Biomass Use and Potential for export to the European Union from 2015 to 2030.

Availability of solid biomass feedstocks - A case study for Kenya

Aristeidis Dardamanis

Master Thesis | Energy Science | Utrecht University | 30 January 2015

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Daily Supervisor: Ms. T. Mai-Moulin (UU)

First Reviewer: Dr. H.M. Junginger (UU)

Second Reviewer: Dr. Floor van der Hilst (UU)

Author: Aristeidis Dardamanis

Student number: 3954501

E-mail address: adardaman@live.com

Postal address: Kanaalstraat 102 Bis 3531CM, Utrecht, The Netherlands

Master Thesis

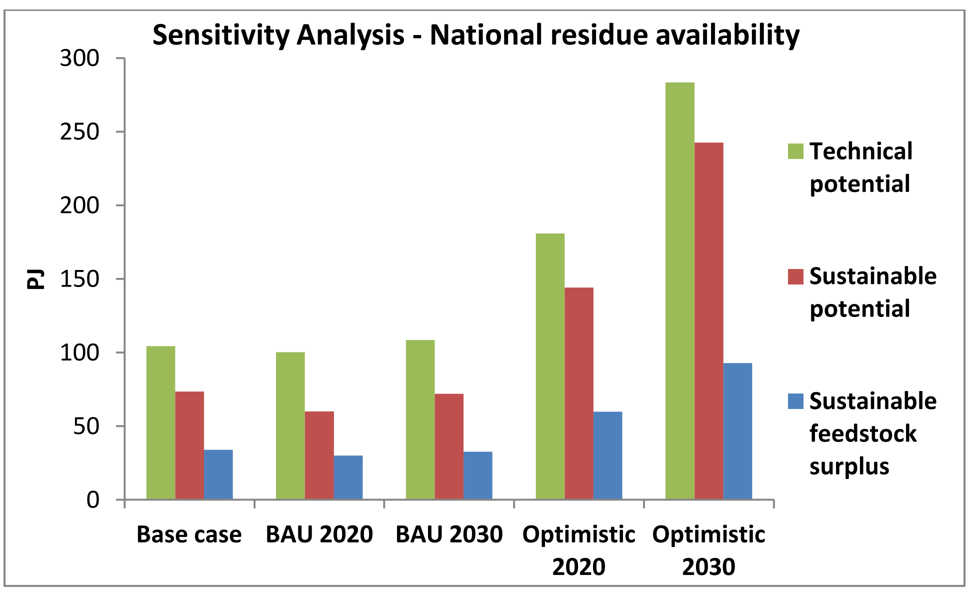
Program: Energy Analysis (track: System Analysis)

Number of ECTS: 30

Summary

European Union is in search of identifying international sourcing countries to import biomass for bioenergy purposes, while ensuring sustainability constraints at present but also until 2030. Under the scope of addressing this challenge, Kenya is a case study selected to investigate its biomass potentials that stem from herbaceous, woody and lignocellulosic biomass and subsequently assess their suitability for export to the EU for the time being and by 2030. This goal was realized primarily through an internship conducted in Kenya, where the most promising feedstocks and the counties where these (feedstocks) were present in terms of residues availability were identified and selected for further scrutiny. In fact, the selected counties were used as case studies in order to determine domestic demand and other important parameters (e.g. farming practices, technological adoption) which were in turn applied to the remainder counties where the selected feedstocks were being produced. Thus, regarding the present situation in Kenya the technical, the sustainable and finally the sustainable feedstock surplus potential for each feedstock was estimated on a county level and subsequently summed up to reach conclusions regarding Kenya's total biomass potential. Accordingly, the costs and GHG emissions induced throughout the entire biomass supply chain were assessed and a discussion on the share of the national sustainable feedstock surplus potential meeting sustainability criteria was provided. With the view to estimating possible future ranges of the total sustainable feedstock surplus potential in Kenya two scenarios (BAU and Optimistic) were devised providing a sensitivity analysis with a moderate and a more optimistic situation under different assumptions for 2020 and 2030.

Timber sawdust and off-cuts & chips, coconut husk, sugarcane residues, sisal bogas & ball, rice husk & straw, coffee husk & pulp were the feedstocks identified for further analysis.



Graph 1-1: Projections of the different types of biomass residues potentials in a short and a medium term under the BAU and the Optimistic scenarios.

The analysis of the data of this research led to the conclusion that the total available biomass potential emanating from herbaceous and woody biomass, when considering domestic demand and sustainability constraints, ranges between:

- 30 to 60 PJ → In a short term;
- 33 to 93 PJ → In a medium term.

No biomass potential from energy crops cultivation was found to contribute to the final results. Subsequently, through a cost and a GHG emissions analysis the entire amount of biomass delivered to the main port for exportation at present was estimated at 9 €/GJ and 6 kg CO_2/GJ, while for 2020 and 2030 the respective total amount under the two scenarios will deliver 7 €/GJ, and more than 90 per cent at 5 kg CO_2/GJ.

With regard to land availability for energy crops cultivation, due to the woody biomass deficit (10.3 million m^3), the high pressure on land use from the agriculture and the livestock sector, and the inaccessibility of the remote arid areas no potential was found. This situation was predicted to remain the same until 2030 due to unfavorable trends of key parameters related to land availability, such as food demand (75 per cent increase by 2030), maize yield (58 per cent decrease by 2030), woody biomass deficit (24 per cent increase by 2030) and livestock nutritional needs (150 per cent by 2030). The most determinant competing uses of the residues among the ones identified were found to be those for fertilizing applications and household domestic needs (fencing, firewood), where in the cases of sisal bogas and off-cuts & chips 100 per cent were used respectively. Subsequently, sugarcane stalks & leaves and bagasse were found to be the most significant sources of solid biomass in Kenya, seeing that they account for more than 70 per cent of the total technical biomass potential at present, implying a strong interdependence between the sugarcane sub sector and the national sustainable feedstock surplus. This is also indicated through the identification of the biomass supply costs and GHG emissions; currently, more than 90 per cent of sugarcane residues are not available due to the lack of access to a freight station in close proximity (<300 km). In fact, only 10 PJ of sustainable feedstock surplus are feasible to be presently delivered. However, in the short and medium term a number of parameters significantly affecting the present condition were taken into account. Namely, through the opening of the Kisumu freight station by 2020 the entire sugarcane residues volumes will become available. As a result, the final biomass supplied to the main port of Mombasa for exportation in 2020 and 2030 may rise from 10 PJ at present to 25 PJ and 27 PJ respectively, under a BAU scenario and delivered at 4 €/GJ and 5 kg CO_2eq/GJ for about 80 per cent of the total sustainable feedstock surplus. Accordingly, in an optimal case through more positive vigorous changes on the same parameters (crop yields and timber supply) coupled with assumed annual harvested areas expansions, reduced logistic (train costs from 0.16 to 0.02 €/km) and fertilizer costs (30 per cent reduction), the total net biomass available at the main port may increase from the 10 PJ to 55 and 87 PJ in 2020 and 2030 correspondingly and 80 per cent of these amounts delivered at 5 and 4 €/GJ and 5 and 4 kg CO_2eq/GJ for the same timelines in that order. In both scenarios additional parameters causing these changes are also the assumed pre-treatment facilities through which bulk and energy densities of the investigated feedstocks are increased. These result in lower logistic costs and GHGs emissions released throughout the biomass supply chain. The shares of sustainable feedstock surpluses holding these costs and GHG emissions are possibly available for exportation to the EU when compared with alternative competing fuels (biodiesel and petro-diesel) in terms of costs and emission reduction rates.

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Definitions

Base case: The analysis of this study incorporates projections regarding the residues potential from 2020 to 2030 under the BAU and the Optimistic scenarios. The Base case represents the current situation upon which the aforementioned scenarios are developed.

Domestic demand: The share of the total residues produced for a given feedstock utilized by indigenous competitive applications, such as households and local industries.

GDP: "*Gross domestic product is an aggregate measure of production equal to the sum of the gross values added of all resident institutional units engaged in production (plus any taxes, and minus any subsidies, on products not included in the value of their outputs). The sum of the final uses of goods and services (all uses except intermediate consumption) measured in purchasers' prices, less the value of imports of goods and services, or the sum of primary incomes distributed by resident producer units*" [1].

GHG: A greenhouse gas is in the atmosphere of Earth, able to absorb and emit long wave radiation (infrared). The most common GHGs are carbon dioxide, methane, nitrous oxide, water vapor and ozone.

LHV: The energy content of a fuel, defined as the amount of heat released per mass of fuel burned during combustion, the measurement of which is performed under 25^0C and 1 bar. During combustion, water is also formed. Thus, the difference between lower and higher heating values, lies on the energy content of water at each of its phases. The energy content of water in the case of lower heating value is measured in the gaseous form, whereas in the case of higher heating value in the liquid form. This distinction is relevant for fuels containing hydrogen [2].

Net sustainable surplus potential: The share of the sustainable feedstock surplus potential estimated, meeting the criteria for export. This term describes the final biomass potential available for export and depends on costs and GHGs emissions incurred throughout the biomass supply chain.

RPR: The residue to product ration shows how much residue is generated per amount of final product under the same units of mass, unless indicated otherwise in the text.

RGR: Same as RPR, used for forestry residues.

Sustainable potential: The fraction of the technical potential, when restrictions related to environmental criteria, such as soil erosion and maintenance control, are considered [3].

Technical potential: The total amount of solid biomass generated owing to agricultural & forestry activities (harvesting and processing), and dedicated energy crops.

1. Introduction

1.1. Background

Kenya is a country located in east Sub-Saharan Africa, lying on the equator, South-east from the Indian Ocean. Kenya extends to an area of 58 million ha and presently has an increasing population of approximately 42 million [4], [5]. The country's GDP in 2013 was 44 billion USD with the agricultural sector accounting for 25 per cent, being the backbone of the national economy. Thus, sustained agricultural growth is crucial not only for the improvement of living conditions but also for boosting economic development [4], [6].

Similarly, the forestry sector constitutes an integral part of the country's economy as timber amounts to a 7 million m^3 supply potential on a national level and charcoal being a major bio-energy resource, covering energy demand of 82 per cent of urban[1] and 34 per cent of rural households. Taking into consideration the increasing demand for wood, the forestry sector greatly affects overall national development [7], [8]. Consequently, at the moment, agriculture and forestry sectors show that large amounts of residue are generated due to their harvesting and processing activities. As a consequence, these residues can create a new market branch of bio-energy production in the country, which is currently unexplored. Furthermore, considering the fact that an area of 6 million ha and 37 million ha is covered by agricultural products and woody biomass respectively, the question that arises is how much land could be available for energy crops cultivation in present and in the future that would add to the bio-energy potential of Kenya [5], [9].

Figure 1-1: Location of Kenya on Earth.

In the EU, the potential development of the bio-based economy, and the discussed implementation of advanced bio-refinery concepts may entail an increase of biomass supply demand, as well as of feedstock for the production of bio-products and for bio-energy generation. This is a direct consequence of the fact that in the Climate and Energy package, European targets

[1] The rest is predominantly covered by paraffin and firewood .

have been set by 2020 and indicate an increase in biomass demand for energy purposes that might not be achieved by solely sourcing raw materials from the EU-zone [10]. In addition, in 2012 the European Commission released the communication “Innovating for Sustainable Growth: A Bio-economy for Europe” calling for a smart and green development in the continent, which addresses a huge demand for biomass not only originating from the continent but also from importing biomass to other international sourcing countries [11]. Therefore, it is of great importance to provide guidelines for the development of a European Bio-energy Trade Strategy ensuring that imported bio-resources are sustainably sourced and used efficiently, while avoiding distortion of other (non-energy) markets. Thus, EU has taken action by initiating the project BioTrade2020+ "Supporting a Sustainable European Bio-energy Trade Strategy", where several universities and institutions participate seeking innovative solutions to overcome this challenge [12]. The project aims at the development of a European Bio-energy Trade Strategy beyond 2020, while taking into account sustainability issues and interactions between the different supply chains and markets.

In the BioTrade2020+ project, Sub-Saharan Africa is identified as one of the prospective sourcing regions, where biomass potentials produced from agricultural & forestry residues and land availability for lignocellulosic dedicated crops are considered promising for export to the EU. Under the framework of this project, Kenya was selected as a case study in order to evaluate its biomass potential available for export, which could increase Kenya's participation in the bio-energy international trade market.

1.2. Problem Description

The bio-energy potential accumulated from solid biomass in Kenya is currently unexplored. Therefore, the principal challenge of this study is to assess Kenya's prospective biomass potential available for export to the EU within the timelines of the present, 2020 and 2030. This task is multilateral due to the fact that in order to assess the biomass potential in Kenya, available for export, agricultural & forestry residues potential and land availability for lignocellulosic feedstock production have to be examined. Biomass potential stemming from these three different sources depends on a number of factors. Consequently, to analyze the miscellaneous biomass potential available in Kenya for export, these factors need to be investigated, including,

- the analysis of current and future domestic production and consumption volumes of the residues;
- potential competition risks originating from existing and possible future residue uses for feed, household and other purposes;
- the sustainable surplus quantity for export under different scenarios;
- on-going and possible future trade routes, delivered costs and GHG emissions in the supply chains;
- current and future potential available land for dedicated energy crops cultivation.

