the lower price band of the enzyme.

5.3.2 Direct combustion

Another option to convert biomass sorghum into energy is direct combustion.

This is a simple process not involving much cost. The variable cost of energy produced through direct combustion works out to 0.09 to 0.10 per kwh. This is much lower than the market price of power and hence economical.

5.3.3 Gasification

Besides direct combustion, biomass sorghum can also be used for production of FT (Fischer-Tropsch) diesel through gasification. Under the biomass sorghum to FT diesel scenario with direct gasification the variable cost net of by-product credits is 1.28 euro / liter under the low case. It declines marginally under the typical and high scenarios (Table 5.3.1). The variable costs are higher under the gasification with prior pyrolysis scenario at 1.68 euros / liter in the low case. These costs are above the world market price of diesel implying negative economic returns.

Break up of processing cost indicates power for conversion is the major cost component followed by catalysts cost (Figure 5.3.1). Under the gasification with prior pyrolysis process the power costs are higher adding to the overall costs. Regarding value of by–product surplus bioenergy is the main by product and its value declines significantly under the prior pyrolysis process (Table 5.3.2).

The capital cost (CAPEX) of biogas plant using sorghum biomass as feedstock with crushing capacity of 1 million tonne of biomass per annum and the operational cost (OPEX) are shown in Table 5.3.3. Break up of operational costs indicates that processing costs account for bulk of the cost under all cases. Feed stock comes next with a share of 15%. All other costs account for a small share (Figure 5.3.2).

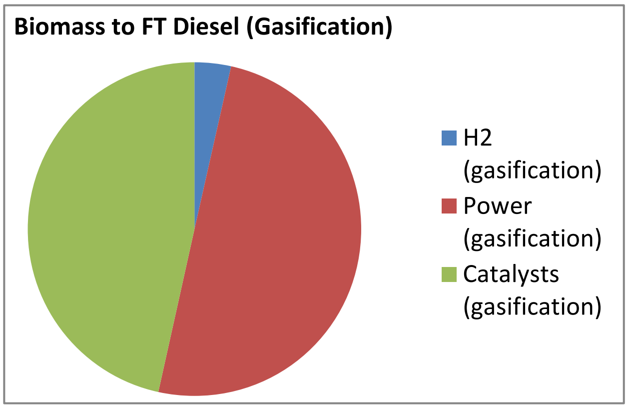
Given the high variable cost of FT diesel from biomass sorghum we observe negative NPV's for all cases. The break-even price is obviously much higher than the world market price of diesel.

Table 5.3.1 Summary of Variable cost of Biomass Sorghum for alternative Scenarios

Cases/ Scenarios (Scenarios 5)	**Output**	**Variable Cost (€/unit of output)**		
		Low	**Typical**	**High**
Second generation Ethanol (Enzyme Price @0.003/g)	Ethanol (in liter)	0.40	0.37	0.36
Second generation Ethanol (Enzyme Price @0.008/g)	Ethanol (in liter)	0.78	0.75	0.75
Direct Combustion	Power (in Kwh)	0.10	0.09	0.09
Direct Gasification	FT Diesel (in liter)	1.28	1.23	1.22
Gasification with Prior pyrolysis	FT Diesel (in liter)	1.68	1.64	1.63

Note: World ethanol price: 0.49€/liter (2012); world power price: 0.2€ /kwh (2012); World diesel price: 0.84€/liter (2012).

Fig. 5.3.1 Break-up of Processing cost of Biomass Sorghum Alternative products Scenarios, Typical Case



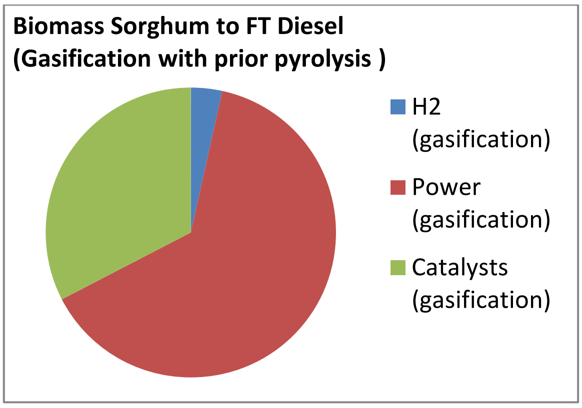


Table 5.3.2 Value of byproduct for Biomass Sorghum Alternative Scenarios (in Euro /ha)

Scenarios (Scenarios 5)→	Biomass sorghum -Direct Gasification			Biomass sorghum-Gasification with prior pyrolysis		
Option→	**5cI**			**5cII**		
Cases/ Items	**Low**	**Typical**	**High**	**Low**	**Typical**	**High**
Surplus bioenergy (gasification)	860	1340	1600	---	---	---
Surplus bioenergy (gasification + pyrolysis)	---	---	---	102	160	192

Table 5.3.3 Capital (CAPEX) and Operational (OPEX) costs of the plant under Biomass Sorghum Alternative Products Scenarios

Cases/ Scenario (Scenarios 5)	CAPEX (Million Euros)	OPEX (in million euros) Low	Typical	High	Crushing Capacity (million tonne /year)
Biomass sorghum 2nd Gen. Ethanol (Enzyme cost @0.003/g)	112.2	66.30	62.50	59.90	0.5
Biomass sorghum FT diesel: Direct Gasification	56.19	210.77	189.62	180.06	1
Biomass sorghum FT diesel: Gasification with prior pyrolysis	56.19	263.72	238.19	226.08	1

