Sweet Fuel

Sweet Sorghum
an alternative energy Crop

SEVENTH FRAMEWORK PROGRAMME
N° 227422

Sweet Sorghum as Energy Crop:

A SWOT Analysis

WIP

Authors: Dominik Rutz, WIP Renewable Energies, Germany
Rainer Janssen, WIP Renewable Energies, Germany

Contact: WIP Renewable Energies
Dominik Rutz and Rainer Janssen
Email: Dominik.rutz@wip-munich.de, rainer.janssen@wip-munich.de
Tel: +49 89 720 12 (-739/-743)
Sylvensteinstr. 2
81369 Munich, Germany
www.wip-munich.de

Published by WIP Renewable Energies, Munich, Germany, 2012

SWEETFUEL reference number: WP6, Task 6.4, D6.5

The main objective of SWEETFUEL is to exploit the advantages of sweet sorghum as potential energy crop through (1) the development of bioethanol production from sweet sorghum in temperate and semi-arid regions through genetic enhancement and (2) improvement of cultural and harvest practices for optimized yields. The SWEETFUEL partnership comprises 10 partners from research, academia and industry. Partners are based in Europe, India, Brazil, South Africa and Mexico. The SWEETFUEL project duration is January 2009 to December 2013 (Contract Number: FP7-227422).

SWEETFUEL website: www.sweetfuel-project.eu

Acknowledgements

The Authors would like to thank the European Commission for the support of the SWEETFUEL project and the coordinator of the project Serge Braconnier from CIRAD and his colleagues for managing the SWEETFUEL project.

The authors highly acknowledge the comments and input to this study from the SWEETFUEL consortium members: Serge Braconnier, Delphine Luquet, Gilles Trouche, Anne-Marie Schelstraete (CIRAD - Centre International en Recherche Agronomique pour le Développement), Belum Reddy and Srinivas Rao (ICRISAT - International Crops Research Institute for Semi Arid Tropics), Robert Eugene Schaffert, Rafael Parrella and Cynthia Damasceno (Embrapa - Empresa Brasileira de Pesquisa Agropecuaria), Guido Reinhardt, Nils Rettenmaier and Maria Müller-Lindenlauf (IFEU - Institut fuer Energie und Umweltforschung), Andrea Monti, Walter Zegada-Lizarazu and Verdiana Bandini (Alma Mater Studiorum-Universita di Bologna), Stefano Amaducci and Adriano Marocco (Universita Cattolica del Sacro Cuore), Francisco Zavala-Garcia (Universidad Autónoma de Nuevo León), Arndt Zacharias (KWS SAAT AG), Wikus Snijman, Nemera Shargie, and Hannelie Terblanche (Agricultural Research Council), and Marcel Bursztyn.

Furthermore, we thank various stakeholders who provided feedback to the SWEETFUEL questionnaire used for this study: Hal Debor (Debor Consulting), Tom Maate Wa' Bukombi (Biogreen Investments East Africa Limited), Peter Sandfort (KATZEN International, Inc.), Xiao Mingsong and Wang Mengjie (China Association of Rural Energy Industry), Julio Menendez (INTA), Thanos Balafoutis (Agricultural University of Athens), Tsiokou Basiliki (Hellenic Organisation for Agricultural Insurances), Ioannis A. Panagiotopoulos (University of British Columbia), Artemios Chatziathanassiou (Managing Authority of the Rural Development Plan 2007-2013 of the Greek Ministry of Rural Development and Food), Paloma Manzanares Secades (CIEMAT - Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas), and Hamimu Hongo (FELISA).

Content

1. Introduction

The energy crop sweet sorghum (*Sorghum bicolor* L. Moench) is raising considerable interest as a source of either fermentable free sugars or lignocellulosic feedstock with the potential to produce fuel, food, feed and a variety of other products. Sweet sorghum is a C_4 plant with many potential advantages, including high water, nitrogen and radiation use efficiency, broad agro-ecological adaptation as well as a rich genetic diversity for useful traits. For developing countries sweet sorghum provides opportunities for the simultaneous production of food and bioenergy (e.g. bio-ethanol), thereby contributing to improved food security as well as increased access to affordable and renewable energy sources (Rao et al. 2009). In temperate and usually more industrialised regions (e.g. in Europe) sweet sorghum is seen as promising crop for the production of raw material for 2^{nd} generation bio-ethanol.

The project SWEETFUEL (Sweet Sorghum: An alternative energy crop) is 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 (Braconnier et al. 2011b). Thereby, the main objective of SWEETFUEL is to optimize yields in temperate and semi-arid regions by genetic enhancement and the improvement of cultural and harvest practices.

In order to get an overview of advantages and disadvantages of different sweet sorghum and biomass sorghum value chains a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was conducted in the framework of the project. Thereby, the analysis investigated several sweet sorghum value chains under different framework conditions: subtropical, tropical and temperate climate. The value chains include the cultivation of sweet sorghum, conversion to different products and end use of the products. More details on sweet sorghum value chains and on scenarios for the sweet sorghum products are described in the report “Handout for the Workshop on Definitions and Settings” (Braconnier et al. 2011a).

2. Method

The breeding programme of the SWEETFUEL project has different main objectives depending on the local circumstances and value chains. In line with these objectives, the following terminology and abbreviations were selected which are used in the SWOT tables:

- **S** as abbreviation for sorghum as energy crop
- **SS** as abbreviation for sweet sorghum with the objective to maximize sugar content and yields
- **BS** as abbreviation for biomass sorghum with the objective to maximize (ligno-cellulosic) biomass yields
- **GS** as abbreviation for grain sorghum with the objective to maximize grain yields.

2.1. The SWOT analysis

A SWOT analysis is a strategic planning tool used to evaluate the Strengths, Weaknesses, Opportunities, and Threats involved in a project or business venture. It involves ***specifying the objective*** of the business venture or project and identifying the ***internal and external factors that are favourable and unfavourable to achieving that objective***.

In this report the SWOT analysis is applied to different value chain systems of sweet sorghum as an energy crop. Factors which are internal to the sweet sorghum pathways (characteristics of cultivation and conversion) are classified as Strengths (S) or Weaknesses (W), and those external to the sweet sorghum pathways (regarding markets, policies and sustainability certification) are classified as Opportunities (O) or Threats (T). The SWOT matrix is shown below.

	Favourable to achieve the objective	Unfavourable to achieve the objective
Internal	**Strengths**	**Weaknesses**
External	**Opportunities**	**Threats**

Figure 1: General scheme of the SWOT tables

2.2. Objective of the analysis

The objective of the SWEETFUEL sustainability analysis is **to identify the best pathways to produce and use sweet sorghum as energy crop from an ecological, economic and social point of view**.

The SWOT analysis is a tool to contribute to this objective. Results of the SWOT analysis shall help in decision making processes for improved sweet sorghum value chains in different climates and framework conditions in order to:

- ensure competitiveness/complementary with other energy (bioethanol) crops
- ensure competitiveness with fossil based energy/products
- guarantee environmental, social and economic sustainability

The SWOT analysis describes the state-of-the-art of sweet sorghum chains in order to formulate optimisation strategies for sweet sorghum production and use pathways. Also potential future developments are considered and integrated in the SWOT analysis. Thereby, the timeframe includes the years 2014 (the real situation at the end of the SWEETFUEL project) and 2020 (expected future based on conservative assumptions).

2.3. Stakeholder involvement

In order to complete the SWOT tables, an extended stakeholder review was included in the analysis. A “Workshop on SWEETFUEL SWOT Analysis” was organised on 17 April 2012 in Bologna, Italy. Furthermore, the draft SWOT analysis report and a dedicated questionnaire (see Annex) were sent to stakeholders for input. Many stakeholders provided very useful comments which were included in the final report. The stakeholders are listed in the Acknowledgements of this report.

2.4. Structure of the SWOT analysis

Sweet sorghum is a promising energy crop adaptable for different climatic conditions and providing a large variety of products and by-products, such as energy, food, fodder, and fibre. This is the result of the large genetic variability of the *Sorghum* genus leading to a wealth of different genotypic and phenotypic traits of sweet sorghum varieties. Therefore, strengths, weaknesses, opportunities and threats are also very diverse among sweet sorghum varieties and different value chains in productions systems.

However, several characteristics are common to sweet sorghum as an energy crop and thus, in a first step (chapter 3), the SWEETFUEL SWOT analysis describes general strengths, weaknesses, opportunities and threats of sweet sorghum.

In a second step, SWOT analyses are elaborated for different production systems in subtropical/tropical (chapter 4) and temperate climate zones (chapter 5). These production systems include centralized ethanol, decentralized syrup and decentralized ethanol systems in subtropical/tropical climate as well as biogas, lignocellulose-ethanol, direct combustion and gasification systems in temperate climate. For several of these systems two SWOT tables are shown: one for the sweet sorghum cultivation and one for sweet sorghum conversion to end products. Thereby, end products may include energy carriers (e.g. biogas), energy (e.g. electricity), fertilizer (e.g. digestate), food (e.g. grains), fodder (e.g. leaves, bagasse) and other co-products. The use of energy carriers for different purposes is included in the SWOT table.

In summary, the following analyses are made and described in dedicated chapters:

- General SWOT for sweet sorghum
- Subtropical and tropical climate
  - Centralised production system (cultivation and conversion)
  - Decentralised syrup production system (cultivation and conversion)
  - Decentralised ethanol production system (cultivation and conversion)
- Temperate climate
  - Biogas production system (cultivation and conversion)
  - Lignocellulose-ethanol production system (cultivation and conversion)
  - Direct combustion system (cultivation and conversion)
  - Gasification system (cultivation and conversion)

The SWOT tables are providing brief statements (in bullet form) on the strengths, weaknesses, opportunities and threats of the production systems. These tables shall allow a quick overview about advantages and disadvantages of each production system.

The SWOT statements address a large variety of environmental, social and economic sustainability aspects. Depending on the value chain, these statements may include the following sustainability aspects.

(a) Land use

- Land use and land use change
- Competitive land use
- Land use conflicts

(b) Social aspects

- Benefits for smallholders
- Income opportunities
- Employment opportunities
- Change in traditional use and knowledge
- Supply with modern energy as substitute for traditional bioenergy
- Energy security

- Gender aspects
- Working conditions
- Health
- Food security
- Food and feed prices

(c) Environment

- GHG emissions
- Human- and ecotoxicity
- Biodiversity
- Soil conservation and soil quality
- Water availability, use and efficiency
- Water quality
- Resource depletion
- Eutrophication (terrestrial and aquatic)
- Acidification

(d) Economics

- Productivity and processing efficiency
- Competitiveness and comparative advantage of the feedstock
- Net energy balance
- National revenues, gross value added
- Energy security (security of supply)
- Infrastructure and logistics
- Pricing of the end products
- State of commercialization / competitiveness with reference products

Finally, a core focus is placed on the competition between the biomass uses for food, feed, fibres, and biofuels and on different scales of sweet sorghum production and use. Furthermore, **policy aspects** such as different policy framework conditions in target countries as well as issues of **social acceptance and public perception** are taken into account.

3. Sweet sorghum as energy crop: general analysis

3.1. Description of the general sweet sorghum value chain

The general value chain of sweet sorghum production systems is similar to other bioenergy/biomass production systems. General value chain steps include:

- Crop cultivation
- Harvesting
- Transport
- Milling (1st process step)
- Processing (2nd process step)
- Transport
- End use

A schematic overview of general sweet sorghum production and use pathways is shown in Figure 2. The life cycle of sweet sorghum includes cultivation, processing, use, as well as end-of-life treatment, recycling and final disposal ("cradle-to-grave approach"). All inputs into and outputs from the system are taken into account including the several by-products obtained.

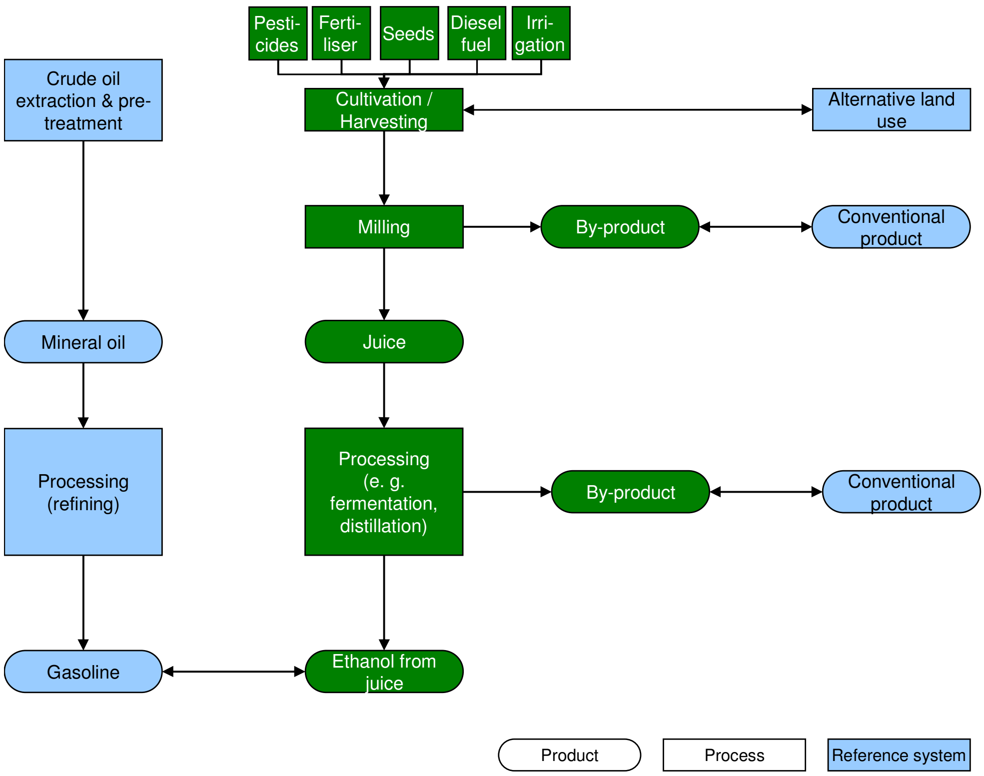

Figure 2: Basic principle of life cycle comparison between sweet sorghum ethanol and gasoline (Braconnier et al. 2011a)

3.2. SWOT for sweet sorghum as energy crop

This chapter presents a SWOT analysis for sweet sorghum as an energy crop describing general strengths, weaknesses, opportunities and threats of sweet sorghum. Thereby, specific reference is made to comparisons with other energy (bioethanol) crops as well as with fossil based energy/products.