All of these issues need to be studied under the scope of certain sustainability criteria. Finally, due to the fact that the findings of this research will be used as input to serve the ultimate goal of the BioTrade2020+ project, a consistent methodology, which will also be applied in other case studies, needs to be implemented.

1.3. Knowledge Gap

Up to now, numerous studies addressing bio-energy potential at a global, national or regional level have been conducted such as van der Hilst, Batidzirai, Smeets et al., Junginger et al., Belward et al.[3], [13]–[16]. Most of them focused on the supply of biomass in terms of costs (logistics, production), environmental criteria (GHG emissions, soil erosion control & soil organic carbon maintenance) and subsequently quantity available for the market to be capitalized. However, the indigenous demand aspect has been predominantly approached through literature review without capturing all the possible competing uses and when that happened some of the above factors were not completely analyzed.

Thus, the most challenging aspect of this research is the analysis of the domestic demand of the different residue types existing in Kenya, coupled with the respective supply potential under certain sustainability requirements. The most recent works on this field are by Kamfor company and Kibulo which investigated both the supply and demand side of biomass in Kenya for the years 2000 and 2007 respectively, nonetheless without providing a cost analysis and without considering environmental criteria [17], [18]. Consequently, a crucial part of this research is the application of a consistent methodology whereby the net biomass potential available, when taking into consideration domestic demand and sustainability constraints, can be estimated. Therefore, the outcome of this study will not be used solely as an input for the next work packages of the BioTrade2020+ but can also serve as a common framework for the study of net biomass potential in other case studies.

Objectives

Main objective: Estimation of the net sustainable biomass surplus potential available in Kenya that can be imported by Europe from 2015 until 2030.

Sub-questions:

1. What are the most prominent agricultural & forestry products in terms of residues potential?
2. What is the technical and subsequently the sustainable potential of the under investigated residue types?
3. What are the streams of the different residue applications of the selected agricultural and forestry products?
4. What is the prospective potential of land for dedicated energy crops cultivation?
5. What are the costs and GHG arising from the generation point of the residues and up until their transportation to the main port?

6. What are the different parameters affecting the current net sustainable surplus biomass potential in Kenya and how this can change under different possible scenarios by 2030?

1.4. Research Scope

This research aims at using the findings of the internship conducted in Kenya in order to evaluate the biomass potential, possibly available for export to the EU from 2015 until 2030. Moreover, to ensure consistency between the existing case studies and exploit the findings effectively, the methodology was developed under close collaboration with Dr. H.M. Junginger and Ms. T. Mai-Moulin within the framework of the BioTrade2020+ project.

Thus, this study is conducted within the following scope:

- The research was carried out within the boundary of Kenya;
- The different tasks of this study are investigated under three timelines. The present situation (2015), the 2020 and the 2030. When data not available for the current situation, information of 2010, 2011 or 2012 is used based on data availability;
- The analysis of this research is conducted at a county level and extends to a national one. The selected counties are those selected during the internship;
- An estimation of the distributions of initially technical and subsequently sustainable potentials, concerning the selected agricultural & forestry lignocellulosic feedstocks and energy crops is essential;
- An analysis of the biomass supply chain costs follows, starting from the sourcing points of the residues and ending up to the main port of Mombasa. Thereinafter, the share of the residues potential meeting a number of economic criteria;
- A registration of the GHG emissions released during the biomass deliverance from the respective sourcing points to the port of Mombasa. Subsequently, the share of the residues potential fulfilling a number of sustainability criteria is discussed;
- The development of two scenarios (BAU and Optimistic) is included in order to provide a sensitivity analysis of the net sustainable surplus biomass potential for the timeframes 2015-2020 (short term) and 2015-2030 (medium term).

Data for the aforementioned tasks was collected through interviews during the internship, literature review, external reports and web search, when information was not available.

2. Methodology

To address research questions concisely and consistently the research set up illustrated in Figure 2.1 is implemented. The different steps included in the research set up are developed based on the designed methodology of the BioTrade2020+ project [19].

The research planning is divided into two parts. The first part is illustrated in the sustainable feedstock surplus section. The set up of this stage leads to the estimation of the biomass potential available currently, in 2020 and 2030, when the preceding tasks are considered. The second part comprises of certain sustainability criteria which are imposed on the outcome of the first part, in order to assess its share that can be available for export to the EU at present, in 2020 and 2030. Two different scenarios (BAU and Optimistic) are developed and applied in both the first and the second parts, with the view to providing a sensitivity analysis of the final result.

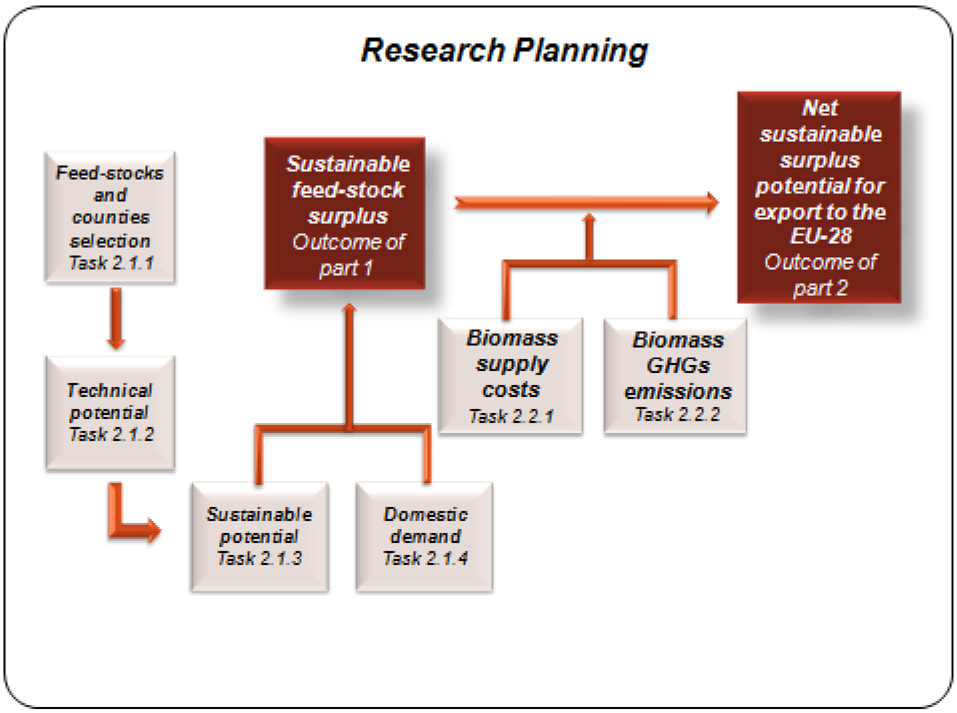


Figure 2-1: Visualization of the research planning and the different tasks to be carried out in order to answer the research questions.

2.1. Part 1: Sustainable feedstock surplus

In this section the elements concerning the first phase of the research set up are described.

2.1.1. Feedstocks and counties selection

This task was carried out throughout the internship in Kenya.

Aim: The five most prominent agricultural and forestry products with respect to their biomass potential available are identified through the implementation of a number of criteria, as described below. Subsequently, after the identification of the most promising feedstocks, the counties holding the highest potentials of the selected agricultural and forestry products is investigated.

Method: Should the number of the products present in the country is high, then the selection is decided on the basis of:

- A preliminary estimation of the technical potential for each feedstock present in Kenya;
- The total livestock nutritional requirements at a county level;
- The location of the production points in relation to their distance from the train freight stations and/or their distance from the main port;
- Expert's opinion on the availability of the different feedstocks;
- The clarity and the scale of ownership;
- Centrality of the production points;
- Data retrieved from previous studies conducted in Kenya, on the disposable potential of miscellaneous residue types.

Initially, the first two points focus on residue types, used as animal feed and provide a general indication on the biomass availability at a county level. Secondly, the rest of the criteria combined with the first are used so as to compare different residue types and narrow them down to the five most prominent in terms of availability.

Data sources:

a) National and provincial statistics on

- production volumes;
- areas;
- and yields

of all the agricultural and forestry feedstocks present in Kenya.

b) Related studies on Kenya's residue potential and insights from experts in the fields of livestock, herbaceous and woody biomass.

2.1.2. Technical potential

Aim: To provide an overview of the national technical potential stemming from the herbaceous and woody feedstocks selected in the previous task but also land available for energy crop cultivation at present, in 2020 and 2030.

2.1.2.1. Agricultural sector

Aim: The different residue types resulting from harvesting and processing activities concerning the selected agricultural feedstocks, are estimated at a county and summed up to a national level at present, in 2020 and 2030.

Method: The residue to product ratio (RPR) describes the amount of residue produced per crop. Residues are separated into the by-products of agricultural practice, which are the result of harvesting crops (e.g. corn stover, straw) and indirect ones originating from processing of agricultural products (e.g. rice husks). First, the amount of crop production is determined and subsequently, by applying the RPR index to the production volume of the corresponding feedstock, the amounts of residues generated can be estimated. Thereafter, low heating values (LHVs) are used for each type of residue and are multiplied with the respective residue production volume in order to express the corresponding technical potential.

Equation 2-1

$$LHV_i * RPR_i * production\ volume_i = Technical\ potential_i$$

Where,

production $volume_{i:}$	The amount of a certain product;
LHVi:	The lower heating value of a residue type;
RPRi:	The residue to product ratio of a residue type.

Furthermore, within the context of developing projections on the technical potential deriving from agricultural residues currently, in 2020 and 2030, a number of indicators and factors are explored. The process of performing the projections is discussed in section 2.3.

Data required	Units
Past trends up to ten year time period of:	
Harvested areas	ha
Production volumes	t
Yields	t/ha
Imports & exports	t (whenever applicable)
In addition:	
Already existing projections (whenever applicable)	N/A
Climatic conditions	N/A
RPR	ration (input from task 2.1.1)
LHV	GJ/t (input from task 2.1.1)

Table 2-1: Data required in order to estimate the current and future technical potential stemming from the agricultural sector.

Data sources: FAOstat, national statistics and whenever applicable reports and records from interviews with stakeholders (governmental authorities, estates, mills etc.)

2.1.2.2. Forestry sector

Aim: Similarly with the previous sub-section, the primary, secondary industrial and tertiary residues originating from the selected forestry feedstocks are provided within the same geospatial orientation.

Method: The production volumes of the respective forestry products have to be estimated conjointly with residue generation ratios in order to have a first order estimation of the technical potential in mass.

Equation 2-2

$$FR = \sum_i (WPi * RGRi)$$

Where,

i= 1 primary;

i= 2 secondary;

i= 3 tertiary;

FR: Biomass potential extracting from primary, secondary and tertiary forest residues;

WPi:

i= 1 Woody biomass production due to cultivation and harvesting (e.g. logging activities);

i= 2 Woody biomass production due to industrial activity (e.g. sawmills, pulp and paper);

i= 3 Wooden products, which are available at the end of life;

RGRi: Residue generation ratio at each phase 1,2,3.

Subsequently, through the corresponding LHVs of each residue type the technical potential at present originating from woody biomass is realized.

That is,

Equation 2-3

$$\sum_{i}(FR_i * LHV_i) = Technical\ Potential$$

Where,

FR_i and LHV_i are the respective values for a certain residue type.

Under the same scope with the agricultural sector for envisaging the technical potential originating now from the forestry sector, the respective key drivers and demand-driven indicators trends are investigated.

Data required: The corresponding data required from the agricultural sector.

Data sources: FAOstat, national statistics and whenever applicable reports and records from interviews with stakeholders (sawmills, governmental authorities etc.)

2.1.2.3. Identification of available land for dedicated energy crops.

Aim: Quantification of the total land area available in Kenya for energy crops cultivation and in turn bio-fuel production for the time being, in a short and a medium term.

Method: In principal, the available land for dedicated energy crops is that of available land base (marginal, degraded and abandoned areas) after subtracting the land needed for food, feed, livestock, built up areas and set aside for nature conservation [20]. However, there is a possible surplus bio-energy potential originating from forests that is to be taken into account. This is defined as forest growth not demanded for the production of fuel wood (wood needed for cooking and heating) and industrial round-wood [21].

Thus, in order to estimate the available land for the cultivation of energy crops a number of factors need to be examined such as whether any surplus land, which can be cultivated, under the following factors is suitable for bio-fuel production.

Data required	Units
With regard to disposable land for the time being:	
Food demand in conjunction with the domestic production of food products	Kcal/capita/day and t or GJ respectively
The supply potential of woody biomass products and the respective demand	m^3
Reforestation & deforestation rates	%
Land use areas under agriculture, forestry, settlements and livestock	ha

With the view of making projections on land availability for 2020 and 2030, past trends up to 10 years of:	
Food demand	Kcal/capita/day
Yields	t/ha
Production and consumption volumes	t
GDP and population rates	€ and million inhabitants respectively

Table 2-2: Data needed to estimate the current and future biomass potential emanating from dedicated energy crops.