Table 5.3.4 Cost of Alternative products from Biomass Sorghum, Euro/ton

Ethanol from Biomass Sorghum			
Cases/ Scenario (Scenarios 5)	**OPEX**		
	Low	**Typical**	**High**
Biomass sorghum 2nd Gen. Ethanol (Enzyme Price @0.003/g)	708	625	599
Biomass sorghum 2nd Gen. Ethanol(Enzyme Price @0.008/g)	1196	1065	1014

*costs are after accounting for byproduct credit

Fig. 5.3.2 Breakup of Operational Cost: Biomass Sorghum,Typical Case

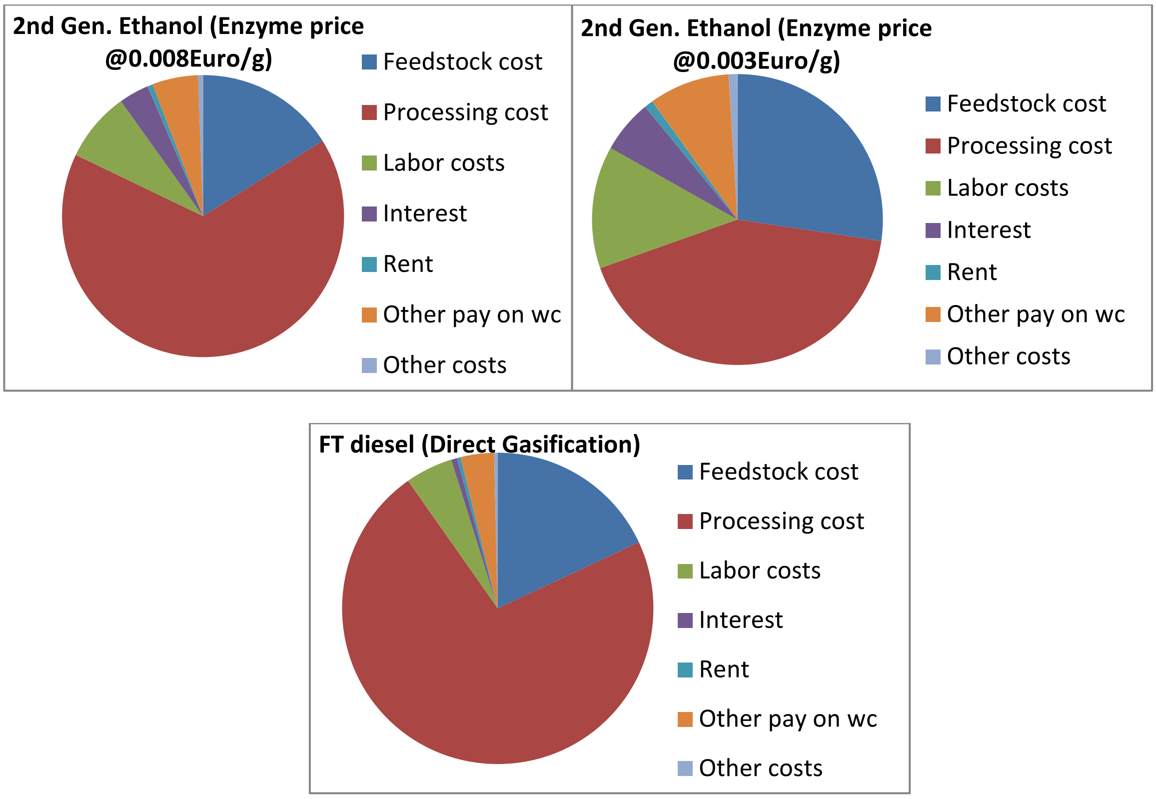


Table 5.3.5 Economic Assessment of Biomass Sorghum Alternative Scenarios

Scenarios	Low		Typical		High	
	NPV € (millions)	IRR (%)	NPV € (millions)	IRR (%)	NPV € (millions)	IRR (%)
Biomass sorghum 2nd Gen. Ethanol (Enzyme Price @0.003/g)	-159	---	-105	---	-87	---
Biomass sorghum 2nd Gen. Ethanol(Enzyme Price @0.008/g)	-475	---	-410	---	-374	---
Biomass: Direct Gasification	- 508	---	-363	---	-299	---
Break-even Price Analysis[1]						
	Break-even price	**IRR**	**Break-even price**	**IRR**	**Break-even price**	**IRR**
Biomass sorghum 2nd Gen. Ethanol (Enzyme Price @0.003/g)	0.68	10%	0.61	10%	0.59	10%
Biomass sorghum 2nd Gen. Ethanol(Enzyme Price @0.008/g)	1.07		0.96		0.92	
Biomass: Direct Gasification	1.52		1.33		1.24	

Note: breakeven is the price at which NPV=0; World ethanol price 0.49€/liter (2012);World average diesel price is 0.84 euro/ltr

6 Overall conclusions, recommendations and outlook

6.1 Conclusions

By 2035, global energy consumption is projected to grow by 41% and consumption of liquid fuels is expected to rise by 20% - almost 15 million more barrels per day. With the world's population projected to reach 8.3 billion by then, an additional 1.3 billion people will need energy. To meet this demand a diverse energy mix is needed. This is where biofuels can help; (BP Outlook 2030, published in Jan 2013).