Table 1: SWOT for sweet sorghum as energy crop

S1 **High genetic variability** of S provides good breeding opportunities in order to create new improved varieties. S2 S is permitting **multiple breeding generations** per year due to a short growth cycle (3-4 months). S3 **Genetics of S are relatively well known**, genetic diversity is extensive and maintained. S4 S can grow in a **broad environmental range** from tropical to temperate regions. S could be a promising energy crop in both developed and developing countries as well as for small and large scale value chains. S5 S as energy crop can be cultivated and further processed at very **different scales**, thus smallholders, but also industry could benefit. S6 S is characterized by **high water, radiation and nutrient use efficiency** in comparison to other energy crops (e.g. maize, sugar cane) S7 S is also suitable for **cultivation on marginal soils**, thus reducing potential LUC and ILUC impacts. However, yields are lower on marginal soils. S8 As an **efficient C4 plant**, S is one of the most efficient crops to convert atmospheric CO_2 into sugar and starch. S9 S is an **annual crop with a short growth cycle**, which can be easily integrated in many cultivation systems. In tropical climates the short growth cycle facilitates several harvests per year, creating opportunities for double cropping. S10 In tropical and sub-tropical climates S is very suitable to be **integrated with sugar cane cultivation**. This leads to strong interest of sugar cane producers (e.g. in Argentina, Colombia) in S cultivation. S11 The **crop rotation cycle** of S is very flexible facilitating many different crop sequences. S12 S is suitable for **intercropping**. S13 S can be well adapted to **no-till planting**. S14 **Full mechanization** of S cultivation is possible, thus, allowing for industrialized value chains. S15 **All aboveground parts of the plant (stalk, leafs, grain) are valuable products**. Since the potential use of S is very broad, it can be used for the production of food (sugar, grains), 1st and 2nd generation ethanol, biomaterials, electricity from bagasse combustion, thermochemical biofuels and products, biogas, feed and fodder. S16 **Commercial technologies are available** for ethanol production from S. S17 Bagasse and leaves can be used as **fuel** for process energy and power generation, thus creating a good GHG balance. S18 Bagasse and leaves can be used as **fodder**, which is an opportunity to subsistence agriculture of small-scale farmers. S19 Small-scale farmers could sell the juice or even the syrup or ethanol, while using grains and leaves as **food** / **fodder** for their own needs. Benefits for small-scale farmers include income generation. S20 S ethanol can contribute to **fossil energy and GHG savings** compared to conventional fuels. S21 Small-scale cultivation of S in rural communities can **benefit local energy supply** through production of ethanol in micro-distilleries and use of ethanol in adapted generators.	W1 Specific **S varieties** for ethanol production are insufficient. Availability of commercial seeds of well-defined SS cultivars is limited. W2 **Specific traits** important for the ethanol industry (e.g. yield of juice, sugar, ligno-cellulose, grain, total biomass) still need to be defined for rapid genetic improvements. Thereby culture and conditions in growing countries and regions have to be taken into account. W3 For the improvement of the S value chain, research on **new cultivars** is needed. W4 Genetic improvement and crop management of S for **sugar yield increases** has lagged behind other crops. W5 Lack of better understanding of **interaction of genetic factors** (associated with sugar and juice potential) **with environmental factors.** W6 There exists a knowledge gap on S **biotic and abiotic stress management** (e.g. weeds, insects, pathogens, soil, water). W7 Breeding efforts risk being mainly achieved for cultivars in **developed countries** (temperate to sub-tropical regions), but not for cultivars in developing countries (sub-tropical to tropical regions) due to the lack of resources. W8 **Intellectual Property** (IP) issues hinder free sharing of germplasm among S researchers. W9 The release of new industrially developed hybrids risks of being **not affordable for small-scale farmers**. W10 Introduction of newly developed S cultivars may pose **risks for traditional cultivation** activities of the rural population. W11 **S as energy crop is still relatively new** to many farmers. If not actively promoted there is a threat to be not sufficiently recognized by farmers. W12 Large scale S cultivation for industry needs **many hectares** that are difficult to be organized for a centralised industrial plant. W13 Large-scale industrial S producers may not be interested in the production of both food and ethanol and thus may have a negative impact on (local) **food security**. W14 **Environmental risks** of large-scale S cultivation may include (depending on the cultivation system) negative impacts on biodiversity, soil erosion, soil compaction, soil fertility as well as surface and ground water resources. Monocultures have negative impacts on the landscape. W15 As SS is a new crop, wrong agricultural practices could lead to environmental problems (to high application of fertilizers and pesticides/herbicides, wrong irrigation, etc.) W16 **Sugars of SS rapidly degrade**. The fresh stalks have to be processed quickly and cannot be stored for a long period. W17 Simple and cheap methods to **stabilise SS juice** have not yet been developed. W18 **Harvesting technologies** for separate seed, stalk and leaf harvest are not yet mature. If no new harvesting technologies for separate seed, stalk and leaf harvest is developed, SS risks of being only sugar or starch crop and not both. W19 Technologies for **small-scale ethanol production** (micro-distilleries) are under development (pilot installations exist) and not yet commercially mature.

S22 S can contribute to **food security** (grains). S23 S is a **climate-change ready crop**. S24 S can be cultivated as a **ratoon crop** (even two ratoon crops are feasible e.g. in the Philippines). S25 S is **photo sensitive** under certain conditions providing high biomass production. S26 **Harvest time** as well as **sugar** and **juice behaviour** is not the same for all genotypes.	W20 **Generators operating on ethanol** are available, but not very common. W21 S has **poor tolerance to cold** in temperate climate. W22 S has **short harvesting season**, usually 20-40 days, resulting in a limited feedstock supply period through the year. W23 Grains from some high biomass yielding natural S varieties have **too high tannin contents** for food or feed. W24 **Resources invested** in studying SS is very little compared to investments in e.g. maize or sugarcane.
O1 Generally, the global **demand for biofuels** is increasing (e.g. through mandates and targets), thus creating market opportunities for bioethanol from S. O2 Emergence of **new market opportunities for ethanol** fuel (e.g. aviation, heavy vehicles, households, rural electrification, military vehicles) may provide opportunities for S ethanol. O3 **Increasing global investment in the agricultural sector** may also support global S cultivation. O4 Technology development on ethanol production from sugars and ligno-cellulosic feedstock may **reduce production costs** and improve the efficiency of the S value chain. O5 GMO free S cultivation may be beneficial to access **European markets**. O6 **Regulations and standards** (quality and sustainability) for ethanol blending in gasoline exist in many countries, thus ensuring market opportunities for ethanol production. O7 **Variable sugar** / **ethanol production** of industrial sugar-bio refineries is generally possible and would be an opportunity to sell products to the best market prices. O8 **Diversification of crops** mitigates risks of the sugar industry associated to the reliance on only few crops. O9 The **trend of increasing fossil fuel prices** increases competitiveness of biofuels, including ethanol from S. O10 **Biofuel promoting policies** currently provide strong incentives for the development of the ethanol sector worldwide. O11 The introduction of **policies on climate change** mitigation and adaptation creates opportunities for the use of new energy crops such as S. O12 **Policies on rural development** which focus on the support of small-scale farmers may also support S production through e.g. out grower schemes. O13 Globally the importance for **increased research initiatives on agricultural commodities** is acknowledged. This may also lead to available funding to further improve S varieties. O14 **Support for biofuels from ligno-cellulosic feedstock** (e.g. through the "double counting" under the RED) may stimulate S as energy crop in temperate regions. O15 Global **sustainability certification schemes** for biofuels are established (e.g. Bonsucro, ISCC, RSB) facilitating proof of sustainability to positively influence public perception. O16 **Discussions on food-fuel conflicts** create opportunities for double purpose crops such as S (ethanol, grains). This may also improve public acceptance for ethanol from S. O17 **Increased droughts and increasing water scarcity** due to climate change favour water use efficient plants such as S. O18 For most crops **yield increases** are achieved over time due to cultivation improvements. This may facilitate competitiveness of S ethanol. O19 Alternative valorisation chains are under development for S based **hydrogen production**. O20 Alternative valorisation chains are under development for S based **biomaterials production** (building material, car industry). O21 Opportunities exist for breeding high yielding varieties of S for **staggered sowing and for post rainy season**. O22 Opportunities exist for valuation/quantification of **environmental benefits** to be incorporated with economic and sustainability perspectives.	T1 Current and future **prices for ethanol** from S could be too high when compared with other current and future products (fossil fuels, 2nd generation fuels), especially in subsidised fossil fuel markets. T2 Increasing **global prices of agricultural commodities** may also affect S and reduce the competitiveness of S ethanol. T3 Limited information is available on **cost of production of S ethanol** in comparison with other crops. T4 **Changes in macro-economic factors** (economic growth, unemployment, interest rates, exchange rates) may negatively affect the prospects of S ethanol. T5 Move towards alternative transport, including **electric vehicles**, may affect biofuel markets worldwide. T6 Most experience on ethanol production in tropical and subtropical regions was made with **sugarcane** and not with S. S risks of remaining a niche crop. T7 Limited market opportunities exist for value-added **co-products** of S compared to e.g. DDG from corn based ethanol production. T8 Changes in **ethanol-promoting policies** as well as trade policies may negatively affect the prospects of S ethanol. T9 As long as no breakthrough in **international climate change policies** can be achieved, the support for and demand of biofuels will be limited. T10 Instable **political and economic framework conditions** in developing countries hinder fast promotion of S, especially in tropical and subtropical regions. T11 If **research on S is not financially supported** only limited improvements in S breeding and crop management can be achieved. Lack of financial support especially in developing countries for S research do not allow efficient and fast progress in breeding of new varieties which are adapted to specific climates in many developing countries. T12 Limited access to **capital markets** as bankers lack understanding of S potential as biofuel feedstock. T13 General **negative image of imported biofuels** into the EU may also affect bioethanol production from S in other continents. T14 General increasing **resource competition** (land, water) for food, fuel, and fibres may lead to conflicts and reduce available land for S cultivation. T15 **Barriers to entry and licensing issues** in developing countries act as a threat for viability of ethanol production from centralized production systems. T16 **Lack of policy support** in the initial years will lead to industry exiting the business. T17 **Social instability** may affect land productivity in general. T18 **Lack of adequate infrastructure** may limit the S from field to refinery. T19 Large-scale industrial S production may lead to **land use conflicts** between industrial operators and small-scale farmers.

O23 **Incentives** to the industry focused on bioenergy, such as **land use or tax rates**. O24 **Alternative products** of SS can be potable alcohol (a high proof alcohol that is drinkable), syrup as a sweetener from the juice, and beer. Stalks can be alternatively used as cooking fuel. The farmer has generally different market choices.	

4. Sweet sorghum in subtropical and tropical climate

The sustainability of the cultivation and conversion of sweet sorghum in subtropical and tropical climate is affected by various factors. Since many potential cultivation areas of these climate regions are either in developing or emerging countries, socio-economic impacts, negative or positive, are of very high importance. In addition, these climate regions are especially prone to impacts of climate change which may affect the poorest people, namely small-scale and subsistence farmers.

In the following chapters SWOT tables are described for sweet sorghum value chains at different scales. They include the cultivation of sweet sorghum, conversion to ethanol and use of the different products. The following three systems are described:

- Centralized ethanol production system
- Decentralized syrup production system
- Decentralised ethanol production system

Whereas for the agricultural cultivation of sweet sorghum for the two decentralised systems is always rather small-scale and at village level, for the centralized production system the agricultural cultivation of sweet sorghum can be both small-scale (outgrower scheme, independent smallholders) or large-scale (managed by the central ethanol plant). Also mixed concepts of feedstock supply are possible.

Generally, the following parameters characterize the agricultural and conversion systems of the sweet sorghum ethanol chain having a large impact on sustainability issues:

- Scale of the system
- Actors of the cultivation system: farmers, industrial farming
- Actors of the production system: villagers, centralized ethanol plant
- Business relationships between the actors: outgrower model, cooperatives, contracted workers
- Economy of the country: emerging country, developing country

4.1. Centralized ethanol production system

This chapter presents a SWOT analysis for centralized ethanol (and cooking gelfuel) production from sweet sorghum for semi-arid tropical climates. Merely the cultivation and harvesting of sweet sorghum is performed at village level. After harvest, the sweet sorghum stalks are transported from the villages to centralized ethanol facilities. A schematic overview of the centralized production system is presented in Figure 3.