Data sources: National and county statistics from the ministries on the different production & consumption volumes of feedstocks and land use areas. Should data not available external reports and web search are used.

2.1.3. Sustainable potential

Aim: The share of the technical potential that adheres to certain sustainability restrictions maintaining the same temporal and geographical perspective with the previous task.

Method: In order to assess the biomass potential that can be sustainably removed for bio-energy purposes, the amount of residues set aside to prevent soil erosion and maintain soil organic carbon (SOC) levels has to be identified. Subsequently, it is subtracted from the corresponding technical potential of the residues, resulting to the sustainable potential.

Residues used for soil erosion control are important to protect the soil against wind and water erosion, whereas the second to maintain or even increase the soil organic matter level at a minimum of 2 per cent [22]. Residues are also valuable due to the positive effect they have on soil quality, drought resistance and water infiltration. However, the main applications are those of soil erosion control and soil organic carbon maintenance, since the amount of residues required for them is assumed sufficient to satisfy the rest of the applications [23]. A soil cover of about 70 per cent or alternatively 2 t/ha of residues is adequate for soil erosion control [22]. The SOC is stemmed from above and below ground residues and rhizodeposition. The amount of residues required to preserve the SOC level at a minimum of 2 per cent is determined for each county based on their respective soil type and annual average temperature and rainfall.

In order to avoid overlapping between these two residue applications, the sustainable potential is calculated as follows:

Equation 2-4

$$IF\ (TS - BGR) > ER \rightarrow SP = TP - ((TS - BGR) * A * LHV)[23];$$

Equation 2-5

$$IF\ (TS - BGR) < ER \rightarrow SP = TP - (ER * A * LHV)[23].$$

Where,

TS	Above and below ground biomass required to preserve 2 per cent SOC level;
ER	Amount of residues required for soil erosion control;
BGR	Below Ground Biomass;
SP	Sustainable Potential;
TP	Technical Potential;
A	Harvested Area;
LHV	The Lower Heating Value for a certain feedstock.

Furthermore, a number of factors, such as crop yields and cultivation management practices, affecting the sustainable potential of the different feedstocks are considered and examined over time, with the aim of performing projections in the future.

Data required	Units
Amounts of residues necessary to maintain soil organic carbon and prevent soil erosion	$t_{residues}$/ha
Current and proposed cultivation management practices	N/A
Crop yields	t/ha (input from task 2.1.2)
Current and eventual future climatic conditions	N/A
Soil type of the feedstock producing areas	N/A

Table 2-3: Data and information necessary to evaluate the sustainable potential of the residues.

Data sources: Interviews with companies and farmer unions active in the area of the investigated feedstock, and web sites.

2.1.4. Market segment analysis

Aim: An overview of the domestic demand for the selected feedstocks per county and an analysis of the elements constituting the market regime of bio-energy in Kenya, are provided representing the current situation, 2020 and 2030. This task is the last step of part 1.

Method & Data required: A number of companies and farmer unions were contacted to collect data in the internship in terms of not only their size and activities, but also of their willingness to provide data and arrange discussions. The aim was to receive information on the different types of domestic demand for each feedstock, such as specific quantities used for cooking, heating and local industries but also quantities used for animal feed. These amounts are subtracted from the sustainable potential as described above, resulting in the present sustainable feedstock surplus. In case of feedstocks, where information from the internship was inadequate to develop a case study, data from literature review are taken into account.

Equation 2-6

$$Sustainable\ feed-stock\ surplus\ = sustainable\ potential - domestic\ demand$$

Under the scope of evaluating the possible sustainable feedstock surplus in 2020 and 2030, energy policies and regulations influencing the expected outcome of the biomass availability are scrutinized. A high number of countries which have signed the Kyoto Protocol continue to revise or develop policies to reduce GHG emission in order to reach the targets and reinforce the share of renewable energies, therefore the assessment of biomass potentials need to take into account changes, incentives as well as adaptation and improvements in agriculture, forestry sectors as result of implementation of related policies and regulations. For instance, incentives to promote large scale investment in the manufacture and marketing of energy efficient stoves in this country may lead to a significant reduction in the consumption of biomass energy by almost 80 per cent [24].

Data sources: Interviews with companies, farmer unions related to each feedstock type and literature review through web search and external reports.

2.2. Part 2: Net Sustainable Surplus Potential for export to the EU-28

2.2.1. Biomass supply chain cost analysis

Aim: A comprehensive estimation of the share of sustainable feedstock surplus potential that meets economic criteria within given conditions. That is, the amount of biomass that can be considered viable against the competition with fossil fuels or carbon prices and other alternative renewable resources. This task focuses on the timelines of current situation, 2020 and 2030.

Method: A breakdown of the whole set of costs incorporated in the biomass supply chain, considering the locations of production of agricultural and forestry feedstocks as a starting point and the export harbor of Mombasa as an end point. The farm gate costs, transportation costs for truck and train, storage costs, pretreatment costs when applicable and port costs are investigated. Subsequently, a cost-supply curve based on the costs acquired is constructed, through which the amount of biomass outweighing fossil fuel and other renewable energy sources in terms of prices is determined. Finally, solutions to reduce costs in the future are provided under different scenarios, in order to render economically viable a bigger share of the sustainable feedstock surplus.

The supply curve is constructed based on the total current cost of biomass supply, and cost changes in short and medium term.

Equation 2-7

$$C_D = C_{Fg} + C_{Pt} + C_{Td} + C_{Pc}$$

Where,

C_D	The total supply cost of biomass (€/GJ);
C_{Fg}	The farm gate cost (€/GJ);
C_{Pt}	The cost of pre-treatment (€/GJ);
C_{Td}	The cost of domestic transport (€/GJ);
C_{Pc}	The cost due to port charges (€/GJ).

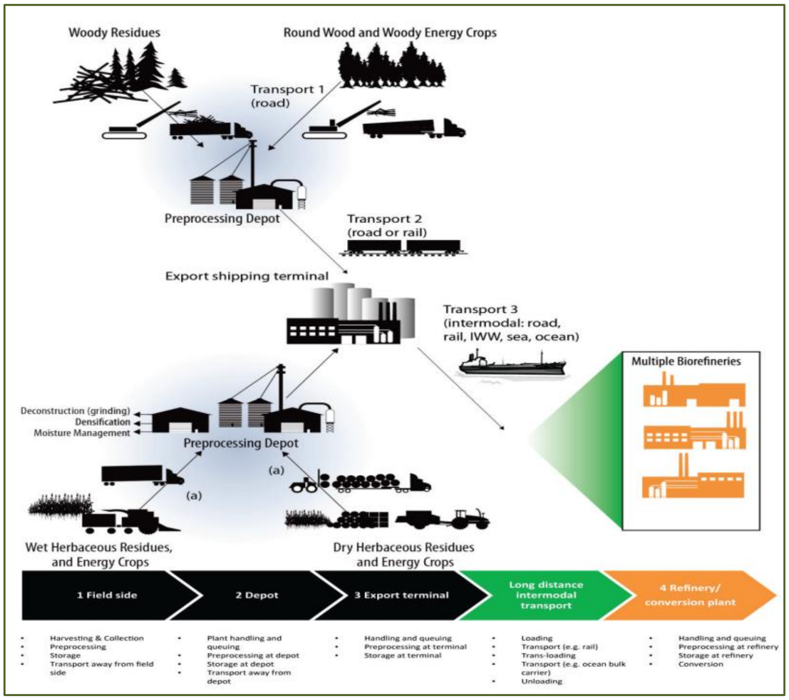


Figure 2-2: Breakdown of the biomass supply chain[2] [19].

All the elements of equation 2-7 are calculated individually based on the following data.

Data required	Units
Residues available potential	t or PJ (outcome of section 2.1.)
Fuel price	€/L
Labor costs	€/h
Electricity price	€/MWh
Exchange rates	Ksh into € (input from task 2.1.2)
Shipping capacities	m^3 and t
Feedstock densities	t/m^3
Prices of alternative sources	€/GJ

[2] The Transport 3 element of the figure is not taken into consideration, since it is outside the geographical scope of this study.

Nutrient compensation costs	€/GJ
Working hours	h
Inland transport routes and distances	km (input from task 2.1.1)
Profit embedded in each step of the supply chain	%

Table 2-4: Data required for the development of the biomass supply cost curve.

The set up of the methodology used to carry out the calculations with the view to deriving the cost supply curves was adopted by Batidzirai [14].

Data sources: Logistic companies (Damco), and through literature review.

2.2.2. Biomass supply chain GHG emissions analysis

Aim: Analysis of GHG emissions, concerning the selected feedstocks, released throughout the supply chain and the respective shares of biomass that meet sustainability criteria in terms of emission avoidance in relation to fossil fuel use. The analysis is followed by recommendations on the GHG emissions reduction in 2020 and 2030.

Method: at first, the biomass supply chain is designed and subsequently the GHG emissions at each stage of the chain are estimated and summed up for each residue type. This is obtained through the different emission factors attributed to corresponding means (e.g. fertilizers, truck transport etc.). Subsequently, due to the fact that this study is carried out within the boundaries of Kenya, a comparison-discussion between different studies elaborating GHG emissions released throughout miscellaneous biomass supply chains, including overseas shipping and final conversion processes, will be done on the basis of emission avoidance rates in relation to fossil fuel uses, in order to provide indications on the promising shares of the sustainable feedstock surplus potential that might be suitable for export.

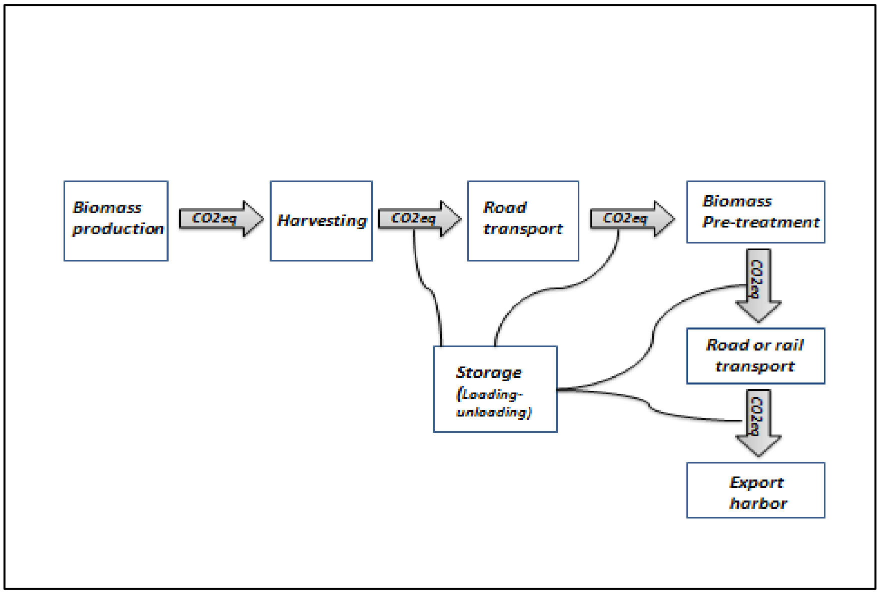


Figure 2-3: Illustration of the biomass supply stages, where GHGs emissions are released[3].

Emission balance:

Equation 2-8

$$GHG = \sum_{i} (E_i pr + E_i hr + E_i rd + E_i r + E_i pt)$$

Where,

i	A specified residue type;
$E_i pr$	Emission factor for biomass production from energy crops (kg CO2eq/GJ_{LHV});
$E_i hr$	Emission factor for harvesting (kg CO2eq/GJ_{LHV});
$E_i rd$	Emission factor for truck transport (kg CO2eq/GJ_{LHV});
$E_i rl$	Emission factor for train transport (kg CO2eq/GJ_{LHV});
$E_i pt$	Emission factor for pre-treatment of biomass (kg CO2eq/GJ_{LHV});
BP_i	Total biomass delivered for a certain feedstock (PJ).

All the elements of equation 2-8 are calculated individually based on the following data.

Data required	Units
Means of transport and distances covered	Km (Input from task 2.1.1)
Fuel usage 1	GJ/km
Fuel usage 2	GJ/$t_{residue\ harvested}$

[3] The GHGs emitted during the storage process of biomass are considered negligible.

Fuel emission factor	$CO2_{kg}/GJ$
Electricity usage	$MWh/t_{residue}$
Electricity emission factor	$CO2_{kg}/MWh$
Fertilizer and pesticide emission factors	$CO2_{kg}/t_{fertilizer/pesticide}$
Amounts of fertilizers and pesticides used	$t_{fertilizer/pesticide}/t_{residue}$
Residues production volumes	t (input from task 2.1.2)
LHVs of the residues	GJ/t (input from task 2.1.1)

Table 2-5: Data required to estimate the GHGs released throughout a range of solid biomass deliverance.

Data sources: National data (same as in previous sections), literature review, European commission reports and web sites.