6.1.1 Why biofuels

- To increase national security of energy supplythe focus is on renewable energy sources as the non-renewable sources get depleted
- Have the potential of substituting petroleum products (blending) within the existing available infrastructure and motor vehicle technology
- Reduction of environmental impacts: ethanol and biodiesel are important options for reducing greenhouse gas emissions and mitigating climate change
- Creates new demand for agricultural crops enabling intensification.
- Promotes economic activity especially in rural areas

In view of growing importance of renewable energy globally the production of biofuels has been increasing during the last 15 -20 years. The pace of growth has picked up since 2000 due to rising crude oil prices and concerns for greenhouse gas emissions. Among the biofuels global ethanol production was 80 billion liters while bio diesel production was around 22 billion liters. However, only 5 countries (including EU) accounted for 92% of ethanol production globally. USA was by far the most important producer of ethanol accounting for 61% of global production followed by Brazil 25% and China 2.5%. A number of other countries (Australia, India, Mexico, New Zealand etc) accounted for small share with production growing from a small base. For biodiesel EU accounted for bulk of the production, and within EU mainly Germany.

To promote use of ethanol several countries have mandated blending targets both short and long term. Brazil has the highestblending target of 20%in 2013. Most other countries have 10-15% targets by 2020.

Worldwide, sugar cane and corn are the main source of bioethanol. However, the cultivation of sugarcane crop cannot be realised in water-limited or temperate and tropical regions. Owing to food-fuel trade off and for food security reasons many countries do not permit use of grains for ethanol production. In China for example where 80% of the ethanol is corn based the government has put a ban on further expansion of corn based ethanol production. Instead the Government is now promoting ethanol from non-food grain crops like cassava, sweet sorghum, sweet potato, etc. Thus the emphasis is on crops that will not compete with land for food grains and can be grown on marginal environments. Similar vision is found in the biofuel policy of government of India although its implementation at ground level continues to be slow with molasses from sugar industry continuing to be the main feedstock for ethanol production.

Under this backgroundof looking for promising alternative feed stocks sweet sorghum (*Sorghum bicolor* (L.) Moench) has several advantages due to its efficiency in both high water use and nutrient uptake. Furthermore, the production of food, feed and fuel can be combined in one crop. This is an important asset on the background of the currently increasing discussion on energy production and food security.

The SWEETFUEL project provides a multi-criteria evaluation of the sweet sorghum and biomass sorghum production and use pathways taking into account technological, environmental, economic and social aspects. This report focuses on the economic aspects of using sweet sorghum and biomass sorghum under different scenarios and use pathways of by-products for production of ethanol from sweet sorghum that includes ethanol from sweet sorghum stalk (cane fallow), stalk+ grain (cane fallow 2020), stalk for ethanol and grain for food, and syrup at village level to ethanol.For biomass sorghum 2nd generation ethanol, biogas, biomethane, and FT diesel through Fischer-Tropsch synthesis of gas are analysed. Further the values of key production and processing parameters are varied by defining *Low, Typical and High* case values for the key parameters like feedstock yield, brix and sugar content in sweet sorghum stalk, conversion efficiency of ethanol / power from sweet sorghum / biomass sorghum.

6.1.2 Sweet sorghum to ethanol

Comparison of calculated net variable cost of ethanol (after allowing credits for by-products) generated from Sweet sorghum stalk, stalk+ grain, grain for food and syrup scenarios with market price of ethanol indicates that the ethanol output in the scenario from stalk+ grain

under typical and high case is competitive and a realistic scenario in 2020. Also, ethanol production under the grain to food scenario is competitive in all cases.Under the grain to food scenario the value of grain significantly reduces the cost of ethanol production after due credit is given to grain value. With the on-going debate on food vs. fuel, sweet sorghum as a feedstock is found to be economically promising when the grain is utilized for food and stalk to ethanol.Ethanol production using syrup route is most uneconomical while production from stalk only scenario is competitive under the high case only. For the syrup route the extraction of syrup at village level is still not commercially viable adding to the overall cost of production. In all cases feedstock costs is the major contributor to the variable production costs of ethanol followed by processing costs followed by labour and other maintenance and operational costs. Besides interest costs etc, make up the rest. Feedstock costs however, tend to come down as we move from low to high case due to higher yields under the high case compared to the low case.

Among the different by-products generated while **producing** ethanol from stalk only or stalk +gain scenarios, generation of electricity from surplus bagasse, excess power and CaO account for a major share followed by vinasse, fusel oil etc. Under the stalk + grain scenario spent grain additionally accounts for a small share in the total value of by-products. As we move from low to high case the share of electricity from surplus bagasse declines significantly as the available quantity of surplus bagasse declines. Under the food to grain scenario grain value makes a significant contribution to the by-product value followed by all others like in stalk only scenario. The use of surplus bagasse as feed does not alter the economics significantly as the value of bagasse as feed is lower than when it is used to generate electricity. The contribution of leaves left on the field via fertilizer though important is small in all scenarios.