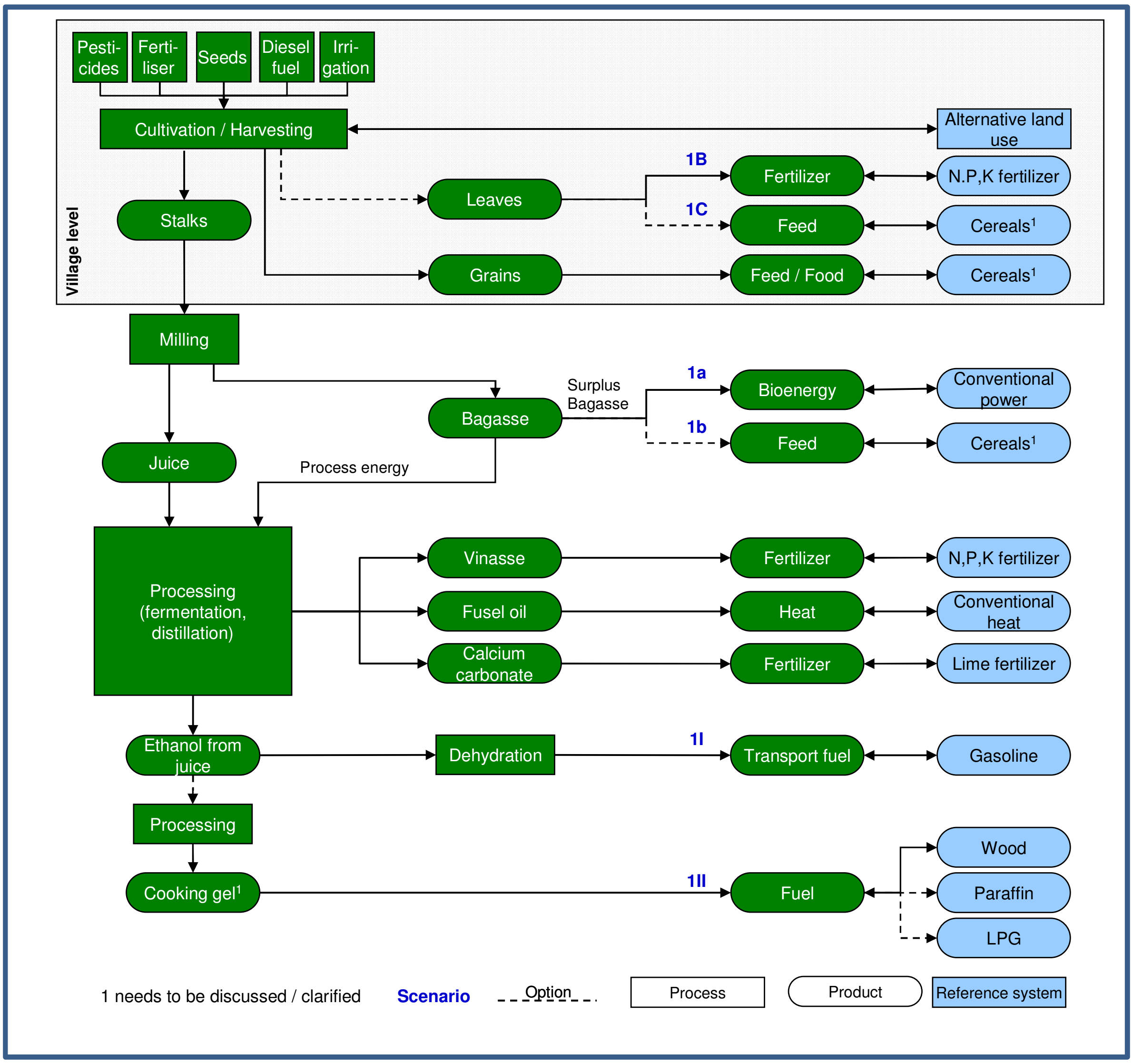

Figure 3: Centralized ethanol production system (Braconnier et al. 2011a)

Table 2: SWOT for centralized ethanol production system

S1 Small scale farmers can produce their own **seed** material. S2 If centralized ethanol plants set-up own large-scale SS plantations, the SS **yields** may be considerably high, since also the cultivation of SS is industrialized. S3 Costs for **input material** (seeds, fertilizer, pesticide) are reduced due to the large quantities bought by centralized ethanol plants. Input materials can be applied very efficiently, without major losses. S4 In larger facilities, **harvests** (grains, stalks, sugar juice) can be stored with less losses in quantity and quality. S5 If centralized ethanol plants and smallholders have established **agricultural maintenance contracts**, also the SS yields from small farmers may be higher as farmers are well trained in cultivation practices and receive input support (seeds, fertilizer, pesticide). S6 If **suitable outgrower schemes** are implemented (ensuring a fair share of revenues) centralised systems can contribute to wealth creation at local level. S7 SS enriches the **diversity of agricultural products** of small farmers, thus reducing risks if only one or few crops are cultivated. Furthermore SS is edible and can be used as multi-purpose crop for own consumption, which is not possible for other (toxic) crops like Jatropha. S8 If **harvest is mechanized**, the efficiency (time) is high. S9 **Manual harvesting** generates jobs, the carbon balance is good. In low labour cost countries, manual harvest is cheap. S10 Since most of the conversion process is made by industrial facilities, the overall **conversion efficiency** is high. S11 **C**entralised systems facilitate the implementation of **modern and well maintained technologies**. S12 **Good management practices** of centralised systems lead to high overall production efficiency and high product quality. S13 **High investment opportunities** of centralised systems lead to high overall production efficiency. S14 Centralised production systems have access to **better trained and higher skilled workforce**. S15 **Average salaries** may be higher in centralised production systems. S16 **Co-products** such as vinasse, fusel oils and carbonisation lime can be further used: Vinasse and carbonisation lime as fertilizer, fusel oils as process energy or industrial applications. S17 The **use of leaves and grains** can contribute to increase welfare of villagers at local level. S18 **Bagasse** can be efficiently converted into electricity by the centralized ethanol plant. Rural electrification schemes may be implemented. S19 SS is the next best **alternative feedstock for ethanol production** under centralized systems after molasses in the semi-arid conditions. S20 SS could **compete** with other dry-land crops for cultivation and land use.	W1 If centralized ethanol plants set-up own large-scale SS plantations in developing countries, this may happen by negatively **affecting the poor** (land grabbing). Since smallholders are not involved, there is no revenue generation for local farmers unless contract agriculture can be established. W2 The risk of creating **monocultures** for the SS cultivation in a centralized ethanol plant is larger than in small-scale scenarios. SS could replace other crops and thus compete for land. W3 Centralised production systems expose the danger of **increased negative environmental impacts** (e.g. soil fertility, soil compaction, deforestation). W4 **Mechanized harvest** reduces the number of needed workers. W5 **Manual harvest** is heavy work. Health of contracted farmers by the centralized ethanol plant risks of being negatively affected. W6 Centralized production facilities may not be interested in harvesting also **grains**. Thus, there is the risk that varieties with low grain yields are cultivated, or that grains are not collected during harvest. W7 **Harvesting stages** may be different for grain (food) and sugar or biomass production. W8 Since the value chain ends for the smallholders at selling the stalks to the centralized ethanol plant, only **small revenues** can be generated by the feedstock producers. W9 The sale of the stalks depends on the centralized ethanol plant which is buying the stalks. If only few local mills exist, farmers have no influence on the stalk prices and are thus **vulnerable**. W10 The **cultivation productivity** of SS is generally smaller in value chains in which smallholders are involved. W11 Since **sugars of harvested SS rapidly decay**, stalks have to be rapidly transported to the centralized facility. This limits the size of the centralized plant and of transport distances. Delay in transportation of stalks to the distillery also leads to financial loss to both the grower and the processor. W12 Centralised production systems may involve **higher transportation costs** due to bulkiness of the stalks. W13 Centralised production systems cause **higher standards and investment for infrastructure**. W14 **Electricity from bagasse** risks of not being accessible for villagers. W15 **Bad sustainability practices** (e.g. working conditions for harvesters and field workers) of internationally traded SS ethanol may contribute to a general negative public perception of biofuels. W16 SS is a season bound crop and can produce **feedstock only for a limited period of 3-4 months**. W17 SS has **short sowing window** as it is a rain-fed crop. W18 SS processing to ethanol under centralized systems require **extensive coordination**, planning and mobilisation of farmers for large scale cultivation. W19 High **costs of knowledge dissemination in the form of continuous technical advice apply**. W20 In centralized systems (with mechanical harvesting technologies) less workers may be needed, thus **avoiding job opportunities**.
O1 Several countries in tropical and sub-tropical regions are introducing national targets and mandates for the use of ethanol in the transport sector. Emergence of **new national market opportunities for ethanol** fuel may provide opportunities for SS ethanol, especially produced on larger scale. O2 **Globalised markets of agricultural commodities** support rather large-scale production systems instead of small-scale. O3 Centralized ethanol plants have more capacities to **sell**	T1 Higher **global ethanol prices** usually make it more attractive for centralized ethanol producers to sell the ethanol to large markets (export markets) instead of providing it to local energy markets. Thus, poor people in developing countries have no improvement regarding access to modern energy (electricity). T2 **High investment** needed for the construction of a centralised ethanol plant requires involvement of investors and a well-defined energy policy. T3 Several countries in tropical and sub-tropical regions are

either sugar or ethanol to best market prices. O4 Good **quality of ethanol** allows selling ethanol to global markets. O5 Centralized ethanol plants have more opportunities for **access to financing**. O6 **Carbon or green certificates** may contribute to additional revenues, especially for large-scale production. O7 **Energy policies** usually support larger scale production. O8 The larger **efficiency** of large scale processing chains contributes to earlier competitiveness with fossil fuels. O9 **Policies on rural development** usually support smaller scale production units, but may also support out grower schemes of centralized SS ethanol plants. O10 **Sustainability certification schemes** may be more readily implemented within centralised production systems. O11 **Monitoring of sustainability impacts** is easier within centralised production systems. O12 Opportunities exists to **integrate SS with sugarcane crushing units** during lean season of sugarcane crushing. O13 Opportunities for breeding varieties suitable for **staggered sowing**. O14 Opportunities for breeding varieties for **post rainy season** to increase the feedstock availability. O15 Large scale SS production can bring **other types of business** such as machinery, shops to repair machinery, trucks for transportation etc.	currently introducing **policies against the set-up of large-scale plantations** for biofuel production in order to avoid land-grabbing. T4 Markets for other agricultural products for food, feed and fibre contribute to increased **land use competition**, thus putting pressure especially on large-scale systems. T5 Larger production facilities are generally more prone to have negative sustainability impacts. Negative **public perception** on biofuels may thus make it difficult for these facilities to market their products. T6 Centralised production systems may face **objections by (international) NGOs**. T7 **Ethical and justice concerns** may arise as poorer countries (small scale farmers) cannot guarantee any protection against being priced out in the international markets. T8 Centralized production units may not be interested in harvesting grain and might be a **threat to food security** of smallholder farmers.

4.2. Decentralized syrup production system

This chapter presents a SWOT analysis for a partially decentralized ethanol (and cooking gelfuel) production from sweet sorghum for tropical climates. In addition to the cultivation and harvesting of sweet sorghum, also the production of syrup from sweet sorghum juice is performed at village level. The syrup is then transported from the villages to centralized ethanol facilities. This system holds advantages if the infrastructure for biomass transportation to large centralized production units is insufficient or not existent and it provides enhanced value creation at village level. A schematic overview of the decentralized syrup production system is presented in Figure 4.