2.3. Scenario Development

In all tasks, scenarios play a key role. To reflect possible changes in local and global biomass market and trade in the future, scenarios are developed to mark the landscape of biomass flows globally and regionally as well as its drivers at different periods. This section aims at focusing on two timelines: short term (2020) and medium term (2030). Both scenarios use the ongoing situation as a baseline. Thus, the aim of this task is to conduct a sensitivity analysis reflecting a sensible range of the net sustainable surplus biomass potential to be exported to the EU in 2020 and 2030.

2015: This is the on-going situation of biomass trade at the current socio-economic development and environmental concerns. It takes into account domestic production and consumption of solid biomass feedstock, import and export data of biomass in order to understand the biomass flow both at national and global level. When data at current situation is not available, statistics from previous years are considered, e.g. 2010, 2011 or 2012.

2020: This scenario looks at the short term potentials of solid biomass, its supply and demand taking into account foreseen socio-economic development, deployment of innovative pre-treatment technologies and newly implemented climate, energy and environmental policies.

2030: The medium term scenario anticipates further prospective economic growth, social changes and climate change impacts, more matured pre-treatment technologies and related future policies.

2.3.1. Business as usual scenario

The business-as-usual (BAU) scenario reflects biomass production and consumption at national levels at current pace and builds on current policies which have already come into effect in the EU, the sourcing regions and other possible world regions on e.g. energy, climate and environmental targets.

Aim: To identify the lower possible limit of the net sustainable surplus biomass potential in the sensitivity analysis, under current farming practices, technological adoption, soil quality, yields and unchanged policies.

Method: Past trends of a ten year period of production volumes and harvested areas regarding the investigated feedstocks are used in order to derive average annual yields increases or decreases and subsequently apply them to the respective current yields in order to carry out projections until 2020 and 2030. Past trends before used are compared and based on the current farming practices, technological adoption and soil quality the more suitable are used. Furthermore, pre-treatment facilities for pellet production are considered with the view to presenting a realistic scenario of solid biomass trade compared with the present situation. Their capacity is selected based on biomass availability at each county, where the investigated feedstocks are present.

Through this process the technical, the sustainable, the sustainable feedstock surplus and subsequently the net sustainable surplus potential are estimated for a short and a medium term, providing this way the lower limit of the sensitivity analysis.

Data required: Past trends of production volumes, harvested areas and yields, current farming practices, technological adoption and soil quality, woody and herbaceous pellet densities, energy consumption of pre-treatment facilities (grinding, drying, pelletizing), current policies and inputs from previous tasks.

Data sources: National reports of the Ministry of Agriculture, FAOstat data, and web sites.

2.3.2. Optimistic scenario

The optimistic scenario explores options whereby larger volumes compared with the BAU scenario of sustainably produced biomass might become available for export in 2020 and 2030 due to the implementation of additional policies and regulations, whereby improved farming practices, higher technological adoption and lower deforestation rates might take place.

Expected outcome: The upper limit of the net sustainable surplus biomass potential in the sensitivity analysis.

Method: Through the assessment of the possibilities to increase the biomass potential available for export to the EU, different indicators vary accordingly (e.g. higher yields of both agricultural and forestry products). In fact, additional expected policies and regulations relative to the agricultural and forestry sector activities are taken into account and hence improved farming practices (no till+double cropping), high technological adoption, and lower deforestation rates are considered. Subsequently, higher annual yields increases and land areas expansions for cultivation are derived through three and two kind of approaches correspondingly based on data availability.

That is, regarding yields in the first approach already carried out projections on consumption and production volumes until 2030 in national reports are used, when a deficit between the two is identified. Consequently, annual yield increase is derived accordingly to offset the gap. In the second approach case studies from neighboring countries of Kenya, where better yields are achieved for a certain crop due to better farming practices and or technological adoption, are used. In more detail, the case study yield is set as a target yield until 2030 and the respective optimum annual yield increase is estimated. Finally, in the third approach based on national reports, indicated optimum yield levels for specific crops are considered and set again as target yields until 2030 in order to derive the optimum yield growth per year.

With respect to the annual land area increase in the first approach alike to the yield increase, different case studies from neighboring countries are used. In the second approach through national reports projections on additional exploitable land available under proper land management for a certain crop are used and set as targets until 2030, from where the annual land area increase is derived. Similar to the BAU scenario pre-treatment facilities of 100 kt and 10 kt capacities respectively are considered and further costs & GHG emissions reductions based on additional policies.

Through this process the technical, the sustainable, the sustainable feedstock surplus and subsequently the net sustainable surplus potential are estimated for a short and a medium term, providing this way the upper limit of the sensitivity analysis.

Data required: Expected policies and regulations relative to the agriculture and forestry sectors, and inputs from the previous tasks.

Data sources: National reports on policies and strategies development (Vision 2030, KETS) and web sites.

3. Studied Areas

This chapter will analyze the steps as described in part 1 of the methodology, in order to eventually provide an answer regarding the amount of the sustainable feedstock surplus available in Kenya at present and until 2030 under two different scenarios (BAU and Optimistic). The analysis summarizes the results on a national level[4].

3.1. Feedstock and selection of studied areas

The most promising agricultural and forestry feedstocks selected in Kenya are presented in a number of counties. The counties holding the highest biomass potentials of the selected feedstocks were chosen to be visited and used as case studies. The different case studies for each feedstock were built on the miscellaneous farming practices, levels of technological adoption and domestic demand shares identified in these areas. These are subsequently applied to the rest of the counties, where a selected feedstock is produced.

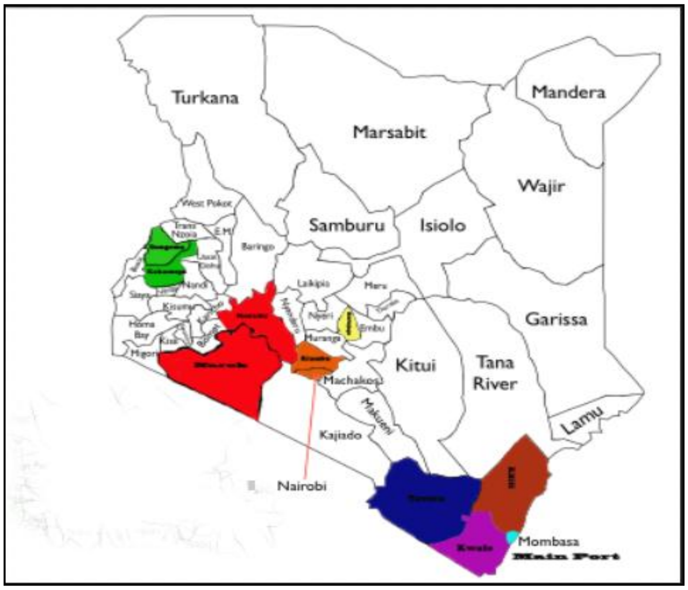


Figure 3-1: Areas visited during the internship for the development of herbaceous and woody biomass case studies.

Figure 3-1 provides a preview of 3.1.1 and 3.1.2 sub sections results, where the green areas (Bungoma, Kakamega) represent sugarcane, the red ones (Narok, Nakuru) timber, the orange (Kiambu) coffee, the yellow (Kirinyaga) rice, the blue (Taita Taveta) sisal, the purple (Kwale) coconut and the brown (Kilifi) both sisal and coconut.

A short summary of the process followed in order to draw conclusions on the counties and feedstock selection is provided below.

3.1.1. Agricultural sector

Initially, 23 products were identified and 8 of which were omitted based on their production volume (t) at national aggregate level. In fact, production volume was significantly small (50-200 times lower) compared to the first ten products [9]. In addition, a literature review based on previous researches on biomass waste from agricultural residues in Kenya together with consideration of expert opinion were deemed necessary in order to identify the first 15

[4] The elaboration was carried on a county level but due to clarity reasons the detailed results are provided in Appendices 8.1 and 8.2.

prominent agricultural products in terms of residue availability [17], [18], [25]. Therefore, maize, mangoes, bananas, sugarcane, irish potatoes, beans, coffee, sisal, wheat, cassava, sorghum, pigeon & cow peas (considered as one product), sweet potatoes, rice and coconuts were selected.

On one hand, when further studies were taken into account, cabbages and tomatoes were not considered of significant potential in the agricultural products in terms of residue availability. On the other hand, although, tea was recommended as a medium potential product by Kamfor Co.Ltd (active in environment and resource planning), according to Dr. George Schoneveld (CIFOR), the primary energy supply today for tea production in the tea sector in Kenya lacks sustainability consideration. This fact leads to an urgent need for the tea sector to conduct an analysis of viable alternative energy options/pathways and opportunities for certification of wood-fuel supply, implying that any remaining residue should be considered as sustainable energy supply for their own purposes. Thus, instead of these feedstocks, the coconut, rice and sisal were preferred.

The technical potential of the residues of the 15 aforementioned products was again estimated, at a national aggregate level and subsequently, with respect to their technical potential the 10 first products, which showed higher production, were selected.

In order to estimate the technical potential, RPR and LHVs were retrieved from literature for each product and used accordingly (see Table 8-1 in Appendix 8.1).

Subsequently, based on the technical potential estimated for each feedstock (see Table 8-2 in the Appendices) at a national level and based on negative indications of previous reports regarding their availability, pigeon & cow peas, sweet potatoes and sorghum were excluded. Although the remaining products are managed by many different farmers of a small scale capacity (clarity and scale of ownership criteria), based on their higher potential, they were selected for further analysis on a county level. The reason for this is that households are directly involved in agricultural activities, in which all food & horticultural products under investigation are involved, accounting for 69 per cent of all households in Kenya. Specifically, in many cases these households raise at least one type of livestock [26]. That implies free and easy access to their livestock units in the residues generated from their agricultural activities and since livestock is one of the main competing uses of the residue utilization, in terms of energy requirements, these products were firstly investigated. Therefore, maize, mangoes, bananas, irish potatoes, beans, wheat and cassava were further examined, since all of them were specified as common animal feeds in Kenya by Mr.Goopy of ILRI (International Livestock Research Institute) and both Mr.Mutua and Mrs.Mwambia of the Ministry of Livestock[5].

[5] Insights on common animal feeds provided by ILRI's research scientist, Mr.Goopy, and both the animal feed specialist, Mr.Mutua, and the Deputy Director of Livestock Production, Mrs.Mwambia, in the Ministry of livestock after personal conversations.

The analysis, in order to identify which of the feedstocks discussed above show positive indications on residue availability, was carried out at a county level. Specifically, the distributions of technical potential of the aforementioned products were obtained and used to determine the respective nutritional value of the different residue types. Consecutively, the livestock population distribution on a county level was also collected from the Ministry of Livestock and based on knowledge about the nutritional needs of cattle, goats, sheeps, pigs and poultry per head per day, the total livestock feed demand per county was estimated on a year basis. This way, an indication of the residue availability concerning the different residue types was investigated. The course of the calculations is provided in more detail in appendices 8.1.

As can be seen from the Table 8-8 there is a total deficit of 105 PJ. Thus, it was likely that there was no potential left for export concerning the aforementioned products, for only livestock needs that were taken into account and not any other competing uses that could further limit the availability of the residues. Furthermore, at present, some counties facing a residue surplus such as Bungoma, Kakamega, Machakos, Migori and Nandi are distant more than 300 km from the nearest freight station, thus increasing the respective biomass deficit to 153 PJ. The location of the feedstock production points was one of the leading criteria, since biomass when transported by truck for such distances is not economically viable [27].

As a result, sugarcane, sisal, coffee, rice, coconut, were selected probably also not suitable as animal feed according to the experts interviewed above (except for rice straw and molasses). Apart from the expert opinion, the selection of the three first crops was principally decided based on their explicit ownership cut and big scale activities (they possibly didn't possess livestock and reliable information was available), and secondly, on positive indications from previous studies [17], [18]. Sugarcane didn't fulfill the location criterion, but owing to the opening of the Kisumu freight station by 2018 it was included. The last two feedstocks were selected due to the centrality and location of their production points and positive indications from previous studies[9], [17], [18].

3.1.2. Forestry sector

In this part the feedstock selection was straight forward. Four woody biomass products dominate the Kenyan market, namely timber, poles, firewood and charcoal. This information was provided by the deputy director of the Forest Extension Services in Kenya, Mr. Patrick, who shared an unpublished report through which the selection was realized.

Year 2013	Timber in million m^3	Poles in million m^3	Firewood in million m^3	Charcoal in million m^3	Total in million m^3
Supply Potential	7.36	3.03	13.65	7.36	31.40
Available Supply	2.40	2.88	12.97	1.18	19.43

Lost Volumes	4.96	0.15	0.68	6.18	11.97
Percentage loss	0.67[6]	0.05	0.05	0.84	N/A

Table 3-1: Woody biomass potential of the four market dominating products in Kenya, and their respective residue generation ratios [7].

In this table, the gross woody biomass and the actual available woody biomass supply are provided, taking into consideration the losses owing to conversion efficiencies of each process. Due to the fact that timber waste, accruing from sawing, accounts for 86 per cent of the 6 million m^3 waste in total, further analysis in this research is carried out on timber, in order to further determine the corresponding net sustainable surplus potential. Regarding the waste aggregate, the respective share stemming from charcoal production (ash) was not taken into consideration due to limited exploitability for bio-fuel production.