A fifteen year cash flow analysis shows that the NPV (Net Present Value) of investment under the stalk only scenario is negative for low and typical cases but positive under high case. under the stalk + grain scenario under typical and high cases the NPV is positive with IRR ranging from 70% to 148%. Under the grain to food scenario the NPV’s are positive with IRR ranging from 67% in the typical case to 120% in the high case. The IRRs are lower when surplus bagasse is used for feed. In the case of syrup to ethanol scenario the NPV’s are negative in all cases.

Thus, sweet sorghum as a feedstock is found to be an effective alternate energy crop. Based on the indicators of investment analysis, the best use pathway in the present condition is to use both sweet sorghum stalk and its grain for ethanol production. Also, the use of both stalk

and grain helps the distillery in terms of higher capacity utilization. However, as the use of grain for ethanol production concerns food security, the use of grain for food as a scenario was also found to be economically feasible though less so in comparison to its use for ethanol. In certain regions (like in India) sweet sorghum grown under semi-arid conditions stalks have to be crushed within a short time after harvest to avoid loss of juice due to drying. To avoid the loss, the process of producing syrup from the juice at the village level and further to ethanol as a scenario is not economical.

Break-even price analysis (i.e., the price where the project NPV becomes zero) is calculated over all the cases by simulating ethanol price. The break-even price ranges from 0.86 under the low case to 0.44 under the high case for the stalk to ethanol scenario. The break even prices are much higher under the syrup to ethanol scenario ranging from 1.43 under low case to 0.63 under high case.

The cost of ethanol production in euro / tonne under the 4 scenarios, i.e., stalk to ethanol, stalk + grain to ethanol, grain to food and syrup to ethanol is 649,422, 58 and 850 respectively under the typical case.

6.1.3 Biomass sorghum to biogas and bio methane

Comparison of calculated total variable cost of biogas and bio methane generated from sorghum biomass shows it has a competitive edge over its counterpart in the market. The variable cost of producing biogas under the typical scenario is 0.09 euro / Kwh. It is the same for biomethane. The market price of power in 2012 is 0.2 / Kwh implying biogas from biomass sorghum is more competitive at current market prices.

A fifteen year cash flow analysis shows that the return on investment is positive under biomass sorghum to biogas scenarios. The internal rate of return (IRR) for the three cases (low, typical and high) under this scenario is observed as 24%, 44% and 57% respectively. The break-even price is consequently much higher than the actual cost of production.

6.1.4 Biomass sorghum to alternate products

Biomass sorghum is also used to produce second generation ethanol although the technology for this is not fully developed. Price data for the enzyme used for processing of second generation ethanol is not readiliy avaliabale. Hence based on information gathered from in-

dustry we have used a price ranging from 200 euro/tonne to 500 euro/tonne. Variable cost analysis indicates that the cost of production of 2nd generation ethanol is competitive at the lower end of the price of enzyme assumed for this study but at the higher end of enzyme price it is not competitive. Economic feasibility analysis also indicated non-viability of 2nd generation ethanol under the assumed price band of the enzyme used for processing. For 2nd generation ethanol to become viable and competitive the processing cost has to come down in the near future.

Biomass sorghum is also used to produce FT diesel through direct gasification. Economic assessment found variable costs ranging from 1.28 to 1.22 as we move from low to high case. The costs are higher under the gasification with prior pyrolysis. With world diesel prices at 0.85 euro / liter the production FT diesel through gasification is not economical. Consequently the returns from the investment i.e, net present value is negative. The break even prices range from 1.2 to 1.5 euro / liter as we move from high to low case.

6.2 Recommendations

The core question of the SWEETFUEL project from economic perspective was to assess the best ways to produce and use sweet and biomass sorghum for energy and its economic competitiveness.The findings of the assessment present sweet sorghum as a promising alternative feedstock for energy production. In the sub-tropical conditions of South America where sugarcane cultivation for ethanol production has led to concerns towards land clearing to meet the increased demand from the processing units, sweet sorghum can be utilized during the lean periods of crushing. Presently only stalk is used for crushing since grain is left on the field due to machine harvesting. Under the 2020 scenario grain will also be harvested. Since grain of sweet sorghum in South America is not demanded for food purpose and conflict of food vs. fuel does not arise in such conditions, distilleries crushing sugarcane for ethanol can utilize both stalk and grain of sweet sorghum by increasing the crushing window during the lean periods. Use of both stalk and grain for ethanol here is more profitable than stalk alone. The industry should however, enter into an agreement with the growers for supply of both grain and stalk for which formal contracts may be arranged upfront.

In semi-arid conditions, where the grain of sorghum is an important commodity in the food basket from food security point of view and farmers will not part with the grain. Hence, breeding efforts should concentrate on improving sugar content there by improving ethanol recovery contributing to economic viability of ethanol production from stalk alone.

The other associated problem to be addressed is the concerns towards in-effective supply chain management leading to deterioration in juice quality. This has led to industries dis-interest in processing sweet sorghum and scaling-up. Converting juice to syrup at village level and further to ethanol, as a solution to address the problem of supply chain management is not economical based on data from the Indian case. Hence, solutions to address technical deterioration in juice quality are to be addressed on priority.

For the industry, utilization of all byproducts generated during ethanol production and economics of alternative utilization pathways of by-products is critical to maintain their profitability. Bagasse obtained as a by-product of sweet sorghum processing substitutes as cheaper source of energy as compared to fossil fuel/electricity and also some surplus is left. The surplus bagasse can be used for electricity generation there by help bringing down cost of production of ethanol. Surplus bagasse can also be used for feed but was found to be relatively less economical.