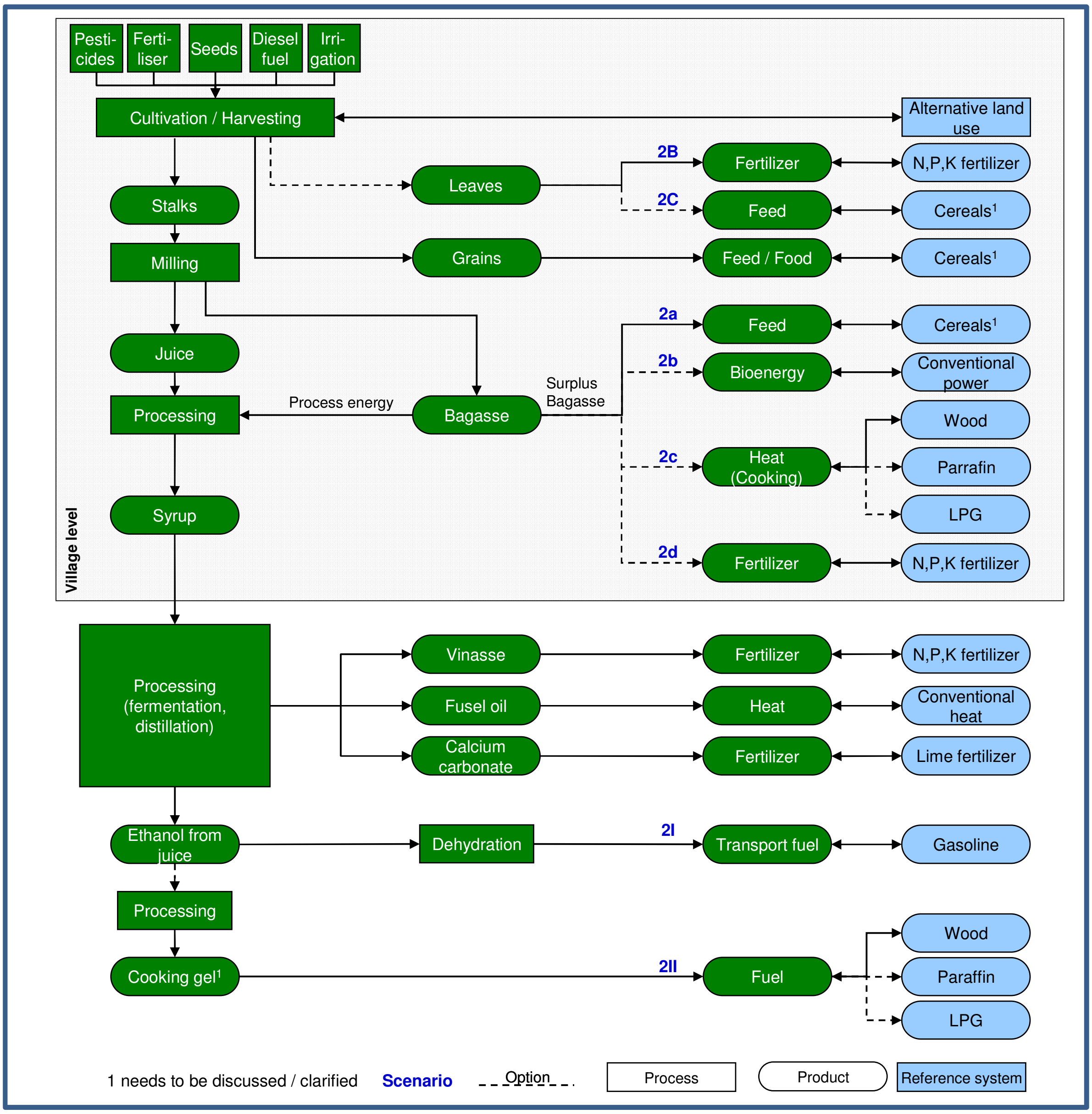

Figure 4: Decentralized syrup production system (Braconnier et al. 2011a)

Table 3: SWOT for decentralized syrup production system

S1 Small scale farmers can produce their own **seed** material. S2 In cases where **infrastructure for biomass transportation** is insufficient or not existent, decentralized syrup or ethanol production may be a good opportunity since smaller quantities have to be transported in comparison to the transport of SS stalks. S3 Cultivation and harvesting of SS on village level allows farmers also to harvest **grains** for food and fodder production. S4 The use of **leaves and grains** can contribute to increase welfare of villagers. S5 SS enriches the **diversity of agricultural products** of small farmers, thus reducing risks if only one or few crops are cultivated. Furthermore SS is edible and can be used as multi-purpose crop for own consumption, which is not possible for other (toxic) crops like Jatropha. S6 **Bagasse** remains at village level, thus it can be used for feed substituting other fodder. Also the use of power, heat and as fertilizer at village level is possible. S7 Transport is reduced since **bagasse** remains at the syrup production site at the village. Thus, general logistics are improved. S8 The **production window** of ethanol plant can be broadened due to longer storability of syrup than SS juice. S9 A **longer value chain** for syrup production on village level generates more local revenues in comparison to the sale of stalks, only. S10 Decentralized syrup production and further processing in a centralized ethanol plant is a good **compromise between small-scale and large scale systems** which has the potential to integrate many sustainability benefits. S11 Centralised ethanol production from syrup guarantees **higher product quality**. S12 Syrup production under decentralized system helps in **enhancing the income** of the smallholder farmers through generation of additional employment due to syrup production. S13 Farmer's collective action in processing sweet sorghum to syrup **strengthens the community** as a whole. S14 Syrup production is **environment friendly** as it does not produce any pollutants. S15 Syrup can be used directly as a **source of energy for the families** or sold or exchanged for other food products within the village.	W1 SS cultivation and syrup production on village level is usually **less efficient** than on larger scales. W2 The use of **bagasse** for power generation is less efficient and more expensive at smaller scales (village level). Thus in many cases, a bagasse combustion and power generation unit at village level is not affordable. W3 **Equipment for syrup production** (presses, evaporators) may be too expensive for villagers. Initial cost of establishment of decentralised crushing unit and processing at village level is high. W4 Decentralised syrup production may use **low quality equipment and lead to lower efficiencies and lower product quality**. W5 In many developing countries there is **lack of education**. . Farmers need to adapt some production practices, such as adaptation of production calendars, to ensure high brix values and avoid loss of quality. Managing a syrup production facility would require additional training and education and hence costs of knowledge dissemination are high. W6 The sale of syrup depends on the centralized ethanol plant which is buying the syrup. If only few local mills exist, farmers have no influence on the syrup prices and are thus **vulnerable**. **Low bargaining power** of the farmers due to high cost of syrup production. W7 **Inability of the decentralized unit to supply large quantity of syrup** as feedstock as required by the centralized processing unit. W8 **Extensive coordination and planning** is required to manage and operate the decentralized unit.
O1 Decentralized syrup production and further processing in a centralized ethanol plant is an innovative concept which may be supported by dedicated **innovation programmes**. O2 Both, **policies for rural development** as well as **policies for large quantities of biofuel production** may support this production system. O3 **Sustainability certificates** in this system may be easier to obtain, since ethanol production facilities may support the certification of the syrup production process which is done by the villagers (and which lack capacities needed to obtain certificates). O4 Opportunities for smallholder farmers at village level are provided to become **micro level entrepreneurs** through establishment and management of decentralised unit. O5 Establishment of decentralised units at villages provides **opportunities for value addition for various products** (e.g. bagasse as livestock feed, for vermicomposting, steam and foam utilization and paper making). O6 The syrup produced under decentralised unit has **alternative uses for the food industry** as sweetener and for the **pharmaceutical industry** due to its medicinal value. O7 Opportunities for the formation of **farmers' cooperatives** may be provided.	T1 Syrup production at village level is usually not directly supported by **dedicated policies**. T2 Due to lacking **access to financing**, electricity production from bagasse is often not feasible. T3 **Monitoring of sustainability impacts** on village level is more difficult to prove compliance with certification schemes. T4 Majority of the processing activities are **labour intensive** and hence labour scarcity might affect syrup production. T5 **Continuous technical backstopping** is needed to ensure the sustainability of decentralized units. T6 **High dependence** of decentralized units on the centralized ethanol distillery might lead to uneconomical prices and uncertain markets. T7 Disagreements may occur regarding the **utilisation of bagasse** (e.g. by decentralized unit or by the farmer). T8 Technicians from the centralised ethanol plant need to **supervise syrup production** at the village level to assure good quality of the syrup. T9 The centralised ethanol plant needs to offer **syrup transportation** from the village to the plant.

4.3. Decentralised ethanol production system

This chapter presents a SWOT analysis for decentralized ethanol production systems from sweet sorghum in subtropical/ tropical climates. In this system, the whole production chain is realized at village level, namely the cultivation and harvesting of sweet sorghum, the milling of the stalks to produce juice, and the processing of the juice into ethanol. Thereby, this system provides maximum value creation and benefit at village level. A schematic overview of the decentralised ethanol production system is presented in Figure 5.

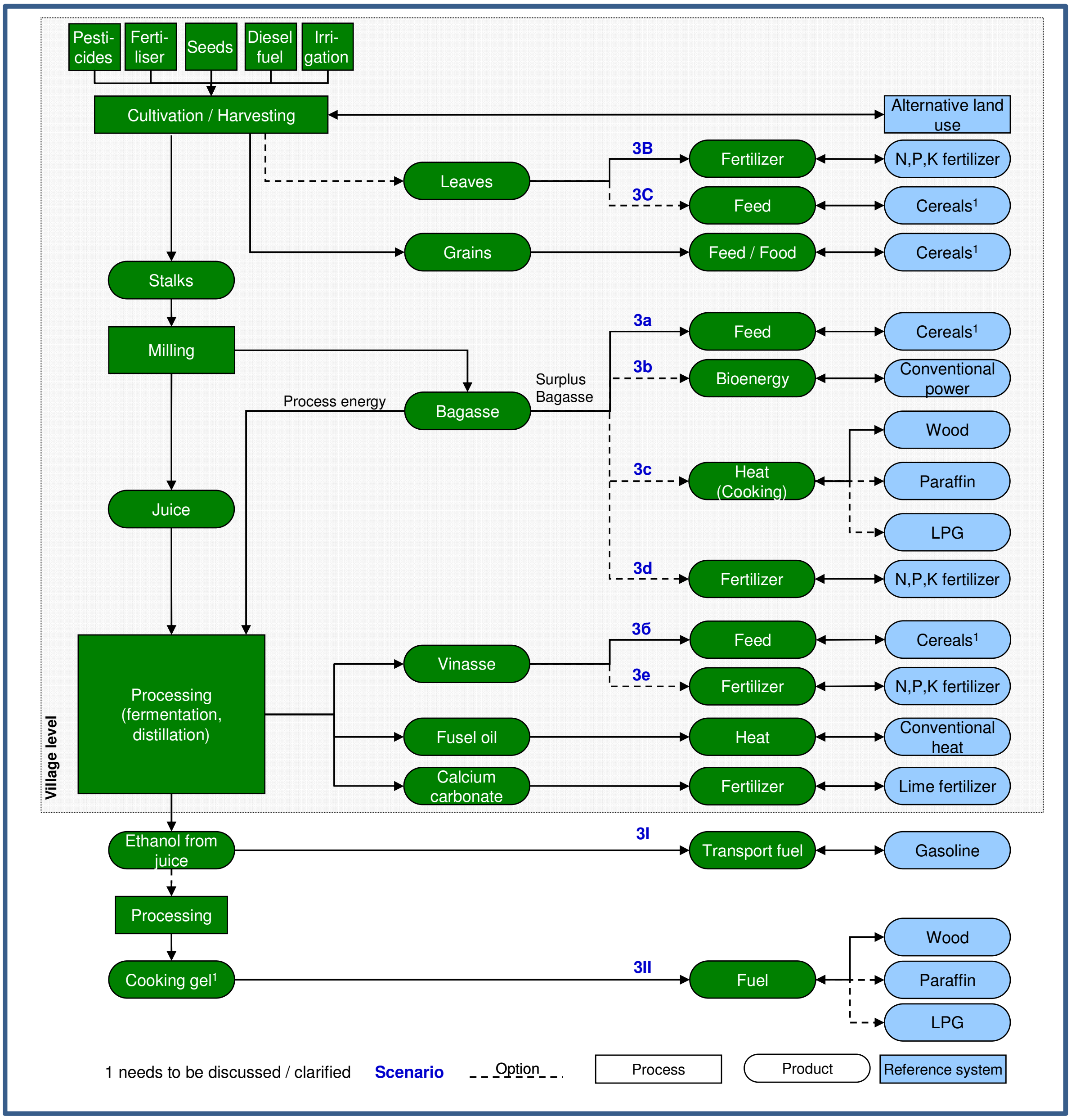

Figure 5: Decentralized ethanol production system (Braconnier et al. 2011a)