Thus, the residue types generated from timber to be further investigated are the off-cuts & chips and sawdust.

Residue type	$Share_{av}$ in timber waste %	LHV_{av} GJ/t	Share range % [22], [28]	LHV range GJ/t [29]–[33]
Off-cuts & chips	57.5	19.2	53.0 - 62.0	17.5 - 20.8
Sawdust	19.5	16.8	11.0 - 28.0	15.4 - 16.5

Table 3-2: Average of residue parameters and their respective ranges regarding timber processing, which are necessary to determine the corresponding technical potential.

The data of this table are going to be used in the sequel of this research to determine the technical potential originating from sawdust and off-cuts & chips. The reason why off-cuts & chips are addressed as one product is due to the fact that the different stakeholders interviewed during the internship, considered them as one type of waste.

3.2. Net sustainable volumes of crop & forestry residues – At present

In this section, the sustainable feedstock surplus potential regarding the present situation in Kenya, is provided. In this analysis, inputs from the previous section are used. In fact, the study focuses on the agricultural & forestry feedstocks selected during the internship, where information and data gathered from the investigated case studies are used to draw the expected outcome of part 1 in the methodology.

3.2.1. Agricultural feedstocks

This sub section examines the sustainable feedstock surplus accruing from the agricultural sector. The technical and subsequently the sustainable potentials of sugarcane, sisal, coffee, coconut and rice are investigated. Consecutively, through the identification of the market regime

[6] It is used as the RGR of timber regarding the process residues.

and domestic demand concerning each different residue type, the corresponding sustainable feedstock surplus is derived.

The miscellaneous residue types generated from the five products, as recognized during the internship are,

- Sugarcane: bagasse, stalks & leaves, molasses;
- Sisal: ball, bogas or pulp;
- Coffee: husk, pulp;
- Coconut: husk;
- Rice: husk, straw.

Due to the fact that data (see Table 8-1 in Appendix 8.1) were retrieved from literature to achieve the results of task 3.1.1, a number of RPR and LHV indexes of the aforementioned residue types are updated and shown in the following table. The update is based on new information gathered from the different stakeholders interviewed during the field work and further literature review, concerning each case of biomass type.

Residue type	RPR_{av}	LHV_{av} GJ/t	Range RPR [18], [34]–[37]	Range LHV GJ/t [18], [35], [38]–[40]
Bagasse	0.38	12.93	0.36 - 0.40	7.75 - 18.10
Sugarcane stalks & leaves	0.22	16.61	0.10 - 0.33	15.81 - 17.41
Molasses	0.04	8.50	0.04	7.00 - 10.00
Sisal ball	4.10	14.85	3.50[7] - 4.70	14.40 - 15.30
Sisal bogas	19.80	14.85	15.60[8] - 24.00	14.40 - 15.30
Coffee husk	0.24	14.10	0.23[9] - 0.25	12.20 - 16.00
Coffee pulp	2.42	0.01	3.40[10]	0.01
Coconut husk	1.10	17.66	0.60 - 1.60	16.70 - 18.62
Rice straw	2.19	13.45	0.42 - 3.96	10.90 - 16.00
Rice husk	0.29	16.17	0.22 - 0.35	13.00 - 19.33

Table 3-3: Averages of the RPR and LHVs of the studied agricultural residues and their corresponding ranges.

The technical potential regarding herbaceous biomass can now be examined through the use of the updated RPRs and LHVs on the fitting production volumes. The analysis is performed at a county level and sums up at a national. That is, regarding the investigated feedstocks, the

[7] This price is calculated based on actual data from Real Vipingo sisal estate in Kilifi County. According to Real Vipingo estate, they harvest about 300 ha per year and they possess 3,000 plants/ha, while a sisal ball weights about 20 kg and their fiber production in 2014 was 5,100 t. Thus, with 18,000 t of sisal ball generated within a year, a RPR of 3.5 is obtained.
[8] The lower limit of sisal bogas RPR is provided again by Real Vipingo's estate measurements.
[9] This value is retrieved from the data sets of Kofinaf (coffee mill) in Kiambu County during the internship.
[10] Similarly to coffee husk RPR, it is retrieved from the data sets of Kofinaf.

respective production volumes and harvested areas found in each county are collected and further investigated through the corresponding conversion indexes. Subsequently, they are summed up to define the aggregated technical potential stemming from herbaceous biomass (Equation 2-1).

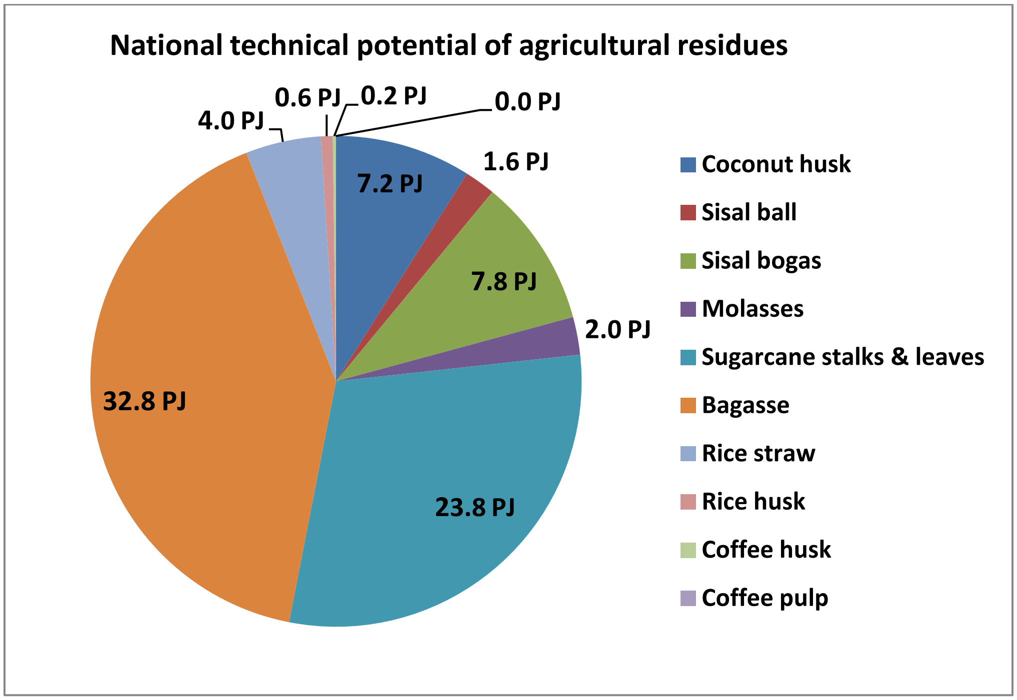


Figure 3-2: Breakdown of the total technical potential originating from the agricultural sector.

Consecutively, the total technical potential at present in Kenya is estimated to be about 80.0 PJ. Bagasse and sugarcane stalks & leaves constitute the most significant part of it with 32.8 PJ and 23.8 PJ respectively. On one hand, this outcome can be attributed to higher yields of sugarcane and larger harvested areas. On the other hand, despite the high sugarcane yields, molasses show a low technical potential of 2.0 PJ owing to its low RPR. The technical potential of coffee pulp is negligible (three to four orders of magnitude less than the rest of the residues), due to its substantially low energy content, which is the result of its high moisture content[11] (80%). Rice and coffee husks technical potential lie in low levels with 0.6 PJ and 0.2 PJ following the same order due to their low RPR conversion indexes. The remainder technical potentials deriving from sisal bogas, sisal ball and coconut husk and rice straw are almost equal, since there are not remarkable differences between their determinant parameters (RPR, LHV, yields, harvested areas). It can already be inferred that the amount of solid biomass available for export to the EU-28 under the three timelines of the present, 2020 and 2030, will be dependant predominantly on the net residue availability of the sugarcane subsector. The figures used to draw the conclusions at national level are provided in Appendix 8.2.

[11] Coffee pulp moisture content is derived from Kofinaf's own measurements.

Now that the technical potential of the agricultural sector has been identified, the fraction of it subject to certain sustainability criteria is estimated. In particular, as described in the methodology section, residues are of significant value mainly due to their capacity to protect the soil against wind and water erosion and their ability to maintain or even increase the 2 per cent SOC levels. This analysis takes into consideration only the field of residues, hence the respective sustainable potentials of sisal ball, rice straw and sugarcane stalks & leaves are further investigated. Similar to the technical potential approach, the sustainable potential is determined for each county and subsequently the aggregate result accounting for the entire country is presented.

Soil erosion control

From literature review, it is concluded that soil cover of 70 per cent, alternatively 2 t/ha of residues is necessary to protect the soil from water and wind erosion.

Soil organic carbon

In the literature review, no guidelines to determine the amounts of the examined herbaceous residue types, contributory to maintaining soil organic carbon at desirable levels were found. Nevertheless, in a forthcoming study, further extensive analysis was conducted to shed light upon:

1. Assessment of the factors that determine the availability of agricultural residues for bio-energy generation
2. Application of these findings in a case study for South Africa by Misha Valk et al.,
3. The required amounts to maintain 2 per cent SOC levels for wheat, maize and sugarcane residues respectively.

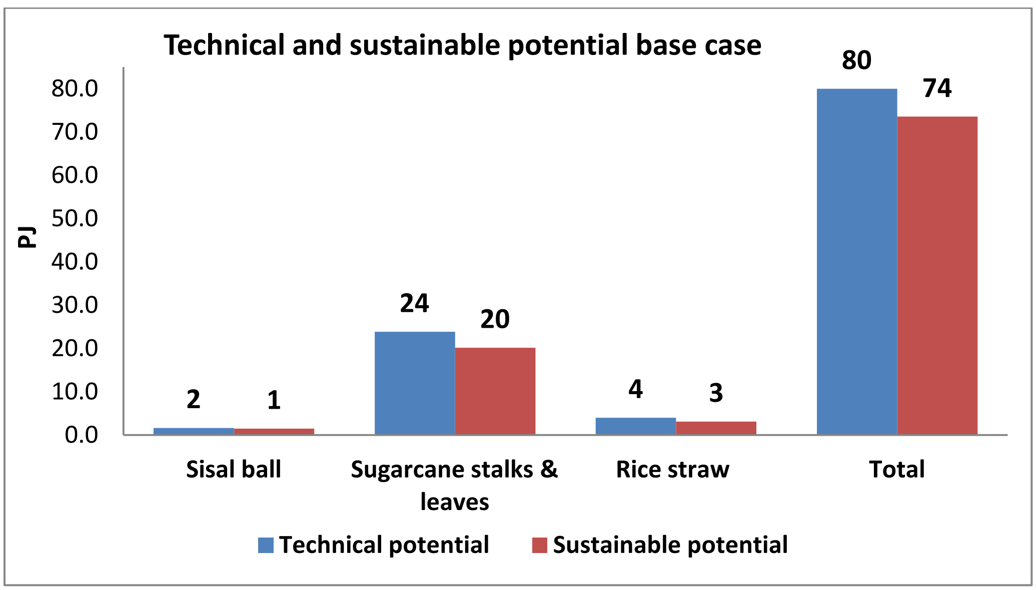
The results were acquired through the use of the Rothamsted Carbon model, and are directly correlated to factors such as rainfall, temperature, clay percentage of the soil and potential of evaporation. The model was applied for nine provinces of South Africa [23].

Parameters	Very low	Low	High	Very high
Rainfall (mm/yr)	<600	600-800	800-1,000	>1,000
Temperature (^{o}C)	<5	5-13	13-20	>20
Clay content (%)	<8	8-15	15-23	>23
Potential of annual evaporation (mm/yr)	500-1,000	1,000-1,500	1,500-2,000	>2000

Table 3-4: Parameterization of required inputs for the Rothamsted Carbon model [23].

The figures of Table 3-4 are used in Misha's Valk study to discuss the model's results. For instance, Western Cape province was found to have significantly low rainfall, a high average annual temperature, a low clay content and a very high potential of annual evaporation, suggesting that areas with similar characteristics might face the same residue requirements for 2 per cent SOC. Thus, the analysis of the sustainable potential is based on these results. That is, the Kenyan counties, where sisal, sugarcane and rice are produced, are investigated on the basis of their average annual rainfall and temperature, and their soil clay content. The potential of evaporation was excluded in the study due to limited and thus inadequate information in literature. Subsequently, the parameters of the respective Kenyan counties are compared with those of the different provinces in South Africa and fitted accordingly.