Cost of ethanol from biomass sorghum using second generation technology is sensitive to enzyme price. The information available from literature on the price of enzyme is highly variable and also depends on type and quantity used. Information from industry sources is not available. Given these limitations, findings from the economic analysis present a promising picture for second generation ethanol production from biomass sorghum at least in the near future, say 2020. Given the rapid pace of on-going research on feedstock processing to produce second generation ethanol, findings from economic analysis for researchers, policy makers and industry are encouraging for its further improvement. However, more research is required on the processing of the second generation ethanol before any firm conclusion can be drawn.

Production of energy using biomass sorghum for biogas/biomethane is economically viable in temperate climatic conditions. More research/ information are required to look at other competing feed stalks like for example maize.

There is a need for considerable improvement in the production technology of FT diesel through Fisher Torpsch synthesis of gas since presently the end product is not economical given the current prices of diesel.

6.3 Outlook

To promote use of ethanol several countries have mandated blending targets both short and long term. Brazil has the highest blending target of 20% in 2013. Most other countries have 10-15% targets by 2020. The feedstalk currently bieng used to prodice ethanol like grains, sugar cane, etc., will not be able to meet the manadatory requirements since thier production on large scale for energy purpose can compromise food security requirements. Hence several countries are exploring alternative feedstalks that do not compete with land used for food production. Use of sweet sorghum does not compromise on food security and hence is bieng promoted for ethanol production.

Under the above scenario the outlook for production of ethanol from sweet sorghum is promising and needs to be promoted aiming for whole plant utilization. Improvements in current crop production technology and ethanol recovery will further improve prospects of using sweet sorghum for ethanol production.

The challenge, however, is to identify the growing domains for sweet sorghum in different countries in areas where it does not compete with food crops. Currently such information is not readily available.

Use of Biomass sorghum to produce energy is viable in temperate zones but here too the challenge is to find enough land to grow biomass sorghum.

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8 Glossary and abbreviations

1st generation biofuels: Biofuels e. g. produced from sugar, starch, vegetable oil or animal fats using conventional technologies.

2nd generation biofuels: Biofuels e. g. produced from non-food biomass such as lignocellulose and waste biomass (stalks of wheat or corn) using innovative technologies.

ARC: Agricultural **R**esearch **C**ouncil, Potchefstroom, South Africa; http://www.arc.agric.za/

Bagasse: Fibrous matter that remains after stalks are crushed to extract the juice.

Biomass sorghum: Sorghum cultivars with high lignocellulosic biomass yield, potentially used as energy crop.

BtL: Biomass-**t**o-**L**iquid; synthetic biofuels produced via biomass gasification.

C4-Plant: Plants using a 4-carbon molecule as a first product in the carbon fixation pathway (in contrary to a 3-carbon molecule of C3-plants) which leads amongst others to higher water use efficiencies.

CIRAD: Centre de **C**oopération **I**nternationale en **R**echerche **A**gronomique pour le **D**éveloppement, Paris, France; http://www.cirad.fr

Cultivar: Plant or group of plants selected for some desirable characteristics. Cultivar is a general word that includes lines, varieties and hybrids.

CAPEX: Capital Expenditure

DG ENVI: ## to be filled ##

EMBRAPA: EMpresa **BRA**sileira de **P**esquisa **A**gropecuária, Brasília, Brazil; http://www.embrapa.br

Energy sorghum: Sweet and biomass sorghum cultivars used in this project.

Fibre sorghum: Biomass sorghum cultivars with a high content of fibre; potentially used as fibre or energy crop.

FT diesel: Fischer-**T**ropsch diesel; synthesis which converts carbon monoxides and hydrogen into liquid hydrocarbons which can be further processed into low-sulfur diesel.

Grain sorghum: Sorghum cultivars with high grain yield established as food or feed crop.

Hybrid: Offspring's resulting from the cross between two genetically dissimilar parental lines. Usually, seeds from hybrids don't consistently provide the desired characteristics, so hybrid seed should be repurchased by growers for each planting season.

ICRISAT-IN: International **C**rops **R**esearch **I**nstitute for the **S**emi-**A**rid **T**ropics, Patancheru, **In**dia; http://www.icrisat.org

Idle land: Reference systems such as degraded soils or land that becomes free due to the intensification of existing land use.

ILCD: International Reference Life-cycle Data system

IFEU: Institute **forE**nergy and **E**nvironmental Research Heidelberg, Germany; http://www.ifeu.de

IRR: Internal Rate of Return

JRC: Joint Research Centre ofthe European Commission.

KWS: KWS Saat AG, Einbeck, Germany; http://www.kws.de

L.: Linné

Line: Breeding material which tends to be genetically identical.

LCA: Life cycle assessment

LC-EIA: Life cycle Environmental impact assessment (assessment of local environmental impacts taking into account the stages during the whole life cycle of a product from cradle to grave)

LCF-ethanol: **L**igno**c**ellulose**F**eedstock; ethanol production from lignocellulose feedstock.

Molasses: Viscous by-product of the refining of e. g. sugarcane, grapes, or sugar beets into sugar.