Table 4: SWOT for decentralised ethanol production system

S1 Small scale farmers can produce their own **seed** material. S2 Since usually no heavy machinery (harvesters) is used for cultivation of SS, **soil compaction** can be avoided, having a general positive impact on yields. S3 Villagers are themselves **responsible** for suitable land use and production practices. They are not forced by large companies to adapt to their rules. S4 SS cultivation systems can be easily **integrated** into existing small-scale agricultural structures without negatively affecting small farmers and villagers (no land grabbing). S5 SS cultivation systems may contribute to social inclusion and **strengthen local communities**. S6 SS enriches the **diversity of agricultural products** of small farmers, thus reducing risks if only one or few crops are cultivated. Furthermore SS is edible and can be used as multi-purpose crop for own consumption, which is not possible for other (toxic) crops like *Jatropha*. S7 Due to the smaller cultivation structure of SS at village level, general **environmental impacts** are reduced. S8 Small-scale agricultural structures contribute to higher **biodiversity** than large-scale plantations (monocultures). S9 **Traditional knowledge** of small scale farmers on sustainable agricultural practices can contribute, in combination with modern practices, to sustainable SS cultivation. S10 A **longer value chain** for ethanol production on village level generates more local revenues in comparison to the sale of stalks or syrup, only. S11 The use of **leaves and grains** can contribute to increase **food security** of villagers. S12 **Bagasse** remains at village level, thus it can be used for feed substituting other fodder. Also the use for power, heat and as fertilizer at village level is possible. S13 Due to general lower mechanisation rates of the conversion process, more **employment** is generated per litre ethanol. S14 Ethanol production at village level not only creates direct employment in the value chain, but also **indirect employment** through related microenterprises. S15 Villagers can themselves decide if ethanol is sold to external markets or also used for local consumption e.g. for cooking. Thus, **access to modern energy** is increased. S16 Villagers can influence their **working conditions**. S17 Villagers can **decide** use SS to produce ethanol or to use it **as food or feed** only.	W1 Farmers are usually not **trained** in best agricultural practices to increase yields. If not properly trained e.g. on the application of pesticides, negative environmental and human health impacts may occur. W2 Access to improved SS **varieties** may be limited for small scale farmers. W3 Small farmers are **vulnerable** to dependencies on improved seeds (e.g. hybrid and GMO seeds). W4 **Harvesting** machinery for SS cultivation may be too expensive for villagers. Furthermore, manual harvesting of sorghum causes itching. Therefore, farmers often hesitate to cultivate SS. W5 **Equipment for ethanol production** (presses, distilleries) may be too expensive for villagers. W6 **Efficient micro-distilleries** are currently still under development and not commercially established. W7 Access to **agricultural input** (fertilizer, pesticide) is expensive and limited for small scale farmers. W8 The use of **bagasse** for power generation is less efficient and more expensive at smaller scales (village level). Thus in many cases, a bagasse combustion and power generation unit at village level is not affordable. W9 **Bagasse may be regarded as waste** (if systems are not properly managed) and even cause environmental hazards when burned. W10 The **quality of ethanol** produced in small-scale facilities may be smaller in comparison to industrial scale produced ethanol. W11 SS cultivation and ethanol production on village level is usually **less efficient** than on larger scales. W12 Villagers need to be **trained** on managing and operating the ethanol facility. Technical support should be maintained in the long run to ensure the success. W13 Sufficiently **skilled personnel** may not be available in small villages. W14 It may be more difficult for small scale ethanol production systems to **sell ethanol** to national/international markets than for larger scale production systems. W15 The use of **ethanol as household fuel** is not widely established today and **suitable appliances are lacking**. W16 Generally, **storage** of harvests, especially of grains, is often not very good in small-scale production units. This may lead to loss of quality and quantity of stored grains. W17 If villages lack **infrastructure** (e.g. roads) the set-up of small-scale SS value chains is difficult due to problems related to supply wit input material and transport of ethanol to markets. Small villages from very remote areas are excluded from markets. However, the lack of infrastructure may be a good argument for smaller scale production systems.
O1 **Policies on rural development** usually support smaller scale production units. O2 Decentralised ethanol production systems aiming to increase access to modern energy may be supported in the framework of the **Global Initiative on Sustainable Energy for All (SE4ALL)**. 2012 is the International Year of Sustainable Energy for All. O3 **Development aid** is often allocated to small-scale initiatives creating the opportunities for SS ethanol production at village level. O4 Generally, socio-economic and environmental impacts are smaller of small-scale production units. Thus, compliance with international **sustainability requirements** is easier to achieve. O5 **Increased droughts and increasing water scarcity** due to climate change favour water efficient plants such as SS, especially affecting positively small farmers. O6 First experiences exist with the **operation of micro-**	T1 **Access to international ethanol markets** is more difficult for small scale systems. T2 **Lack of suitable infrastructure** may limit the access to international ethanol markets. T3 Ethanol production at village level is often not supported by **biofuel policies**. Renewable energy policies often only support large-scale production. T4 International **sustainability certification** may not be affordable and too complicated for small scale systems. T5 **Carbon or green certificates** may be too complicated and not affordable for small scale systems. T6 **Climate change** may lead to increased temperatures, water scarcity and more frequent extreme weather conditions, leading to harsher agricultural cultivation conditions, affecting mainly small-scale villagers. T7 Access to **financing** for equipment and input material as well as **governmental support** is generally more difficult for small scale systems than for larger scale systems.

distilleries on village level. O7 First experiences exist with the **use of ethanol as household fuel** in several African countries. O8 S stalks can be alternatively used as **household fuel** for the use with improved stoves (e.g. with the “Mwoto” stove in Uganda)	T8 Larger liquid biofuel markets (national or international) usually require very high **fuel quality** standards. T9 Sufficient **extension services** to support small-scale farmers may not be available in several developing countries. T10 The use of ethanol as **replacement of traditional household fuels** often faces objections and needs to be supported by strong marketing campaigns. T11 **Ethanol gel-fuel** is not regarded as suitable household fuel due to disadvantages such as low flame temperature. T12 In many developing countries ethanol production from SS is seen as high **risk for venture capital**.

5. Sweet sorghum in temperate climate

5.1. Biogas production system

This chapter presents a SWOT analysis for the use of sweet sorghum/biomass sorghum for biogas production in temperate zones. For the biogas production, the sweet sorghum biomass is crushed after harvest. The biogas is used for heat and power production replacing conventionally produced heat and power. Alternatively, the biogas can be further processed into biomethane and used for heat and power production (replacing conventional heat and power) or as transport fuel replacing conventional gasoline and natural gas. In all processes, digestate is produced as by-product. It is used as fertilizer replacing mineral fertilizer.

A schematic overview of the biogas production system is presented in Figure 6.

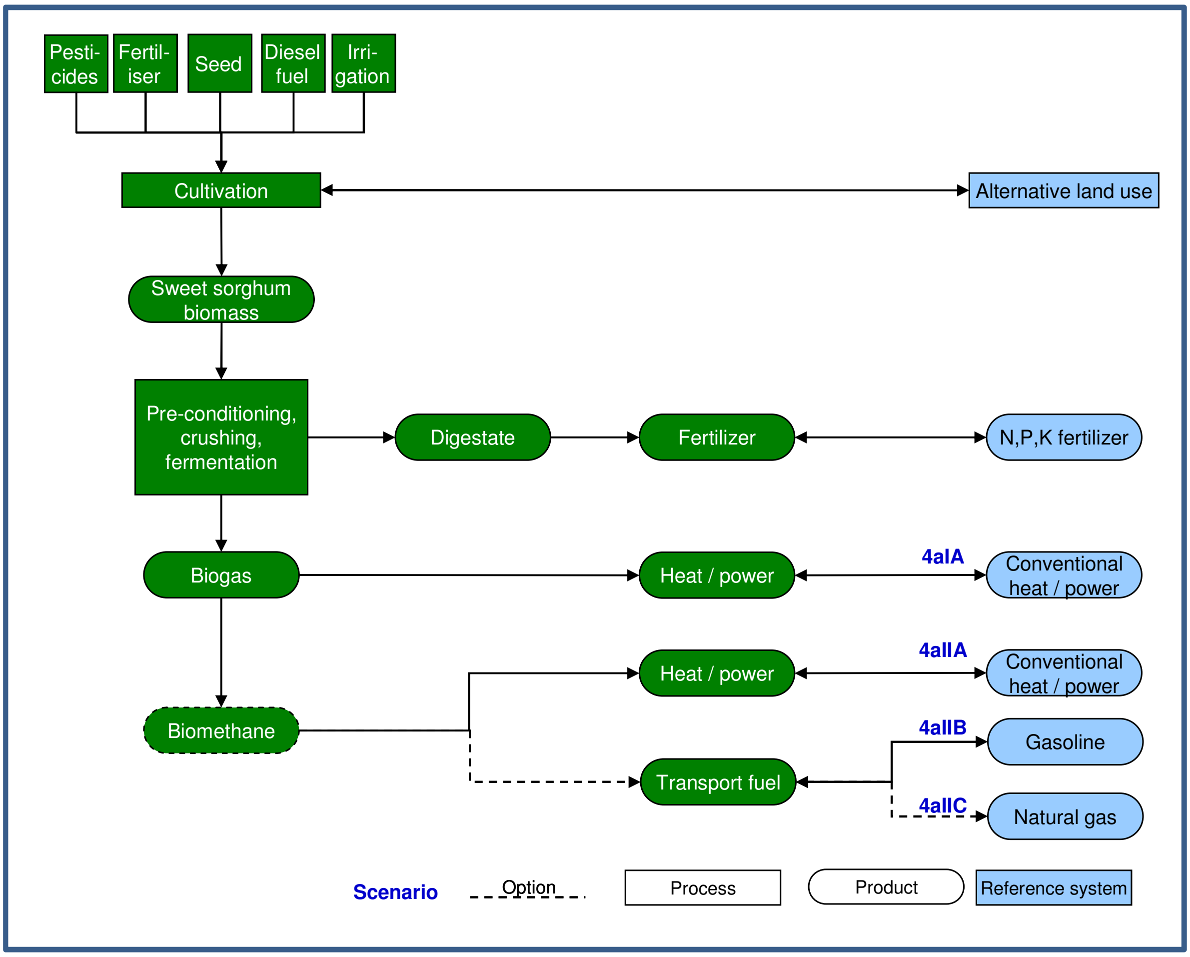

Figure 6: Biogas production system (Braconnier et al. 2011a)

Table 5: SWOT for sweet sorghum cultivation in the biogas production system

S1 Several seed producers in Europe **offer BS varieties** for biogas production in their product portfolios. S2 Optimisation of **irrigation systems** possible for yield increase (e.g. drip irrigation). S3 Optimisation of **harvesting time** possible for obtaining best BS feedstock for biogas production. S4 BS offers the chance to **complement mono-cropping of maize** to increase crop species diversity and reduce pest pressure and nutrient losses. S5 BS varieties show **high biomass yields** in comparison to alternative energy crops **(to be confirmed, in comparison with e.g. miscanthus)**. S6 High biomass sorghum (forage) is already cultivated with **high yields** per unit of land. S7 Varieties exist and they differ in their **chemical composition** with respect to DM content and NDF (Neutral Detergent Fibre) digestibility of silage, lignin and polysaccharides content. S8 BS has genes for sensitiveness to **day length** to help produce more biomass.	W1 **Specific traits** important for efficient biogas production from BS still need to be defined for rapid genetic improvements. Thereby culture and conditions in growing countries and regions have to be taken into account. W2 BS has a very **high spoilage potential** through yeast and mould activity during silo storage. W3 BS is very sensitive to **cold stress** and often expresses poor early season vigour and reduced competitive ability against weeds. W4 Due to limited experiences there is still need to **optimise various breeding and husbandry practices** such as sowing date, harvesting date, row spacing and plant density. W5 **Plant density** can (negatively) affect BS biomass yield and quality (e.g. chemical composition). W6 **Planting date** can (negatively) affect BS biomass yield and quality (e.g. chemical composition). Hereby, soil water content at and after the planting date and the ambient temperature at the establishment phase is of high importance. W7 Research needed to what **extent storage conditions** and the **age of the biomass** affects viability of feedstock for biogas production. W8 Lack of **dedicated harvest equipment** for optimised bioenergy production. W9 **Economic tools** (for farmers) for the full value chain of BS based biogas production need to be developed. W10 In Germany, BS is a **new crop** and still not well adapted to the local climatic conditions.
O1 Improved use of other crops in biogas production systems will contribute to **optimise handling, processing, transportation and storage**. O2 Opportunities exist for breeding B**S varieties** specifically suited for biogas production. Optimisation of contents (sucrose, glucose, cellulose, hemicellulose) possible for high biomass yielding and carbohydrate rich varieties. O3 Opportunities exist to use **organic farming** for BS cultivation (e.g. using digestate as fertiliser). O4 Optimisation of Dry Matter (DM) content (23-28%) and chop length (10-20 mm) is possible for **siling process**. O5 Opportunities exist to **optimise silage** (e.g. through additives) to avoid energy losses and promote the breakdown of fermentable substrate during storage phase. O6 Opportunities exist to **adapt the fermentation profile** (e.g. content of acetic acids and lactic acids) of BS silage (e.g. through additives). O7 Opportunities exist to reduce process **inhibiting substances** (ammonia, mycotoxins, heavy metals). O8 Opportunities exist to use BS as feedstock for **fermentative hydrogen production** (from sugar extracts) and subsequent methane production from the effluent and the remaining solids after sugar extraction. O9 Opportunities exist for **lipid production** either through natural processes or GMO strategies.	T1 In many countries with temperate climate, the main energy crop for biogas production is still corn, due to its very high biomass yield. It is difficult for BS **to compete with these high yields**. T2 The generally **increasing prices (inputs) of feedstock** may discourage livestock farmers to be involved in biogas projects.

Table 6: SWOT for sweet sorghum conversion in the biogas production system

S1 BS has a similarly **good fermentation profile** (high fermentable carbohydrate content) as silo maize. S2 The production of biogas is a **commercially mature** technology. S3 In Europe **several thousand biogas production systems** are in operation since many years. S4 **Experiences** for biogas production from a variety of different feedstock are existing. S5 Several universities and research institutions (in Europe) have gained considerable **experience** in biogas production processes and technologies. S6 Biogas production systems can be implemented in a **large variety of scales**, offering opportunities for decentralised as well as for centralised industrial applications. S7 Biogas has **beneficial GHG balances** with respect to conventional and alternative fuels. S8 The combustion of biogas has **low exhaust emissions** (NOx, CO, PM, HC) compared to fossil petrol or diesel.	W1 Until today, BS has not been regarded as **major feedstock** for biogas production. W2 **Limited experience** is available for BS as feedstock for biogas production. W3 Overall **process efficiency** for biogas production still needs to be improved. W4 The utilisation of **waste heat from CHP biogas plants** still needs to be improved. W5 Further research is still needed on efficient and competitive **gas cleaning technologies** for biomethane upgrading technologies.
O1 Currently natural gas (and biogas) is **promoted** as future energy carrier in many European countries. O2 Natural gas (and biogas) fired power plants are regarded as **suitable complement** for increased RE market penetration due to their large flexibility. O3 Biogas can be **fed into natural gas grids** after suitable treatment (upgrading to biomethane) and thus presents a “storable” RE source. O4 Biomethane is used as clean and renewable fuel in the **transport sector i**n several European countries. O5 Large efforts are currently undertaken to improve and promote the **utilisation of heat** from biogas plants, thus increasing the overall efficiency. O6 Biogas is regarded as suitable technology for developed and emerging economies (China, India, Brazil) as well as for developing countries. O7 The introduction of **policies on climate change** mitigation and adaptation creates opportunities for biogas production due to its good GHG balance. O8 Biogas production systems are currently **supported** in several European countries, such as through the German feed-in tariff system. O9 **Lobby groups** for biogas exist on national and European level (e.g. European Biogas Association). O10 **Technical standards** for biogas are available (e.g. SS155438 in Sweden). O11 The enforcement of a process for an **European standard** on biomethane will be advantageous for the biofuel market.	T1 Currently, biogas production from dedicated energy crops faces **public perception** problems in several European countries (due to negative experiences with corn monocultures). T2 Insufficient and decreasing **funding** is currently available at EU and national level for RTD on biogas production systems. T3 **Infrastructure** for biomethane use in vehicles is still insufficient in many countries. T4 For transport applications of biomethane **considerable investments in the infrastructure** are necessary. T5 **Biogas losses** need to be avoided as methane is a strong greenhouse gas. T6 No common European **quality standard** exists for biomethane. T7 Currently, biogas production is often **more expensive** than conventional fossil alternatives. T8 The use of **digestate** as fertilizer needs proper plans and rules for disposal in order to avoid eutrophication. This is more urgent in European countries high density agricultural regions (e.g. Denmark) are sensitive to nitrate pollution.