With respect to the producing counties of sisal and rice in Kenya, the average value of the proper maize and wheat residues requirements from Table 8-10 in the Appendices are used. Both consider conventional tillage, since this is the most common farming practice for sisal, rice and sugarcane in Kenya. This fact is based on expertise obtained during the internship by the chairman of the farmer union in Mwea rice irrigation scheme, Mr. Maurice Mutugi, the assistant production manager of Real Vipingo sisal estate, Mr. Samson Kimani, the production manager of Mumias sugar company, Mr. Jastus Esthitimo, and , Mr. Fredrick Muga and Mr. Clement Muyesu, from the Crop department of the Ministry of Agriculture. With regard to the sugarcane producing counties, all of them are located in the western part of Kenya, having similar rainfall levels, temperatures and clay content characteristics. Thus, 3.5 t/ha sugarcane residues requirements to maintain 2 per cent SOC in KwaZulu-Natal are adopted for the sugarcane sector in Kenya. The counties in Kenya showing similar climate conditions with those of South Africa are further discussed in Appendix 8.2.



Graph 3-1: Amounts of herbaceous residues required to set aside for soil erosion control and 2% SOC maintenance.

The results presented in Graph 3-1 are derived according to the method described in task 2.1.3 (Equations 2-4, 2-5). For the determination of the following ground biomass needed to carry out the calculations, a 23 per cent on average to the total biomass production (residues + harvested product) is implemented [41]. Thus, the fraction of the technical potential adhering to the aforementioned sustainability criteria amounts to 74 PJ. It is apparent from the graph that sugarcane contributes more to this outcome predominantly due to its higher residue requirements for soil erosion control. Sisal's technical potential appears not to have been significantly affected by sustainability criteria. In fact, according to Real Vipingo, Teita, Taru, Athinai and Kilifi sisal plantation estates sisal bogas is regarded as a valuable, free- accessed source for fertilizer substitution. They all indicated to use 100 percent of sisal bogas (apart from Kilifi plantations) for this specific application. Thus, the amounts required to be set aside for sustainability constraints regarding sisal ball are considered to be first covered by sisal bogas, and subsequently if not adequately by sisal ball. Consequently, 2 PJ of sisal bogas are additionally deducted from the total technical potential.

The framework is now set to acquire a deeper insight into the last step in order to estimate the sustainable feedstock surplus of the agricultural sector. Thus, the market regime related to bio-energy and domestic demand for the under investigation feedstocks is analyzed.

Residues	Households & local industries (%)			Internal use[12] (%)			Livestock (%)		
Range	Low	High	Average	Low	High	Average	Low	High	Average
Sugarcane stalks & leaves	N/A	N/A	N/A	N/A	N/A	N/A	10	20	15
Bagasse	N/A	N/A	N/A	60	75	68	N/A	N/A	N/A
Molasses	50	100	72	N/A	N/A	N/A	0	50	28
Coconut husk	10	30	20	14	18	16	N/A	N/A	N/A
Coffee husk	60	80	70	10	20	15	N/A	N/A	N/A
Coffee pulp	N/A	N/A	N/A	100	100	100	N/A	N/A	N/A
Sisal ball	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sisal bogas	N/A	N/A	N/A	100	100	100	N/A	N/A	N/A
Rice husk	5	10	8	N/A	N/A	N/A	N/A	N/A	N/A
Rice straw	N/A	N/A	N/A	N/A	N/A	N/A	60	70	65

Table 3-5: Shares of the different residues applications composing the respective current market regime of herbaceous biomass.

The shares of the respective amounts of residues utilized by local industries, households, livestock, or used internally by the owners are shown in Table 3-5. The internal use refers to the amount of residues used by the companies or farmers, producing a certain feedstock, to serve their functional needs. However, when the indoor use of the residues is realized for fertilizing purposes, the field residues are not taken into consideration, since the sustainability criteria have already been considered.

Sugarcane

[12] The internal use is the share of the residues generated, which are capitalized by the same stakeholders producing the feedstock and is considered part of the domestic demand.

With respect to the sugarcane residues, six from the eleven in total sugar companies present in Kenya were examined during the internship. In particular, Mumias was visited and Nzoia, Butali, West Kenya, Kibos and Chemelil's representatives were interviewed through phone calls, all under the guidance of the Sugar Board in Kenya.

Picture 1: Mumias cropland area, where stalks & leaves are left on the ground after harvesting.

Stalks & leaves

Specifically, stalks & leaves were indicated to be used as fertilizer in the range of 75 to 85 per cent. Furthermore, 10 to 20 per cent of the residues were suggested to be sold to farmers as animal feed and another 5-10 per cent to be burnt on the ground to prepare the field for the next cultivation.

Bagasse

In most of the cases, there was no quantitative data on its uses. Mumias use internally the entire amount of its bagasse in their 35 MW cogeneration power plant for steam generation. Furthermore, Butali and Kibos also utilize all of their bagasse. The former supplies free of charge Mumias to cover its energy needs and the latter uses its residues internally for paper and cardboard manufacturing. However, the remaining companies possess undetermined amounts of bagasse, which are not utilized internally to fire their boiler. Thus, based on a study conducted by Sawa consulting company and the capacity of the Nzoia (the third largest sugar company in Kenya) power plant, 40 and 71 per cent respectively of bagasse at a national level was found to remain unused [34], [42],[43]. Therefore, 66 per cent on average regarding the internal use of bagasse in each of the remainder sugar companies is considered.

Picture 2: Bagasse stored in Mumias deposited point.

Molasses

The records of the aforementioned companies have provided a deeper insight into the shares of the different uses of molasses. It is important to note that Mumias owns a Backend Distillery for ethanol production and as a result uses all of its molasses internally. Thus, the case study on molasses for the sugar companies, in which information is not available, is built on Nzoia, Butali, West Kenya, Kibos and Chemelil, who sell their molasses to external actors such as, Agrochemical and Specter International companies, and farmers for ethanol production and animal feed respectively. In detail the sharing ratio of molasses for ethanol and animal feed concerning each company:

- West Kenya and Nzoia 50:50;
- Kibos and Chemelil 80:20;
- Butali 100:0.

Thus, a 72 per cent on average of bagasse is sold for ethanol production and another 28 per cent on average is bought by farmers as animal feed.

Coconut husks

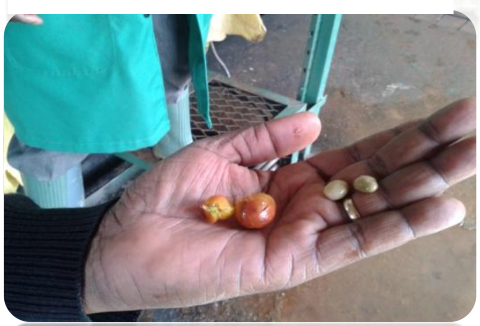
In order to explore the market regime and domestic demand of the coconut residues, Kocos Kenya LTD, Serendi Kenya LTD and the delegate of the coconut farmer union in Kwale county were contacted during the internship, under the guidance of the Kenya Coconut Authorities. Thus, based on their indications 14 to 18 per cent respectively of the husk generated within a year is used for mulching and subsequently as manure. Finally, 10 to 30 per cent of the husk was indicated by the farmers to be provided to locals as firewood to cover their domestic energy needs free of charge, contributing another 20 per cent on average to the total domestic demand.

Picture 3: Coconut husks used for mulching in Kwale county.

Coffee husk-pulp

The case study of the coffee sub sector is built on information collected during the internship but also through literature review. In fact, only Kofinaf, the third larger in production capacity coffee mill in Kenya[13], was feasible to be visited and investigated. Therefore also through a study by Kibulo examining the bio-energy potential emanating from herbaceous and woody biomass residues, the respective market regime and the indigenous demand are identified [18]. That is, 10 to 20 per cent of coffee husk is used internally to improve the soil quality of their farms and another 60 to 80 per cent of husk is indicated to be sold to cement and brick construction companies such as, Bidco, Bamburi, Clay Works and Kenya Clay Product. With respect to coffee pulp the entire amounts generated are suggested to be applied for soil fertility, since it is reach in nutrient content and reduces

Picture 4: Coffee husk during the de-hulling process in Kofinaf.



Picture 5: On the left side is coffee pulp and on the right side is the parchment after the de-pulping process.

[13] This information is retrieved from the data bases of Coffee Board in Kenya.

costs incurred by fertilizer application.

Sisal ball-bogas

Picture 6: After the decortication process of sisal leaves, bogas is generated.

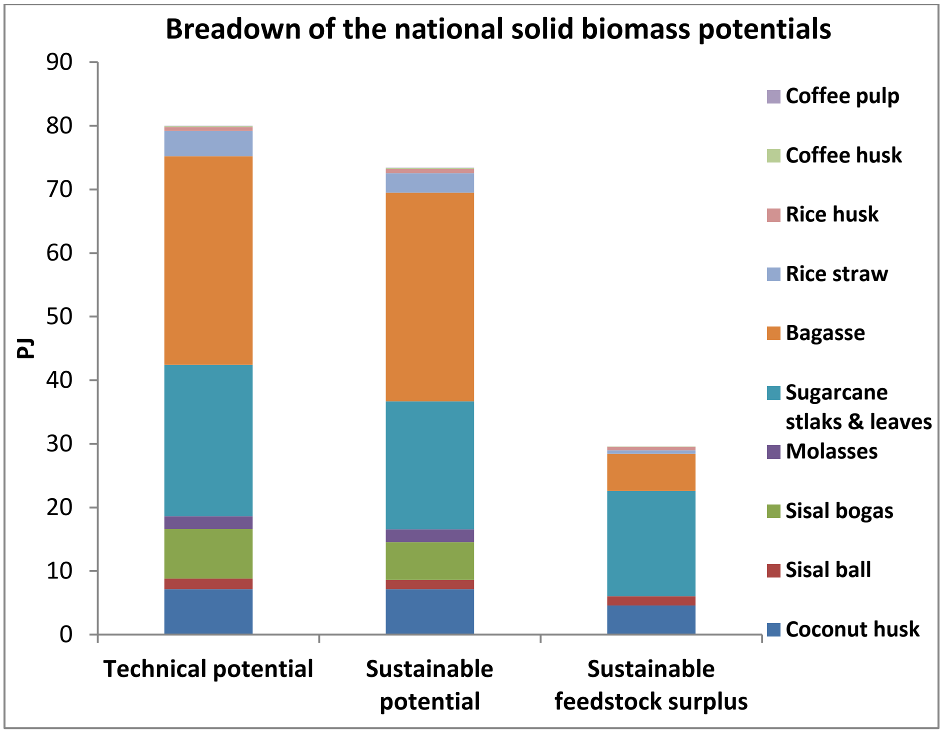
Picture 7: After all the sisal leaves are harvested, the trunk of the plant becomes a waste (sisal ball).

The case study of the sisal sub sector is built on seven out of ten sisal estates present in Kenya. In particular, Real Vipingo, Kilifi plantations, Teita, Taru, Athinai, Migotio and Lomoro sisal estates were examined. This process was held with the assistance of the statistician, Mr.Dickson Kibata, of Sisal Board, who also provided additional insights. Regarding sisal bogas all of them (apart from Kilifi plantations) indicated to utilize it on the field instead of applying commercial fertilizer due to its rich nutrient content. Thus, the indigenous demand is determined to be 100 per cent for fertilizing purposes. With respect to sisal ball, the vast majority of the waste was suggested to be set aside on the ground (as fertilizer) and partly to be burned. In some occasions, such as in Kilifi plantations, employees were suggested to use it as firewood, in small amounts though. However, information on the shares of the different applications was not explicitly provided and hence only the respective amounts required for environmental criteria addressed above are considered.

Rice husk-straw

Picture 8: Rice husk after the de-hulling process in Mwea Rice Mills.

Kirinyaga county stands for more than 60 per cent of total rice production in Kenya [9]. Thus, the case study of the rice sector is built on the information collected from the different stakeholders interviewed in the framework of the internship in Kenya. In fact, concerning rice straw, information provided by the chairman of the farmer union in Mwea irrigation scheme, Mr. Maurice Mutugi, and the superintending engineer, Mr. Fredrick Muga, in the Ministry of Agriculture, is used. As a result, 60 to 70 per cent is sold to locals as fodder and the remaining is left on the ground as manure. With respect to rice husk, inputs were provided by the supervisor, Mr. Joseph Kinyanjui, of Mwea rice mills (under the National Irrigation Board), and the managers of the Nice Rice Millers and Global Rice Mills with the assistance of the Ministry of Agriculture. Thus, only 5 to 10 per cent of the husk is used either by farmers to reduce the acidity of the soil or by locals for bricks manufacturing, while the remainder is land filled.



Graph 3-2: Aggregated technical, sustainable and sustainable feedstock surplus potentials originating from the agricultural sector.

All in all, the sustainable feedstock surplus that stems from herbaceous residues, is estimated approximately 30 PJ (Equation 2-6). That is, mainly through the intensive internal use of sisal bogas and bagasse, and the high domestic demand of molasses the biomass potential is reduced by approximately 40 PJ compared to the respective sustainable potential. However, bagasse and sugarcane stalks & leaves represent the most promising herbaceous feedstocks for continuing research in terms of their corresponding sustainable feedstock surplus potential with 6 and 17 PJ respectively.

3.2.2. Forestry feedstocks

The sustainable feedstock surplus potential originating from the forestry sector is investigated in this part. The technical potential of sawdust and off-cuts & chips is firstly estimated and subsequently, through analysis of the market policy and the domestic demand concerning each different residue type, the corresponding sustainable feedstock surplus potential is estimated. The sustainable potential is a task related to herbaceous feedstocks and is not relevant in this case.