NPV: Net Present Value
OPEX: Operational Expenditure

Pesticide: Pesticides are substances meant for preventing, destroying or mitigating any pest.

SWEETFUEL

Project "Sweet Sorghum: an alternative energy crop"; supported by the European Commission in the 7th Framework Programme to exploit the advantages of sweet sorghum as potential energy crop for bio-ethanol production.

Sweet sorghum: Sorghum cultivars with juicy stems and high juice sugar content in their stalks, potentially used as an energy and food crop.

UANL: **U**niversidad **A**utónoma de **N**uevo **L**eón, México; http://www.uanl.mx

UCSC: **U**niversità **C**attolica del **S**acro **C**uore, Piacenza, Italy; http://www.unicatt.it

UniBO: **UNI**versità di **Bo**logna, Italy; http://www.unibo.it

Variety: Elite lines that are ready to be released as open pollinated variety

Variant: Term used here to summarise sweet, grain, biomass, energy and fibre sorghum.

Vinasse: By-product of the fermentation of molasses to e. g. ethanol.

WIP: WIP Renewable Energies, Germany; https://www.wip-munich.de

WP: Work package

9 Appendix

Appendix 9.1 Net Variable cost, Net Present Value (NPV), Internal Rate of Return and Break-even Price Analysis

Net Variable Cost

Variable costs are those that fluctuate with production volume.In this study the net variable cost is the sum of production, processing and transportation cost minus revenue from the by product.

Net present value (NPV)

Net present value (NPV) is an important financial index that plays a key role in decision making of long-term investment projects. A positive, higher NPV indicates that the net profits are higher so the investment may have favorable economic performance, or the investment is considered as economically feasible.

NPV is calculated as

$$NPV = \sum_{n=0}^{N} (B_n - C_n)/(1+d)^n$$

Where $B_n = P_{n*} Q_n$, Bn=Benefits or the returns from the distillery by selling ethanol and by-products, P_n is the ethanol selling price during year n, Q_n is the annual production volume of ethanol in year n, C_n = Costs of ethanol production during year n, d is the discount rate (the required rate of return), n is the economic life of the investment.

Internal Rate of Return (IRR)

The IRR refers to the average earned capacity of an investment/project during its economic life. It equals the discount rate when NPV is set to zero. In general, the IRR should be greater than the discount rate for a project for economic feasibility.

IRR is calculated as

$$IRR \Rightarrow \sum_{n=0}^{N} (B_n - C_n)/(1+d)^n = 0$$

B_n=Benefits or the returns from the distillery by selling ethanol, C_n=Costs of ethanol production, d is the discount rate (the required rate of return), n is the economic life of the investment.

Break-even Price Analysis

Break-even analysisis the analysis of the level of sales at which the firm breaks even. The break even price provides the finformation regarding what price to be charged to your goods/services.

Appendix 9.2Detailed Variable Cost Breakup

9.2.1 Sweet Sorghum Scenarios

Table 9.2.1.1 Cane Fallow: Stalk to Ethanol

Scenario: Cane Fallow			
Cost type	**Low**	**Typical**	**High**
Production cost/ha	441	695	1,089
Transport cost/ha	13	13	13
Processing cost/ha	196	572	1556
Total variable costs/ha	650	1280	2657
By-product (all relevant byproducts + Elect. From Surplus bagasse)/ha	221	411	770
Net Variable cost/ha	428	869	1887
Total output: Ethanol per ha (ltr/ha)	684	1,990	5,410
Cost per litre of ethanol	0.63	0.44	0.35

Table 9.2.1.2 Canefallow: Stalk + Grain to Ethanol

Variable Cost of Production (in Euros)			
Scenario: Cane Fallow + Grains to ethanol			
Cost type	**Low**	**Typical**	**High**
Production cost	459	747	1181
Transport cost	13	13	13
Processing cost	196	572	1556
Additional processing costs/ha	2	5	14
Total variable costs/ha	669	1338	2764
By-product (all relevant byproducts+Excess power)/ha	222	415	784
Net Variable cost/ha	447	922	1980
Ethanol from juice(ltr/ha)	684	1,990	5,410
Additional ethanol/ha from grains(ltr/ha)	392	1570	2750
Total output: Ethanol per ha (ltr/ha)	1,076	3,560	8,160
Cost per litre of ethanol	0.42	0.26	0.24

Table 9.2.1.3 Grain to food

Scenario: grain to food			
Cost type	**Low**	**Typical**	**High**
Production cost	459	603	747
Transport cost	13	13	13
Processing cost	196	377	572
Total variable costs/ha	667	993	1332
By-product/ha (stalk)	377	709	1048
Net Variable cost/ha	290	284	284
Ethanol from stalk(ltr/ha)	684	1,300	2,090
Cost per litre of ethanol	0.42	0.22	0.14

Table 9.2.1.4 Sweet Sorghum Syrup to Ethanol

Scenario: Syrup to Ethanol			
Cost type	**Low**	**Typical**	**High**
Production cost/ha	436	724	1159
Transport cost/ha (feed stock to village)	4	4	4
Transport cost/ha (Syrup to distillery)	21	21	21
Processing cost/ha	319	1001	2852
Total variable costs/ha	780	1751	4036
By-product valuation (surplus bagasse at village+syrup converted to ethanol)	224	778	1460
Net Variable cost/ha	555	973	2575
Total output: Ethanol per ha (ltr/ha)	468	1500	4380
Cost per litre of ethanol	1.19	0.65	0.59