5.2. Lignocellulose-ethanol production system

This chapter presents a SWOT analysis for the use of sweet sorghum/biomass sorghum for lignocellulose-ethanol production in temperate climates.

In this system the biomass is crushed and pre-treated in order to render the cellulose accessible for a subsequent hydrolysis step. After the hydrolysis of the cellulose for breaking down the long chains into sugars, the substrate is fermented. The ethanol is used as transport fuel replacing conventional gasoline.

Vinasse is obtained as by-product and either used as feed replacing soy meal or as fertilizer replacing mineral fertilizer. If there is surplus bioenergy from the process, it is fed into the grid and replaces conventional power production.

A schematic overview of the lignocellulose-ethanol production system is presented in Figure 7.

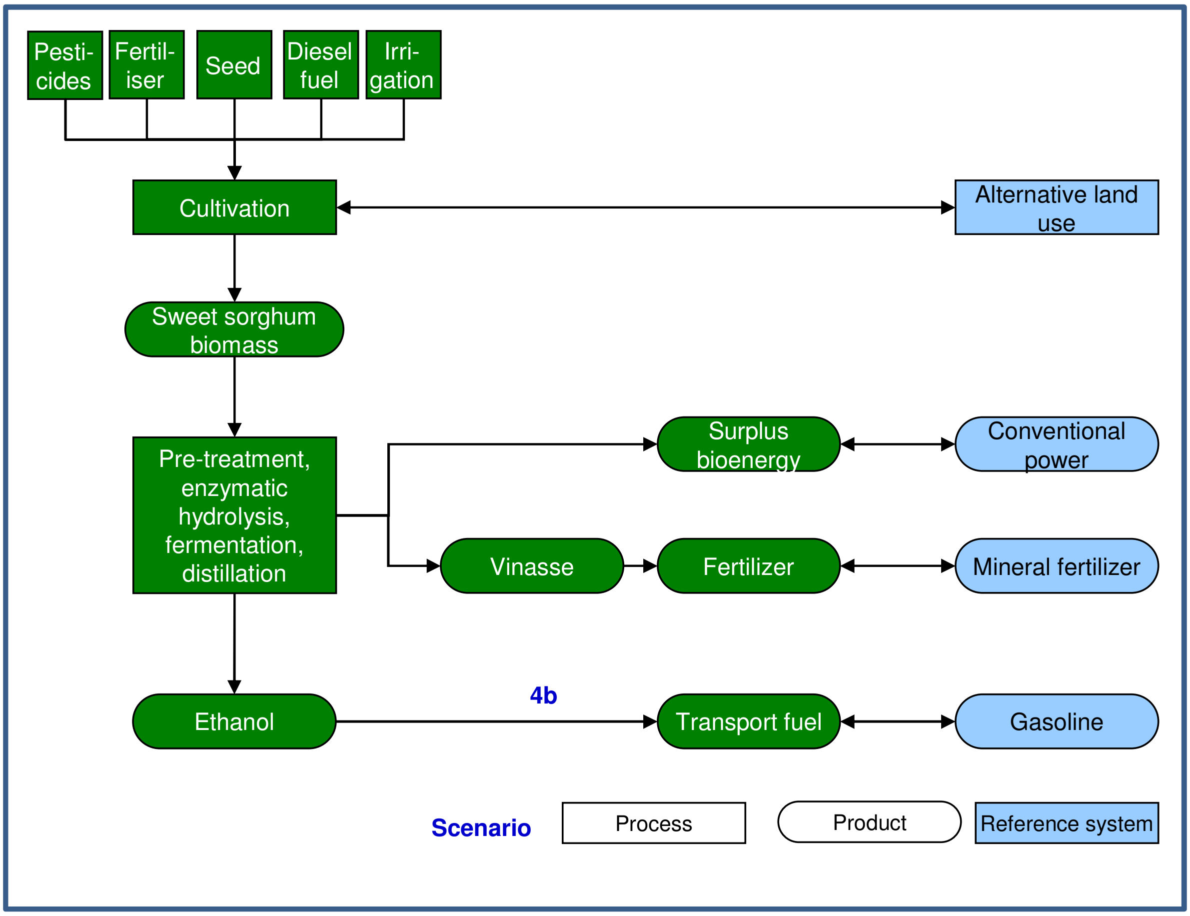

Figure 7: Second generation ethanol production from sweet sorghum lignocellulose for temperate climates (Braconnier et al. 2011a)

Table 7: SWOT for sweet sorghum cultivation in the lignocellulose-ethanol production system

S1 Many temperate regions are also prone to climatic changes due to global warming and many regions are facing increasing problems due to longer periods of droughts. BS has a **higher drought tolerance** compared to many other crops in temperate regions. S2 Good opportunities exist for **breeding BS varieties** specifically suited for the production of ligno-cellulose ethanol due to the high genetic variability of BS. S3 BS varieties show **high biomass yields** in comparison to alternative energy crops. S4 **High biomass sorghum (forage)** is already cultivated. S5 For ligno-cellulosic fermentation of BS, biomass does not have to be completely dry as it is for thermo-chemical conversion processes. Thus it can be harvested with **higher water contents**. S6 As annual species BS offers **fast benefits** as compared to multi-annual crops. S7 BS offers **low cost of installation and cultivation** compared with others crops (e.g. miscanthus). S8 BS is not regarded as **invasive species** (unlike e.g. miscanthus). S9 **Day length sensitive reaction** in BS is due to only few genes making it suitable for high biomass production. S10 **Bmr genes** can improve cellulose yield by decreasing lignin.	W1 **Specific traits** important for the efficient ligno-cellulose ethanol production from BS still need to be defined for rapid genetic improvements. W2 Research is needed to what extent **storage conditions and the age of the harvested BS biomass** affects the suitability of BS for the lignocellulosic conversion process. . W3 Lack of **dedicated harvest equipment** for optimised bioenergy production. W4 **Economic tools** (for farmers) for the full value chain of BS based ligno-cellulose ethanol production need to be developed. W5 There is a **lack of experience** of farmers with this new crop in temperate regions. Training and awareness rising on the cultivation and logistical requirements are needed. W6 BS is **sensitive to cold**. This could be a problem in regions with high weather variability, such as late frost. W7 Until today no consensus has been achieved regarding the **pre-treatment of BS for saccharification**. On the other hand several pre-treatment technologies have been shown to be effective on sorghum biomass. W8 **Tools to evaluate the relevance** of BS genotypes for different 2G ethanol production process remained to be developed. W9 **Competitive end use** (forage vs 2nd generation biofuels) of high biomass sorghum could happen.
O1 **Improved use of other crops** in ligno-cellulose ethanol production systems will contribute to optimise handling, processing, transportation and storage of BS biomass. O2 Although the current focus for ligno-cellulosic bioethanol production is on the use of waste materials, in the long-term **also dedicated energy crops are needed**, thus creating a large demand of BS biomass. O3 In many temperate regions such as in the European Union, agricultural production is usually fulfilling certain **sustainability standards**. In the EU agricultural production needs to include Cross Compliance and Good Agricultural Practices in order to get subsidies. This existing framework would facilitate sustainability certification ofBS ethanol produced in the EU. O4 **Intercropping systems** can be developed, either through relay cropping or intercropping with leguminous species.	T1 Current policies **focus rather on the use of waste materials** for lignocellulosic bioethanol production than on the use of dedicated energy crops. General increasing land use competition supports the use of waste materials. T2 Current policies **focus on perennial woody** (Short Rotation Woody Crops) **and non-woody** (Miscanthus) crops and not on annual crops such as BS. Perennial crops often perform better in terms of impacts on soil, biodiversity, and use of chemicals.

Table 8: SWOT for sweet sorghum conversion in the lignocellulose-ethanol production system

S1 Biomass from BS is generally very good for fermentation process since it has **higher contents of sugars** and less ligno-cellulosic compounds than other currently used feedstock such as corn silage or straw. Also bagasse from SS can be used for ligno-cellulosic ethanol production. S2 **Ethanol yields** accomplished for BS feedstock are comparable with corn stover, wheat straw, wood, switch grass and miscanthus. S3 Recent progress has been achieved on **improving yeasts and enzymes** for ligno-cellulose ethanol production. S4 **Improved yeast strains** for pentose fermentation are currently being subject to industrial validation. S5 Several **demonstration facilities** for ligno-cellulose ethanol production are currently in operation in European countries. S6 Ligno-cellulose ethanol has **beneficial GHG balances** with respect to conventional and alternative fuels. S7 Ligno-cellulosic ethanol can be **easily blended** with gasoline. S8 Most **emissions types** of ethanol fuel are lower than for conventional gasoline.	W1 Specific **detailed compositional analysis** of BS ideotypes as feedstock for ligno-cellulose ethanol production is still needed. W2 BS shows a large **variation in composition** across different cultivars providing benefits for breeding. W3 Ligno-cellulose ethanol production technologies are currently **not commercially mature**. W4 Ligno-cellulose ethanol production technologies are **cost and energy intensive**. W5 Up to date **no specific expertise** exists for ligno-cellulose ethanol production from BS feedstock. However, several references in the literature exist for lab scale. W6 Overall **process efficiency** for ligno-cellulose ethanol production still needs to be improved. W7 **High costs of enzymes** today limit the economic viability of ligno-cellulose ethanol production. Costs for adapted enzymes for BS fermentation may be even higher, since only limited research has been done of BS feedstock. W8 Development of **optimised pre-treatment technologies** for BS biomass is still necessary. Pre-treatment and conversion

S9 Ethanol is **not toxic** to humans and the environment. S10 SS bagasse has a relatively low **ash content** (3-4% of dry matter), and is therefore advantageous for fermentation against other crop residues such as wheat straw, which contains 7-11% ash.. S11 SS bagasse typically contains cellulose of relatively low **crystalinity**, which increases efficiency of enzymatic hydrolysis of the cellulose and, thus, the fermentable sugar recovery from the material.	process need to be tested at a larger scale. W9 Development of **optimised lignin utilisation pathways** is still necessary as well as valorisation of the co-products (e.g. tannins, aconictic acids) through a biorefinery approach. W10 Ligno-cellulose ethanol can only be produced economically at **very large-scale industrial facilities**. W11 The large size of ligno-cellulose ethanol production facilities requires large amounts of biomass feedstock, thus causing challenges in **biomass logistics and supply**. W12 Large **up-front investment costs** provide a barrier for the implementation of commercial large-scale ligno-cellulose ethanol production. W13 Detailed **information** on ligno-cellulose ethanol production costs and potential cost reductions are currently not available. W14 Research still needed on **optimising the mix of products** (including ligno-cellulose ethanol) within biorefinery concepts and ensuring the quality of products.
O1 Most European countries **favour ligno-cellulose ethanol** rather than BtL fuels as future 2^{nd} generation biofuels. O2 The future development of ligno-cellulose ethanol will be supported by the recent promotion and funding for biorefineries as cornerstones of the **European Knowledge-based Bioeconomy**. O3 Ligno-cellulose ethanol production is regarded as **priority technology** in Europe, USA and Brazil, thus rapid technological progress can be expected. O4 Ligno-cellulose ethanol production is regarded as **priority technology for cooperation** between Europe and other countries (e.g. USA, Brazil, Chile). O5 Recently the National Renewable Energy Laboratory (NREL) of the U.S. Department of Energy has implemented the "**Sorghum to Ethanol Research Initiative**". O6 NREL performed **various testing** (compositional analysis, lab scale pre-treatment, enzymatic hydrolysis, fermentation) on BS as ligno-cellulose feedstock for ethanol production. O7 **Calls for flagship demonstration projects** on ligno-cellulose ethanol production was launched by the European Industrial Bioenergy Initiative (EIBI), an initiative of the European SET (Strategic Energy Technology) Plan. O8 **Considerable funding is currently available** on EU and national level for RTD on ligno-cellulose ethanol production. O9 **Technical standard** for ethanol as blend component in gasoline is available (EN 15376). O10 The introduction of **policies on climate change** mitigation and adaptation creates opportunities for ligno-cellulose ethanol due to its good GHG balance. O11 **Support for biofuels from ligno-cellulosic feedstock** (e.g. through the "double counting" under the RED) may stimulate BS as energy crop for ligno-cellulose ethanol production in temperate regions. O12 **Costs and efforts for sustainability certification** of lignocellulosic ethanol is generally no problem for large-scale plants. O13 Ligno-cellulosic ethanol biorefineries will not only be able to produce ethanol, but also other **high-quality products such as lignin**. The demand for these products is currently increasing. However, "woody" biomass has higher lignin contents. O14 There are still opportunities to improve the cellulosic ethanol process in terms of **efficiency and cost**.	T1 The **present economic crisis in Europe may** cause difficulties in ensuring the **large capital requirements** of large-scale commercial ligno-cellulose ethanol production facilities. T2 Difficulties exist in Europe (public acceptance) concerning improved yeasts, bacteria and enzymes from **genetically engineered microbes** (GMO). T3 Current **production costs** of ligno-cellulose ethanol are too high to be competitive with conventional fuels.