In order for the technical potential to be calculated, the production volumes of timber in 2012 are used and multiplied by 65 per cent, which is the timber share procured to sawmills [7]. Subsequently, the RGR for timber waste from Table 3-1 is applied to this amount to draw conclusions regarding the total residue potential from process. By using the corresponding RGR and LHV indexes for sawdust and off-cuts & chips from Table 3-2 the desired result is then achieved [7]. Similar to the calculations conducted for the agricultural sector, the analysis to derive the technical potential originating from woody biomass is conducted at a county level and sums up at a national one (see Appendix 8.2).

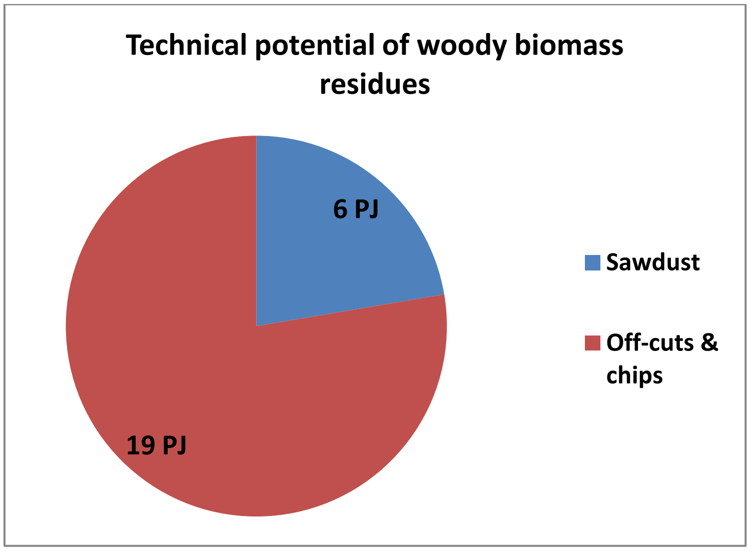


Figure 3-3: Breakdown of the total technical potential originating from process residues of woody biomass.

The total technical potential from woody biomass residues is estimated to be about 27 PJ (estimated through Equation 2-2 and 2-3). Off-cuts & chips stands for 19 PJ accounting for 78 per cent of the total amount of process residues, when sawdust accedes to 6 PJ. This difference is attributed to the higher RGR and LHV of the off-cuts & chips compared to the corresponding indexes of sawdust.

Consequently, through the identification of the respective market regime and the domestic demand, the sustainable feedstock surplus potential emanating from the forestry sector is estimated.

Residues	Households and local industries (%)			Internal use (%)			Livestock (%)		
Range	Low	High	Average	Low	High	Average	Low	High	average
Sawdust deficit	25	50	38	N/A	N/A	N/A	N/A	N/A	N/A
Sawdust surplus	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A
Off-cuts & chips	100	100	100	N/A	N/A	N/A	N/A	N/A	N/A

Table 3-6: Shares of the different residues applications composing the respective current market regime of solid woody biomass.

Sawdust

With regard to sawdust, a number of people and sawmills were approached during the internship. Namely, Biashara Master LTD, Comply, Savanah Eldoret and Timsales sawmills. Additional valuable information was provided by the extension forest service in Nakuru.

The counties examined to construct the case study of sawdust are classified into two categories. The first category comprises all the counties with a firewood deficit and the second, counties holding a firewood surplus. For the first category, Biashara sawmill located in Nakuru county is used as a case study to examine the market approach and predominantly the domestic demand for sawdust, since Nakuru is facing a significant firewood deficit potential [7]. As a result, the domestic demand for sawdust accounts to 38 per cent on average, with 25 and 50 per cent the corresponding lower and upper limits.

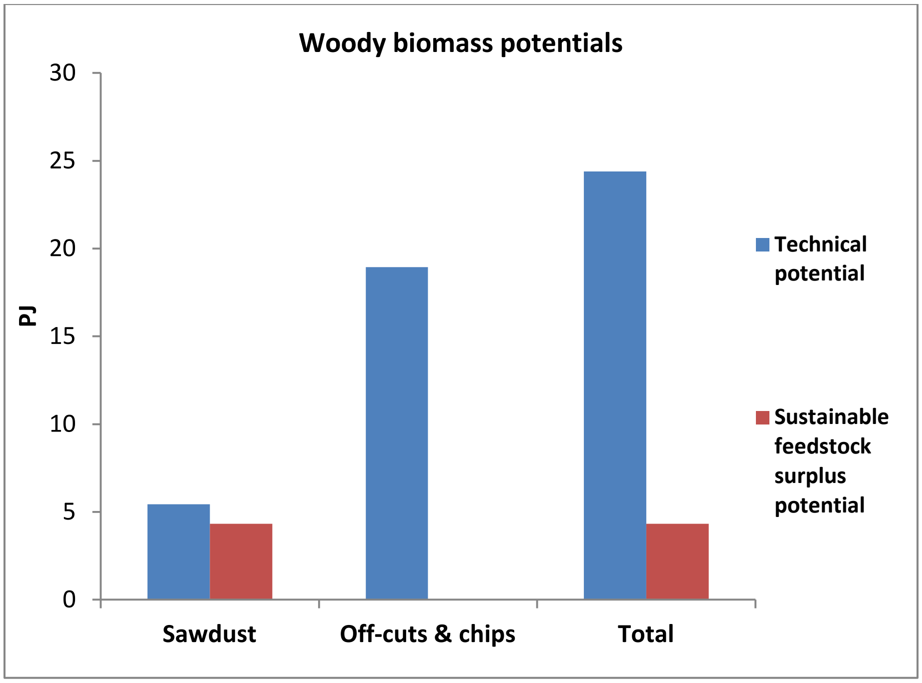
Picture 9: Deposited sawdust in Biashara sawmill.

Savanah Eldoret sawmill located in Uasin Gishu county, is used as a case study for the second category of the counties under investigation. The reason that Savanah Eldoret was selected is because Uasin Gishu is an autonomous county in terms of firewood usage. Thus, 100 per cent of sawdust availability is used. This assumption is supported by the fact that even for the counties encountering a deficit in firewood, sawdust is considered as a last fuel option for domestic energy needs.

Off-cuts and chips

Regarding off-cuts & chips, the same sources used for sawdust are taken into account in this case. According to the sawmills visited, all of their off-cuts and part of their chips are sold locally for fencing, heating and cooking. Thus, 100 per cent of off-cuts & chips are attributed entirely to households and local industries.

Picture 10: Stacked off-cuts in Biashara.



Graph 3-3: Technical and sustainable feedstock surplus potential of woody biomass at present.

As a consequence, the sustainable feedstock surplus accumulating from the forestry sector amounts to 4 PJ and is solely attributed to sawdust. The miscellaneous applications of the domestic demand regarding off-cuts & chips eliminated the corresponding sustainable feedstock surplus potential.

3.2.3. Dedicated energy crops

This sub task focuses on assessing the potential of prospective lands available for energy crop cultivation. Unlike the previous sub sections, the analysis of this problem is directly performed at a country level, owing to non quantitative information on marginal and abandoned land areas, as well as on occupied land by livestock. As a result, the future situation will also be conjointly gauged. By the end of this task, a broad identification of land availability for second generation bio-fuel production will have been provided for the present and until 2030.

To estimate the potential for lignocellulosic biomass cultivation stemming from forests, the woody biomass balance is examined. Based on data found in an unpublished report provided by Mr. Kariuki of the KFS (Kenya Forest Service), national supply and demand quantities of timber, charcoal, poles and firewood, in 47 counties of Kenya, were analyzed [7]. In fact, a 31.4 million m^3 of woody biomass supply in comparison to a 41.7 million m^3 of woody biomass demand in total, results in a 10.3 million m^3 woody biomass deficit in Kenya for 2013. Thereby, given the fact that more than 80 per cent of Kenyan households rely on woody biomass to cover their energy requirements, the need for extra land is urgent resulting to no potential available from forests for energy crop cultivation at present [8], [26].

Type of Land	Area in thousand ha			
	1990	2000	2005	2010
Indigenous closed Canopy	1,240	1,190	1,165	1,140
Indigenous Mangroves	80	80	80	80
Open woodlands	2,150	2,100	2,075	2,050
Public Plantation Forests	170	134	119	107
Private Plantation Forests	68	78	83	90
Bush-land	24,800	24,635	24,570	24,510
Grasslands	10,730	10,485	10,350	10,350
Settlements	8,256	8,192	8,152	8,202
Farms with Trees	9,420	10,020	10,320	10,385
Inland water Bodies	1,123	1,123	1,123	1,123
Total area	58,037	58,037	58,037	58,037

Table 3-7 : Different Land use types of Kenya and trends from 1990 to 2010 [5].

The first five categories of Table 3-7 incorporate the forest cover in Kenya, which is about 6 per cent of the total land area. It is estimated that 241 thousand ha of forest area have been reduced between 1990 and 2010, which subsequently results in a deforestation rate of 12 thousand ha annually mainly due to the conversion of forest areas to agriculture [44]. Thus, even though deforestation rates are currently slowly decreasing by 1 per cent on a year basis, considering the strong reliance of households on woody biomass combined with an increasing population rate of 3.8 per cent annually, the present situation with respect to the forestry sector is not likely to change until 2030 [5], [45].

Land is also of significant value in agricultural production. Kenya includes an area of about 58,000 thousand ha out of which 1,100 thousand ha is water bodies. Of the remaining 57,000 thousand ha landmass, approximately 16 per cent is of high and medium agricultural potential with adequate and reliable rainfall [6]. This potentially arable land is mainly utilized for commercial agriculture with cropland occupying 31 per cent, grazing land 30 per cent, and forests 22 per cent [6], [9]. As for staple food crops in the country, these are maize, beans, wheat and rice, with maize accounting for more than 40 per cent of the total food crops production [9]. At the time being, 55 per cent of Kenyan inhabitants calorific needs are covered by these products and the rest is supplemented from livestock and imports [46]–[48]. Furthermore, according to experts of the International Livestock Research Institute (ILRI), livestock is malnourished. Consequently, it is apparent that land pressure from agriculture, livestock and forestry in these areas allow no space for energy crop production even in the future.

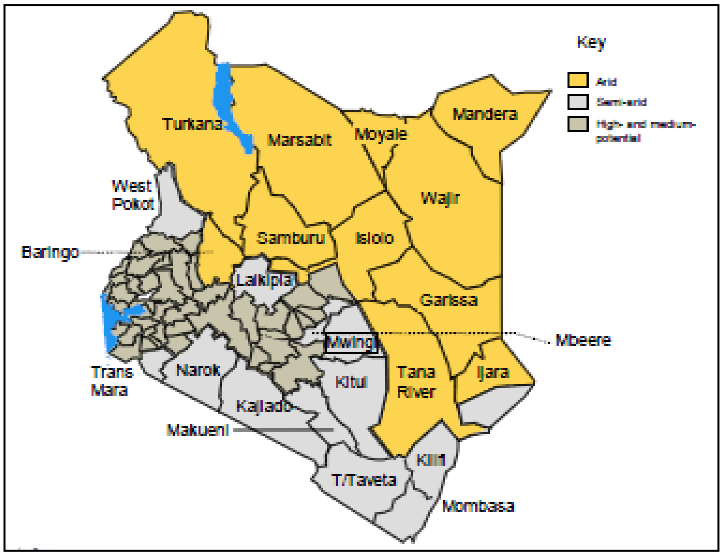


Figure 3-4: Land status of Kenya regarding arid (yellow), semi-arid (light grey) and high potential (dark grey) areas [49].

The arid and semi-arid areas, constitute about 84 per cent of the total land mass of the country. In the semi arid regions, more than 50 per cent is occupied by livestock and agricultural activities. Semi arid areas if properly managed and irrigated can double the land area potential for both the agricultural and livestock sectors [9], [50]. Thus, given the existing food, feed and woody biomass demand deficit at a national level, it is unlikely for the semi arid regions to have land available for dedicated energy crops. However, there is a need to investigate how the determining factors for bio-fuel production change in the future.

Increase or decrease	2020 %	2030 %
Woody biomass deficit	10	24
Maize yield	-58	-58
Food demand	32	75
Livestock feed needs	50	150

Table 3-8: Projected future situation of the major factors affecting land availability [7], [9], [45], [51].