9.2.1.1 Sweet Sorghum Scenarios with all relevant byproduct and surplus bagasse for feed

Table 9.2.1.5 Cane Fallow: Stalk to Ethanol

Scenario: Cane Fallow			
Cost type	**Low**	**Typical**	**High**
Production cost/ha	441	695	1,089
Transport cost/ha	13	13	13
Processing cost/ha	196	572	1556
Total variable costs/ha	650	1280	2657
By-product(all relevant byproducts+Electricity from surplus bagasse)/ha	116	296	727
Net Variable cost/ha	534	983	1931
Total output: Ethanol per ha (ltr/ha)	684	1,990	5,410
Cost per litre of ethanol	0.78	0.49	0.36

Table 9.2.1.6 Cane fallow: Stalk + Grain to Ethanol

Scenario: Cane Fallow + Grains to ethanol			
Cost type	**Low**	**Typical**	**High**
Production cost	459	747	1181
Transport cost	13	13	13
Processing cost	196	572	1556
Additional processing costs/ha	2	5	14
Total variable costs/ha	669	1338	2764
By-product(all relevant byproducts+Electricity from surplus bagasse)/ha	122	326	783
Net Variable cost/ha	547	1012	1981
Ethanol from juice(ltr/ha)	684	1,990	5,410
Additional ethanol/ha from grains(ltr/ha)	392	1570	2750
Total output: Ethanol per ha (ltr/ha)	1,076	3,560	8,160
Cost per litre of ethanol	0.51	0.28	0.24

Table 9.2.1.7 Grain to food

Scenario: grain to food			
Cost type	**Low**	**Typical**	**High**
Production cost	459	603	747
Transport cost	13	13	13
Processing cost	196	377	572
Total variable costs/ha	667	993	1332
By-product(all relevant byproducts+Electricity from surplus bagasse)/ha	273	600	939
Net Variable cost/ha	394	392	393
Ethanol from stalk(ltr/ha)	684	1,300	2,090
Cost per litre of ethanol	0.58	0.30	0.19

9.2.2 Biomass Sorghum Biogas and Bio-methane Scenarios

Table 9.2.2.1Biomass Sorghum to Biogas

Scenario: Biomass to Biogas			
Cost type	**Low**	**Typical**	**High**
Production cost/ha	**623**	**855**	**984**
Transport cost/ha	8	8	8
Processing cost/ha	802	1240	1500
Total variable costs/ha	1433	2104	2493
By-product/ha	8	12	14
Net Variable cost/ha	1425	2092	2478
Biogas out put (kwh/ha)	14900	23300	28000
Cost /kwh	0.10	0.09	0.09

Table 9.2.2.2Biomass Sorghum to Biomethane

Scenario: Biomass to Biomethane			
Cost type	Low	Typical	High
Production cost/ha	623	855	984
Transport cost/ha	8	8	8
Processing cost/ha	802	1240	1500
Total variable costs/ha	1433	2104	2493
By-product/ha	8	12	14
Net Variable cost/ha	1425	2092	2478
Bio methane output (kwh/ha)	12000	18700	22400
Cost /kwh	0.12	0.11	0.11

9.2.3 Biomass Sorghum Alternative Products Scenarios

Table 9.2.3.1Biomass sorghum for 2nd generation Ethanol

Table 9.2.3.1Biomass sorghum for 2nd generation Ethanol (Enzyme Price @0.003/g)

Scenario: Biomass sorghum for second generation Ethanol			
Cost type	Low	Typical	High
Production cost/ha	623	855	984
Transport cost/ha	8	8	8
Processing cost/ha	880	1466	1759
Total variable costs/ha	1511	2330	2752
By-product/ha	0	0	0
Net Variable cost/ha	1511	2330	2752
Ethanol output (ltr/ha)	3797	6329	7595
Cost per litre of ethanol	0.40	0.37	0.36

Table 9.2.3.2Biomass sorghum for 2nd generation Ethanol (Enzyme Price @0.008/g)

Scenario: Biomass sorghum for second generation Ethanol			
Cost type	**Low**	**Typical**	**High**
Production cost/ha	623	855	984
Transport cost/ha	8	8	8
Processing cost/ha	2345	3910	4692
Total variable costs/ha	2977	4773	5684
By-product/ha	0	0	0
Net Variable cost/ha	2977	4773	5684
Ethanol output (ltr/ha)	3797	6329	7595
Cost per litre of ethanol	0.78	0.75	0.75

Table 9.2.3.3Biomass Sorghum -Direct Combustion

Scenario: Biomass sorghum-Direct Combustion			
Cost type	**Low**	**Typical**	**High**
Production cost/ha	623	855	984
Transport cost/ha	8	8	8
Processing cost/ha	0	0	0
Total variable costs/ha	631	864	993
By-product/ha	0	0	0
Net Variable cost/ha	631	864	993
output (kwh/ha)	6190	9680	11600
cost per kwh	**0.10**	**0.09**	**0.09**