5.3. Direct combustion system

This chapter presents a SWOT analysis for the use of sweet sorghum/biomass sorghum for direct combustion in temperate climates.

Due to the high water content of the crop, before combustion the biomass has to be dried or (if possible) remain on the fields for several days for drying. Through combustion, heat and power are produced that replace conventionally produced heat and power. The only by-product is ash which has to be disposed in landfills.

A schematic overview of the direct combustion system is presented in Figure 8.

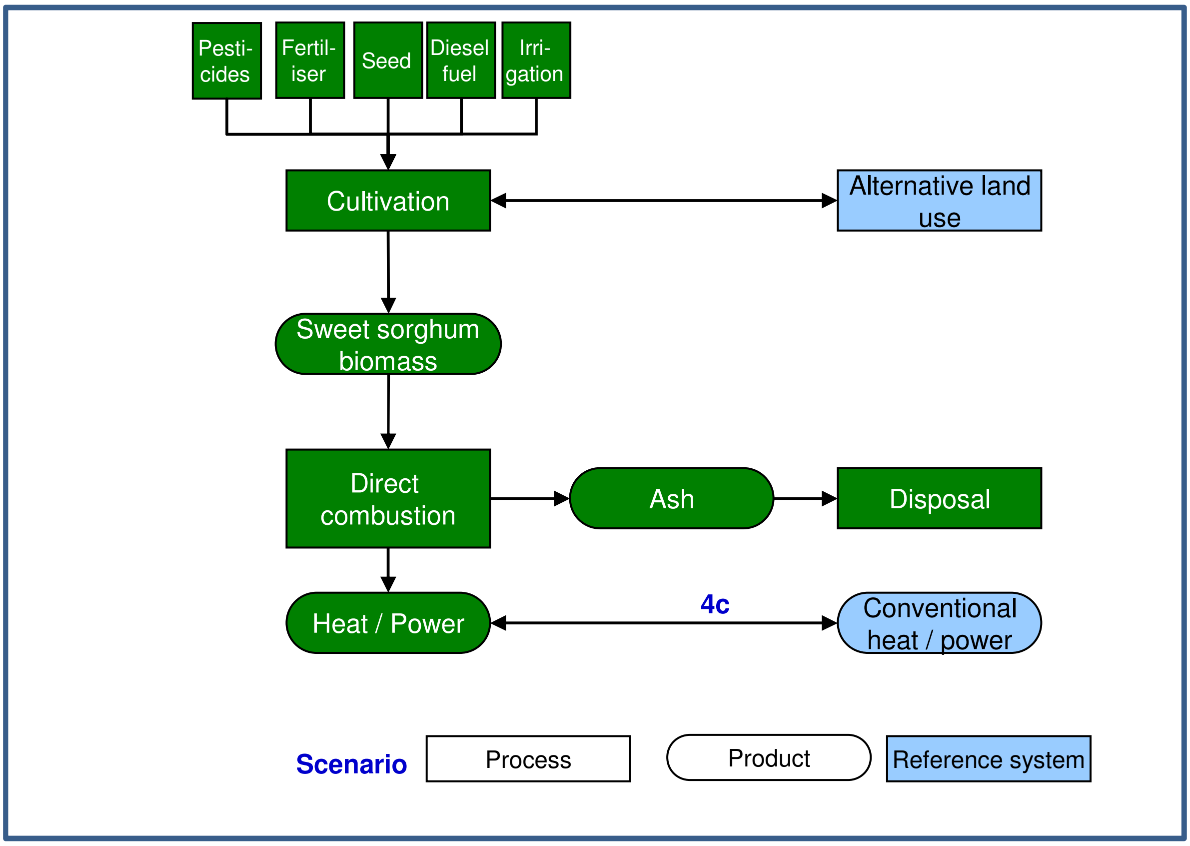

Figure 8: Direct combustion system (Braconnier et al. 2011a)

Table 9: SWOT for sweet sorghum cultivation in the direct combustion system

S1 Due to the high **genetic variability** of BS, good opportunities exist for breeding BS varieties specifically suited for direct combustion (high total biomass yield and high lignin content to maximise energy production). S2 First experiences exist with respect to **breeding BS varieties** specifically suited for direct combustion (high total biomass yield). S3 **BS varieties** show high biomass yields in comparison to alternative energy crops. S4 **High biomass sorghum** (forage) is already cultivated.	W1 **Specific traits** and targeted biomass composition still need to be defined for rapid genetic and crop management improvements. Thereby culture and conditions in growing countries and regions have to be taken into account. W2 Research needed to what extent **storage conditions and the age** of the biomass affects viability of feedstock. W3 Lack of **dedicated harvest equipment** for optimised bioenergy production. W4 **Economic tools** (for farmers) for the full value chain of BS based direct combustion need to be developed. W5 Thermo-chemical conversion does not allow to close the **agricultural nutrient cycle**, an advantage of biogas production from BS. Furthermore, no carbon is put back on the fields as it is the case of spreading digestate from biogas production on the fields.

	W6 Existing combustion power plants (using waste, lignite, coal) are usually **very large**. Thus co-combustion with BS biomass is challenging with respect to **logistics** of harvested biomass.
O1 **Improved use of other crops** in direct combustion systems will contribute to optimise handling, processing, transportation and storage. O2 For larger utilities, costs for biomass **sustainability certification** are negligible.	T1 In the long-term, BS will be needed as feedstock in a **bio-based economy** (for bio-products and liquid biofuels) rather than for electricity production for which also other renewable energy options exist. T2 So far **no sustainability certification scheme** for solid biomass for combustion is in place. However, some utilities are currently setting up voluntary certification schemes. T3 Several European **quality standards for solid biomass** are currently under development. T4 Currently, the European Commission is investigating the necessity for the introduction of **sustainability standards** for solid biomass.

Table 10: SWOT for sweet sorghum conversion in the direct combustion system

S1 The direct combustion of biomass is a **commercially mature** technology. S2 In Europe biomass direct combustion systems are **in operation since many years**. S3 **Experiences** for direct combustion of a variety of **different feedstock** are existing. S4 Several universities and research institutions (in Europe) have gained **considerable experience** in direct combustion of biomass (processes and technologies). S5 Direct combustion systems can be implemented in a **large variety of scales**, offering opportunities for decentralised as well as for centralised industrial applications. S6 Direct combustion of biomass has **beneficial GHG balances** with respect to conventional and alternative fuels.	W1 Until today, BS has not been regarded as **major feedstock** for direct combustion. W2 Limited **experience** is available for BS as feedstock for direct combustion. W3 Currently, direct combustion of biomass is often **more expensive** than conventional fossil alternatives. W4 **Overall process efficiency** for direct combustion still needs to be improved. W5 Further research is still needed on the impact of **impurities** for BS direct combustion. W6 **Combustion technology** generally needs to be more sophisticated than for wood combustion. Combustion of BS requires specific technical solutions on emission filters and corrosion resistance of materials. Low ash melting temperatures require technical adaptation to boilers. W7 With direct combustion of BS, its compositional advantage of having **high contents of readily fermentable sugars** (sucrose) is lost.
O1 Many decades of **experience** exists for the direct combustion of fossil energy carriers. O2 **Dedicated combustion systems for the use of biomass feedstock** have been developed. O3 Currently **co-firing of biomass with fossil energy carriers** (e.g. coal) is promoted as option to achieve the European RE targets. O4 **Experience of biomass co-firing** exists for a variety of feedstock. O5 Recently, **torrefied biomass is regarded as promising fuel** for co-firing in fossil power plants. O6 Solid biomass presents a **"storable" RE source** for heat and power production suitable for complementing other intermittent RE sources. O7 **Considerable international trade** of solid biomass (e.g. pellets) for direct combustion is already on-going and international markets have been established. O8 The introduction of **policies on climate change** mitigation and adaptation creates opportunities for biomass direct combustion due to its good GHG balance. O9 Biomass direct combustion systems are currently **supported** in several European countries, such as through the German feed-in tariff system. O10 **Lobby groups** for biomass exist on national and European level (e.g. AEBIOM). O11 **Technical standard** for solid biomass are available.	T1 Insufficient and decreasing **funding** is currently available at EU and national level for RTD on biomass direct combustion systems.

5.4. Gasification system

This chapter presents a SWOT analysis for the use of sweet sorghum/biomass sorghum for gasification in temperate climates. Thereby, two options exist namely direct gasification of the biomass feedstock and production of intermediate energy carriers (e.g. through pyrolysis and torrefaction) prior to gasification.

For both options, the biomass needs to be dried as a pre-treatment. Direct biomass gasification can only be realized in large scale centralized units. Here, waste heat can be used for biomass drying. Torrefaction or pyrolysis of biomass is often used in decentralized systems for making biomass transportable. In this case, external energy would be necessary for biomass drying.

As a next step, the biomass, the pyrolysis oil or the torrefied biomass are gasified into a synthesis gas (mixture of hydrogen and carbon monoxide). After cleaning the gas, it is synthesized into the so-called BtL (biomass-to-liquid) fuels. The standard synthesis is the Fischer-Tropsch synthesis where biodiesel is produced as main product. Naphtha is obtained as by-product which replaces fossil naphtha. If there is surplus bioenergy from the process, it is fed into the grid and replaces conventional energy.

A schematic overview of the gasification system is presented in Figure 9.

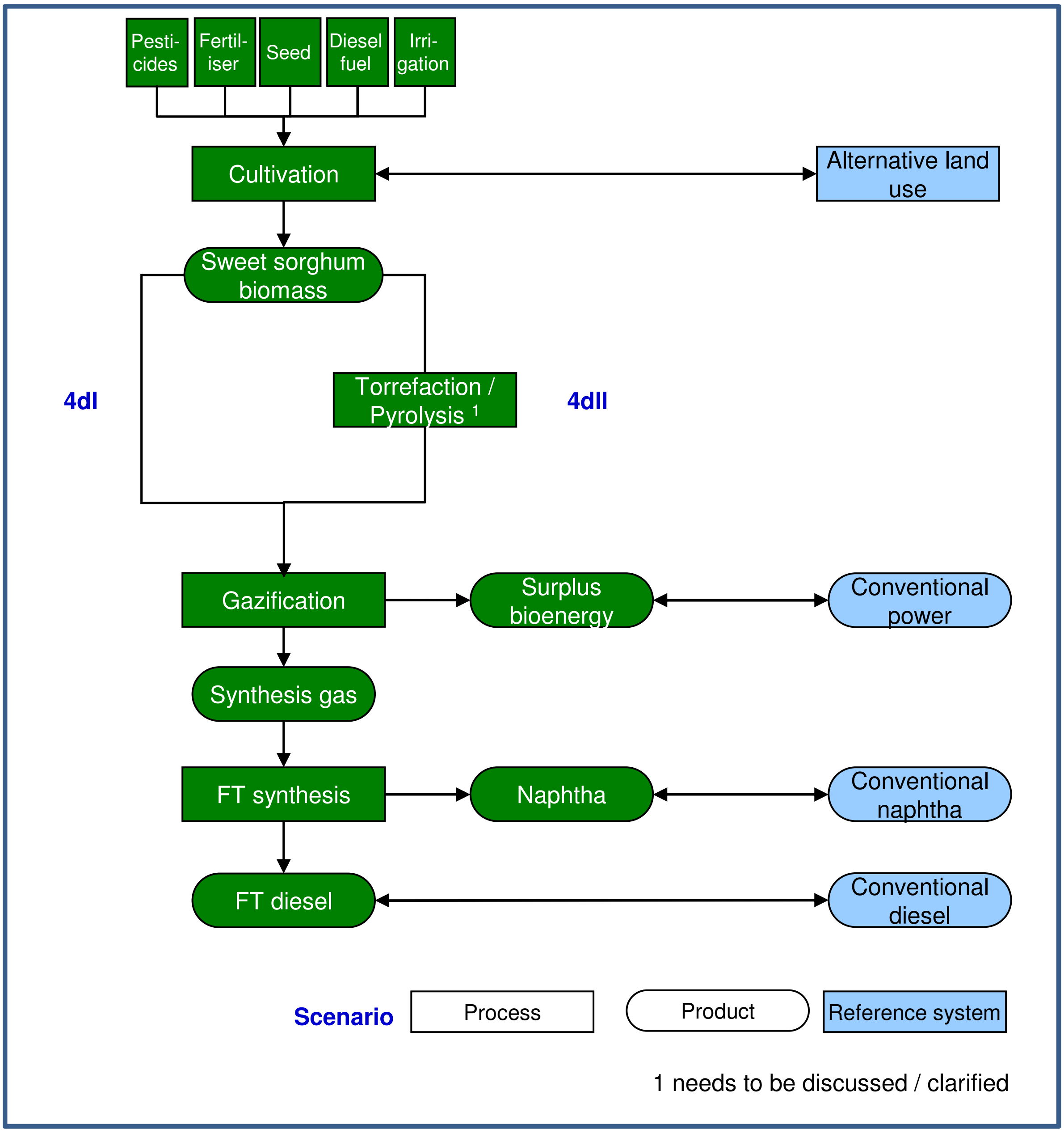

Figure 9: Gasification system (Braconnier et al. 2011a)