Table 9.2.3.4Biomass sorghum for FT Diesel-Direct Gasification

Scenario: Biomass sorghum -Direct Gasification			
Cost type	**Low**	**Typical**	**High**
Production cost/ha	623	855	984
Transport cost/ha	8	8	8
Processing cost/ha	2437	3804	4563
Total variable costs/ha	3068	4667	5556
By-product/ha	860	1340	1600
Net Variable cost/ha	2208	3327	3956
FT Diesel output (liter/ha)	1731	2705	3246
Cost /liter FT Diesel	**1.28**	**1.23**	**1.22**

Table 9.2.3.5Biomass sorghum for FT Diesel-Gasification with prior pyrolysis

Scenario: Biomass sorghum-Gasificationwith prior pyrolysis			
Cost type	**Low**	**Typical**	**High**
Production cost/ha	623	855	984
Transport cost/ha	8	8	8
Processing cost/ha	3196	5007	6007
Total variable costs/ha	3827	5871	7000
By-product/ha	102	160	192
Net Variable cost/ha	3725	5711	6808
FT Diesel output (liter/ha)	2223	3473	4168
Cost /liter FT Diesel	**1.68**	**1.64**	**1.63**

Table 9.2.3.2Biomass Sorghum -Direct Combustion

Scenario: Biomass sorghum-Direct Combustion			
Cost type	Low	Typical	High
Production cost/ha	623	855	984
Transport cost/ha	8	8	8
Processing cost/ha	0	0	0
Total variable costs/ha	631	864	993
By-product/ha	0	0	0
Net Variable cost/ha	631	864	993
output (kwh/ha)	6190	9680	11600
cost per kwh	**0.10**	**0.09**	**0.09**

Table 9.2.3.3Biomass sorghum for FT Diesel-Direct Gasification

Scenario: Biomass sorghum -Direct Gasification			
Cost type	Low	Typical	High
Production cost/ha	623	855	984
Transport cost/ha	8	8	8
Processing cost/ha	2437	3804	4563
Total variable costs/ha	3068	4667	5556
By-product/ha	860	1340	1600
Net Variable cost/ha	2208	3327	3956
FT Diesel output (liter/ha)	1731	2705	3246
Cost /liter FT Diesel	**1.28**	**1.23**	**1.22**

Table 9.2.3.4Biomass sorghum for FT Diesel-Gasification with prior pyrolysis

Scenario: Biomass sorghum-Gasificationwith prior pyrolysis			
Cost type	Low	Typical	High
Production cost/ha	623	855	984
Transport cost/ha	8	8	8
Processing cost/ha	3196	5007	6007
Total variable costs/ha	3827	5871	7000
By-product/ha	102	160	192
Net Variable cost/ha	3725	5711	6808

FT Diesel output (liter/ha)	2223	3473	4168
Cost /liter FT Diesel	**1.68**	**1.64**	**1.63**

Appendix 9.3 Breakup of Feed stock and processing cost across scenarios and cases (€/liter)

Table 9.3.1Sweet Sorghum Scenarios

Cases / Scenarios	Low		Typical		High	
	Prod	Proc	Prod	Proc	Prod	Proc
Cane Fallow: Stalk (Scenario 1)	0.65	0.42	0.35	0.42	0.20	0.42
Cane Fallow: stalk + Grains (2020)	0.43	0.26	0.21	0.23	0.14	0.28
Grain to food (Scenario 3)	0.67	0.42	0.46	0.42	0.36	0.40
Syrup at Village Level (Scenario 4)	0.93	0.81	0.48	0.80	0.26	0.78

Prod = Production, Proc = Processing

Table 9.3.2 Biomass to Biogas and biomethane

Biomass Sorghum Scenarios (Scenario 5)	Low		Typical		High	
	Prod	Proc	Prod	Proc	Prod	Proc
Biogas	0.04	0.05	0.04	0.05	0.04	0.05
Bio methane	0.05	0.05	0.05	0.05	0.04	0.05

Prod = Production, Proc = Processing

Table 9.3.3 Biomass Alternative Product Scenario

Cases/ Scenarios (Scenarios 5)	Low		Typical		High	
	Prod	Proc	Prod	Proc	Prod	Proc
Second generation Ethanol (in liter)	0.16	11.58	0.14	11.58	0.13	11.58
Direct Combustion (in kwh)	0.10	0.00	0.09	0.00	0.08	0.00
Direct gasification (in liter)	0.36	1.41	0.32	1.41	0.30	1.41
Gasification with prior pyrolysis (in liter)	0.28	1.44	0.25	1.44	0.24	1.44

Appendix 9.4Input Quantities

	Units (per ha × year)	Sweet sorghum Cane fallow	Sweet sorghum Grain to food	Sweet sorghum Syrup	Biomass sorghum
Agricultural inputs					
Seeds	kg	5-10	5-10	5-10	8
Pesticides	kg	5	5	2.5	5
Fertiliser*					
N	kg	350	260	350	356
P_2O_5	kg	120	90	120	125
K_2O	kg	380	285	380	450
Diesel fieldwork	L	90	85	90	110
Yields					
Biomass	t (dry matter)	20	15	20	25
Extraction efficiency	%	95	95	85	-
Sugar	t	3.1	2.0	2.8	-
Outputs					
Ethanol (from stalks)	t	1.6	1.0	1.2	-
Ethanol (from grains)	t	1.2	-	-	-
Surplus bagasse	t	3.7	4.5	5.5	
Biogas – power	kWh	-	-	-	23,300
– heat	MJ	-	-		17,100