Table 11: SWOT for sweet sorghum cultivation in the gasification system

S1 Due to the high **genetic variability** of BS, good opportunities exist for breeding BS varieties specifically suited for the production of intermediate energy carriers (pyrolysis, torrefaction) as well as for direct gasification. S2 BS **varieties** show high biomass yields in comparison to alternative energy crops. S3 **High biomass sorghum** (forage) is already cultivated. S4 BS broadens the options for the **agricultural crop rotation system** in temperate regions. S5 BS is suitable for **intercropping with leguminous species** to maximize the C/N cycle equilibrium.	W1 **Specific traits** important for the efficient gasification of BS still need to be defined for rapid genetic improvements. Thereby culture and conditions in growing countries and regions have to be taken into account. W2 Research is needed to what extent **storage conditions and the age** of the biomass affects viability of feedstock. W3 Research is needed on the best **time for harvest** in temperate regions, in order to minimize water content of biomass. W4 Lack of **dedicated harvest equipment** for optimised bioenergy production. W5 **Economic tools** (for farmers) for the full value chain of BS based BtL production need to be developed. W6 Since generally thermo-chemical conversion chains (especially without the production of intermediate products) are very large, also **very large BS cultivation areas** are

	needed. W7 Thermo-chemical conversion does not allow to close the **agricultural nutrient cycle**, and advantage of biogas production from BS. Furthermore, on carbon is put back on the fields as it is the case of spreading digestate from biogas production on the fields.
O1 **Improved use of other crops** in technologies for the production of **intermediate energy carriers** (pyrolysis products, torrefied biomass) will contribute to optimise handling, processing, transportation and storage. O2 **Improved use of other crops** in **gasification systems** will contribute to optimise handling, processing, transportation and storage.	T1 BS for second generation biofuels will **increase land competition** with the cultivation of energy crops (especially corn) for already installed biogas plants. T2 The **habitus of BS is similar to corn**. Increasing negative public perception on corn monocultures for biogas production will thus also affect the **public perception** on BS.

Table 12: SWOT for sweet sorghum conversion in the gasification system

S1 Production of **intermediate energy carriers** (pyrolysis products, torrefied biomass) facilitates decentralised gasification systems. S2 **Gasification processes** for the production of BtL fuels are in general suitable for a large variety of feedstock. S3 The **chemical properties of BtL fuels** permit efficient and complete combustion with low exhaust gas emissions. S4 BtL fuels can be **used in modern engines** without technical modifications. S5 **Properties of BtL fuels can be fine-tuned** through specific process parameters (such as pressure, temperature, and catalysts) during synthesis. S6 BtL fuels have **beneficial GHG balances** with respect to conventional and alternative fuels.	W1 Technologies for the production of **intermediate energy carriers** (pyrolysis, torrefaction) are currently not **commercially mature**. W2 Limited **experience** exists with regards to pyrolysis and torrefaction of BS feedstock. W3 **Gasification technologies** are currently not **commercially mature**. W4 Limited **experience** exists with regards to the **gasification of BS feedstock**. Thereby, developments especially on the pre-treatment and on the feeding system of the plant are needed. W5 **Gas cleaning processes** required for the efficient production of BtL (Biomass-to-Liquid) fuels still face significant technical problems. W6 BtL fuels can only be produced economically at **very large-scale industrial facilities**. W7 The large size of gasification systems for the production of BtL fuels requires large amounts of biomass feedstock, thus causing challenges in BS biomass **logistics and supply**. W8 **Large up-front investment costs** provide a barrier for the implementation of commercial large-scale gasification systems for the production of BtL fuels. W9 **Current production costs of BtL fuels are too high** to be competitive with conventional fuels. W10 Detailed **information on BtL production costs** and potential cost reductions are currently not available. W11 Research still needed on **optimising the mix of products** (including BtL fuels) within biorefinery concepts and ensuring the quality of products.
O1 Calls for **flagship demonstration projects** on thermochemical production of biofuels (via gasification) was launched by the European Industrial Bioenergy Initiative (EIBI), an initiative of the European SET (Strategic Energy Technology) Plan. Three out of seven selected value chains concern gasification technologies O2 Considerable **funding** is currently available on EU and national level for RTD on intermediate energy carriers (pyrolysis, torrefaction). O3 Intermediate energy carriers are **currently widely discussed** in the European research community as future promising option for decentralised bioenergy production. O4 BtL fuels are **well adapted to current engine concepts** of most car manufacturers. O5 During recent years the production of BtL fuels has been **supported by major car manufacturers**. O6 The introduction of **policies on climate change** mitigation and adaptation creates opportunities for BtL fuels due to their good GHG balance. O7 **Support for biofuels from ligno-cellulosic feedstock** (e.g. through the "double counting" under the RED) may stimulate BS as energy crop for BtL production in temperate regions.	T1 Most European countries **favour ligno-cellulosic ethanol** rather than BtL fuels as future 2nd generation biofuels. T2 The present economic crisis in Europe may cause difficulties in ensuring the **large capital requirements** of large-scale commercial gasification systems. T3 Due to **economic problems of a large and well-known German BtL production facility** this technology is currently viewed with scepticism by investors and other stakeholders. T4 Currently, n**o technical standards for intermediate energy carriers** exist. However, they are currently under development.

6. Conclusion

This SWOT analysis was conducted in order to complement the environmental and sustainability assessments on sweet sorghum and biomass sorghum of the SWEETFUEL project (Braconnier 2011b).

The objective was to collect and present qualitative arguments for the cultivation of sweet and biomass sorghum for the conversion into ethanol as energy carrier. This is important as current discussions on the sustainability of biofuel value chains mainly focus on environmental and quantifiable aspects. The evaluation of socio-economic and qualitative impacts is generally more challenging (Rutz et al. 2011, Rutz & Janssen 2012a, Rutz & Janssen 2012b) and thus, a SWOT analysis is a good method to present a comprehensive picture of these aspects. Besides the illustration of sustainability aspects, also several qualitative technical aspects can be shown in a SWOT analysis (Rutz & Janssen 2007, Glekas et al. 2007). This was applied to the sorghum to energy value chain and presented in the report.

In total, more than 450 arguments have been collected and categorised into strengths, weaknesses, opportunities and threats. Thereby, a clear categorisation was not always possible and repetitions of similar arguments occur in some tables. The analysis can be further extended and completed with additional arguments.

The aim to show different qualitative aspects of sorghum cultivation and processing was successfully achieved. The report shows a very broad picture of many aspects associated with some key value chains of sorghum use for ethanol and other biofuels. This shall help stakeholders and decision makers building their own opinion about this topic.

References

Antonopoulou G., Gavala H.N., Skiadas I.V., Angelopoulos K., Lyberatos G., 2008. Biofuels generation from sweet sorghum: fermentative hydrogen production and anaerobic digestion of the remaining biomass. Bioresource Technology, 99, 1, 110–119.

Braconnier S., Reinhardt G., Köppen S., Rettenmair N., Detzel A., 2011a Handout for the Workshp on "Definitions and Settings" in Potchefstroom, South Africa, February 22, 2011

Braconnier S., Gutjhard S., Trouche G., Reddy B., Rao S., Schaffert R., Parella R., Zaccharias A., Rettenmaier N., Reinhardt G., Monti A., Amaducci S., A. Marocco, Snijman W., Terblanche H., Zavala-Garcia F. Janssen R., Rutz D., 2011b Definition of new sorghum ideotypes to meet the increasing demand of biofuels. - Proceedings of the 19th European Biomass Conference and Exhibition; pp. 782-786; ISBN 978-88-89407-55-7; DOI: 10.5071/19thEUBCE2011-VP1.3.78

de Vries S.C., van de Ven G.W.J., van Ittersum M.K., Giller K.E. 2010. Resource use efficiency and environmental performance of nine major biofuel crops, processed by first-generation conversion techniques. Biomass Bioenerg, 34, 5, 588–601.

Glekas D., Kamakiotis N., Christou M., Panoutsou C., Lychnaras V., Yanakieva A., Angelova R., Tomova D., Garofalo R., Flueraru C., Mikucki O., Ogrodniczuk J., Jarzemska M., Jossart J.M., Schoeling O., 2007 Strategy formation: D 17 SWOT Analysis; Case studies: Belgium, Bulgaria, Cyprus, Greece, Poland, Romania; http://www.cres.gr/biodiesel/downloads/reports/Other/SWOT_Oct_07.pdf

Ntaikou I., Gavala H.N., Kornaros M., Lyberatos G., 2008. Hydrogen production from sugars and sweet sorghum biomass using *Ruminococcus albus*. International Journal of Hydrogen Energy, 33, 4, 1153–63.

Panagiotopoulos I.A., Bakker R.R., de Vrije T., Koukios E.G., Claassen P.A.M., 2010b. Pretreatment of sweet sorghum bagasse for hydrogen production by *Caldicellulosiruptor saccharolyticus*. International Journal of Hydrogen Energy, 35, 15, 7738–7747.

Rao PS, Rao S, Seetharama N, Umakanth AV, Sanjana Reddy P, Reddy BVS and Gowda CLL. 2009. Sweet sorghum for biofuel and strategies for its improvement. Information Bulletin No. 77. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 80 Pp. ISBN:978-92-9066-518-2

Rutz D., Janssen R. (2007) Biofuel SWOT Analysis. - EU-IEE Biofuel Marketplace Project; 21p. www.biofuelmarketplace.com

Rutz D., Janssen R., Van Eijck J., Faaij A., Vis M., Van Sleen P., Abban-Mensah I., Bottriell K., Gerber P., Hilbert J.A., Wright A., Ouattara O., Burrell T., Sawe E.N., Cárdenas A., Fallot A. (2011) Sustainability of Biofuels and Bioproducts: Socio-Economic Impact Assessment. - Proceedings of the 19th European Biomass Conference and Exhibition; pp. 2355-2364; ISBN 978-88-89407-55-7; DOI: 10.5071/19thEUBCE2011-OC3.2

Rutz D., Janssen R. (2012a) Socio-economic impacts of different scales of biofuel production in Africa. – In: Janssen R., Rutz D. (eds.) Bioenergy for sustainable development in Africa. – Springer Science+Business Media B.V.; Dordrecht Heidelberg London New York; DOI 10.1007/978-94-007-2181-4_25; ISBN 978-94-007-2180-7

Rutz D., Janssen R. (2012b) Opportunities and risks of bioenergy in Africa . – In: Janssen R., Rutz D. (eds.) Bioenergy for sustainable development in Africa. – Springer Science+Business Media B.V.; Dordrecht Heidelberg London New York; DOI 10.1007/978-94-007-2181-4_31; ISBN 978-94-007-2180-7

Sree N.K., Sridhar M., Rao L.V., Pandey A., 1999. Ethanol production in solid substrate fermentation using thermotolerant yeast. Process Biochemistry, 34, 2, 115-119.

Annex: Questionnaire for stakeholder participation

Questionnaire on Sweet Sorghum

SWEETFUEL Project

This survey is implemented in the project **SWEETFUEL**, which is supported by the European Commission in the 7th Framework Programme. SWEETFUEL is a research project on improving sweet sorghum varieties for ethanol production by different breeding activities.

In the framework of the project a **SWOT analysis** (strength, weaknesses, opportunities, threats) is conducted on different sweet sorghum value chains, ranging from micro-scale to large-scale systems, from temperate to tropical climates. The aim of the SWOT analysis it to illustrate especially socio-economic impacts of different sweet sorghum value chains.

Since socio-economic impacts are most relevant in developing countries, a main focus of the questionnaire is on sweet sorghum value chains in tropical climates.

SWEETFUEL Website: www.SWEETFUEL-project.eu

SWEETFUEL Duration: January 2009 to December 2013

Survey Objective

The core objective of this survey is to collect further input to the SWOT analysis on SWEETFUEL value chains in tropical climates. This questionnaire is not representatives and includes only open questions.

Results of the survey will be included in the SWOT analysis which will be published on the project website. If you want to provide comments directly into the draft SWOT analysis document, please contact us.

Questionnaire submission

Please send back the filled questionnaire **by email** (Dominik.rutz@wip-munich.de, Rainer.janssen@wip-munich.de) or **fax** (0049 89 720 12 791) to us.

1 What are the *general* *strength/opportunities* of SS as energy crop?

2 What are the *general* *weakness/threats* of SS as energy crop?

3 What are the main *socio-economic* *advantages* of sweet sorghum cultivation and use in developing countries?

4 What are the main *socio-economic* *problems* of sweet sorghum cultivation and use in developing countries?

5 What are the main *environmental* *advantages* of sweet sorghum cultivation and use in developing countries?

6 What are the main *environmental* *problems* of sweet sorghum cultivation and use in developing countries?

7 What are the *most important products* of sweet sorghum in developing countries?

8 Should sweet sorghum as energy crop (for ethanol production) be *promoted* in developing countries, and *why*?

9 Do you have any *other comments/suggestions* which should be included in the SWOT analysis on sweet sorghum?

For acknowledging your contribution in the SWOT report as well as for further clarifications (if necessary) we would be happy to also receive the following contact details.

Your name: ____

Your organisation: ____

Your email address: ____

Thank you very much for participating in the survey on sweet sorghum!

Domink Rutz and Rainer Janssen

WIP Renewable Energies

Sylvensteinstr. 2

81369 Munich, Germany

www.wip-munich.de