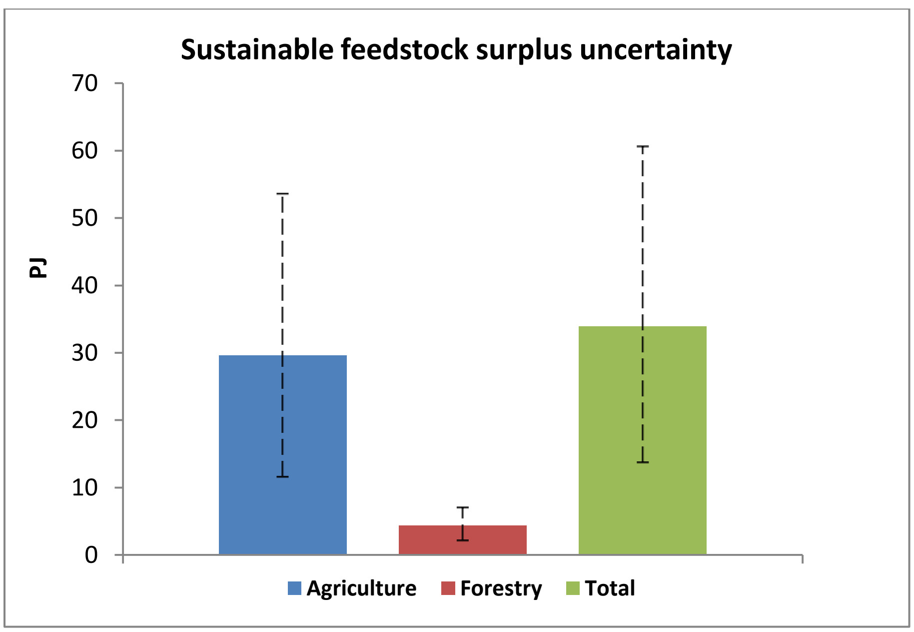
The future situation of food demand, livestock nutritional needs and maize yield derives based on past trends from national and FAOstat data. Specifically, maize yield decrease is attributed to high fertilizer and seeding costs [47], [52]. However, the yield was expected to stabilize from 2020 and onwards owing to technological advancement and more efficient management in the agricultural sector. The increase in food demand can be attributed to the increasing population and GDP rate. This increase is offset to a certain degree by the augmented livestock population, which in turn explains the incremented livestock nutritional needs [4], [26], [53]. The woody biomass deficit increases by 10 per cent in 2020 compared to the present situation and reaches a 24 per cent by 2030. These rates have been estimated by the KFS and are based on the increasing population rates and current plantations and natural forests yields [7]. Thereinafter, the decreasing yield of maize in conjunction with the increasing demand for food, feed and woody biomass imply a high demand for additional land in the future, rendering the semi arid regions unfeasible and thus inappropriate to become partly available for energy crop cultivation.

Concerning the arid areas, even though they can be exploited to some extent by the agricultural and livestock sectors, it seems that there is space accruing from existing marginal and degraded lands, for second generation bio-fuel production [50]. However, the under construction train line will connect only the South-west and South-east part of Kenya by 2020 without any plan for extension until 2030[14]. Specifically, due to the fact that biomass should be transferred by truck for less than 300 km, arid regions are excluded. Some parts of the north coast might be available but the area is too small for further consideration.

All in all, considering the data presented, it is concluded that either there is not or in the best case scenario there is limited potential for dedicated energy crops production.

3.2.4. Uncertainties

The derived results regarding the sustainable feedstock surplus potential of herbaceous and woody biomass respectively indicate some uncertainties. These are caused by the estimation of the technical and sustainable potential and finally through the application of the shares constituting the current market regime of biomass in Kenya.



Graph 3-4: Illustration of the uncertainties incorporated in the final results of the current situation.

Eventually, the current total sustainable feedstock surplus potential is estimated to be approximately 35 PJ, with a range from 15 to 60 PJ.

[14] Source: National report and the head of railway division, Mr. D.Hunda, of the ministry of transport [61].

With regard to the agricultural sector, the uncertainty is estimated based on the following parameters:

- RPR;
- LHV;
- 2 % SOC requirements;
- Households & local industries, animal feed and internal use shares.

Accordingly, the uncertainty incorporated in the forestry sector results is addressed through,

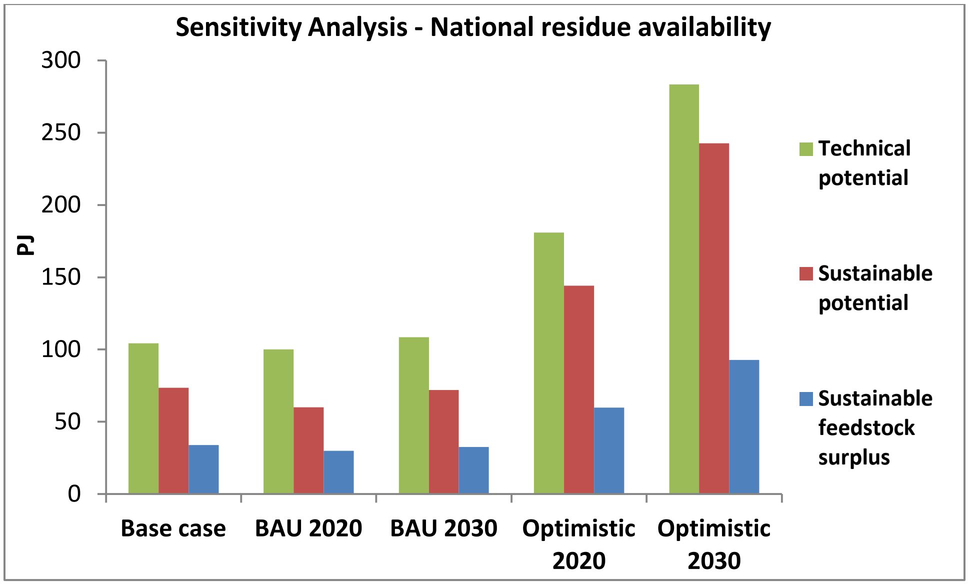
- RPR;
- LHV;
- Households & local industries, animal feed and internal use shares.

In more detail, firstly the upper and lower limits of the different RPR and LHV values are used to define the higher and lower limit of the technical potential of both the agricultural and forestry sector (see Table 3-2 and Table 3-3). Subsequently, regarding the herbaceous feedstocks, the respective upper and lower values of the 2 per cent SOC residue requirements from Table 8-10 are applied. Finally, for both the herbaceous and woody biomass residues the corresponding extremes of households & local industries, animal feed and internal use shares are used (see Table 3-5 and Table 3-6). Thus, by summing up the upper and lower limits of the two sustainable feedstock surplus types, the uncertainty of the final result is obtained.

3.3. Net sustainable volumes of crop residues – BAU & Optimal case

After having analyzed the present sustainable feedstock surplus potential in Kenya, the BAU and Optimistic scenarios to explore the respective potential in 2020 and 2030 are employed.

The results shown in Graph 3-5 provide the overall picture regarding the miscellaneous biomass potentials. Sub sections 3.3.1 and 3.3.2 present the process leading to these results.



Graph 3-5: Projections of the different types of biomass residues potentials in a short and a medium term under the BAU and the Optimistic scenarios.

In Graph 3-5 the total technical, sustainable and sustainable feedstock surplus potentials originating from both the agricultural and forestry sector are illustrated. Thus, the total available biomass potential stemming from the two sectors for further research ranges from:

- 30 to 60 PJ → In a short term;
- 33 to 93 PJ → In a medium term.

The major contributors of the sustainable feedstock surplus potential in every timeline and scenario are bagasse and sugarcane stalks & leaves, both occupying more than 50 per cent of the final result.

3.3.1. Biomass potential under BAU scenario

Under the scope of defining the future sustainable feedstock surplus potential, the technical and sustainable potential concerning the agricultural & forestry sector are explored. The domestic demand might have been conducive to the final results but seeing that no explicit correlation between the different parameters (GDP rate, caloric intake per capita, population rate, primary energy consumption per capita) affecting domestic demand was found due to lack of information, it is not considered in the following analysis. This task is carried out for a short and a medium term. Yields of the different feedstocks are projected on the basis of:

- Technological adoption-poor[15] (limited fertilizer and pesticides use, no irrigation-6 per cent of total cropland is irrigated) [26], [49];
- Farming practices-conventional tillage;

[15] This information was also provided by the Ministry of Agriculture and the different stakeholders interviewed during the internship. The same also holds for the farming practices.

- Soil quality-of high and medium potential[16] [9], [50], [54];
- Deforestation levels-slightly decreasing [5], [7].

The aforementioned criteria represent the current situation in Kenya and a continuation in the future is assumed. No additional policies are considered.

Agriculture

In order to perform the projections for each of the five feedstocks, past trends of a ten year period from FAOstat and data provided from the Kenyan Ministry of Agriculture are used. These include the production volumes, areas and yields for sugarcane, coconut, sisal, coffee and rice respectively. The different trends from both sources were compared before used and when a significant divergence between them was observed, a further literature review was conducted with the view to selecting the most proper ones for elaboration. Through the production volumes and areas of each product, the corresponding yields are retrieved and subsequently the annual yield increases or decreases are estimated. Subsequently, the average yields per annum are estimated and used to expand the original yields in 2020 and 2030[17].

Crop yields	Annual increase/decrease %	2020 %	2030 %
Coconut	2.0	15.0	40.3
Coffee	0.1	0.8	2.5
Rice	2.8	24.3	63.2
Sisal	0.6	4.9	11.3
Sugarcane	-3.5	-22.2	-22.2

Table 3-9: Crop yield percentage change on a year basis of the five agricultural crops and the aggregate change of the respective yields in a short and a medium term.

The yield increases of coconut, sugarcane and rice are identified after examining national data, whereas the remaining from FAOstat. All of them were compared on the basis of these two sources and only sugarcane and sisal were found to be similar. Thus, the percentages shown in Table 3-9 are selected based on information found in literature and insights acquired during the internship concerning the current farming practices, technological adoption and soil quality underlying the five feedstocks.

All the products, except for sugarcane, show a slight increase regarding their yields. The reason that sugar sub sector is governed by a decreasing annual yield, derived from a 2004 to 2013 trend, is firstly due to the fact that sugarcane crop cultivation is mainly rainfed with a low rainwater use efficiency and secondly due to lack of farming management (fertilizers, improved seeds and technology), which can be attributed to high costs [46], [55]. Thus, the current situation is expected to remain the same until 2020, while with minimal or no investments in soil

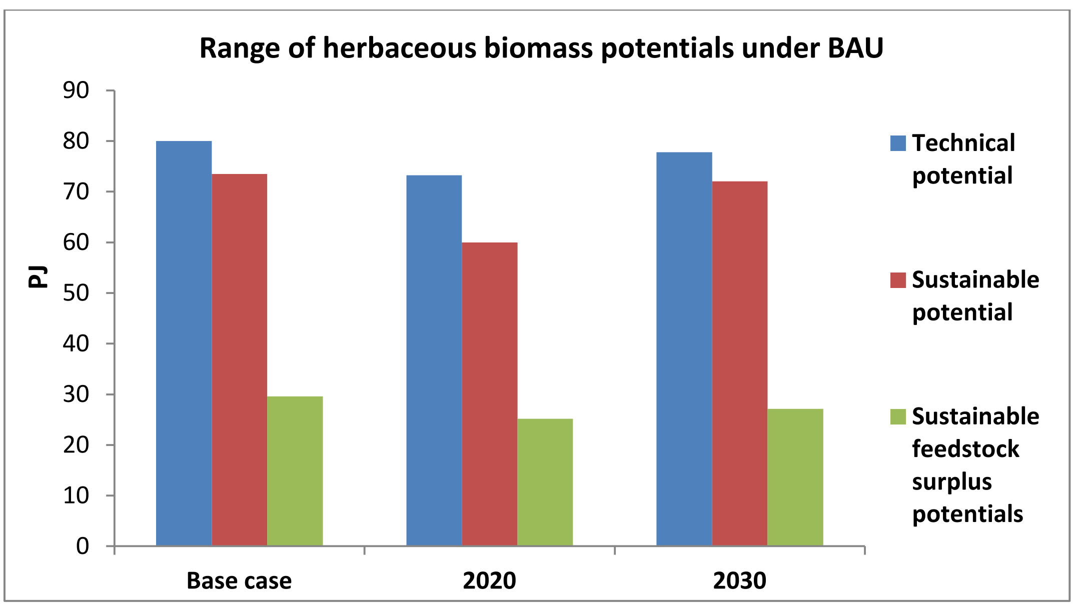
[16] The soil quality concerns the areas, where the majority of each of the aforementioned crops lies.
[17] The cropped areas are assumed to remain constant due to the adverse competition with the livestock sector (17 per cent of the total agricultural GDP) resulting to high pressure in land possession and subsequently increasing market share [6].

improvement nutrient depletion is unavoidable, resulting to decreasing yields. However, the resulting yield of sugarcane in 2020 is considered to be stable until 2030. This is assumed due to the fact that a constant decreasing yield would force the sugarcane farmers to exit the market owing to higher costs for sugarcane production. Furthermore, this is also supported from the average annual yield increase of sugarcane in Uganda, Ethiopia, and Mozambique based on FAOstat yield trends from 2004 until 2013, which implies that the estimated decreasing yield could be attributed to impermanent adverse climatic conditions (e.g. very low rainfall levels) of the past.

For the rest of the products, the most moderate yield increases are chosen based on similar farming practices followed (rainfed cultivated areas and low fertilizer use) and technological adoption (conventional tillage) [55]. This situation was also endorsed by the different stakeholders interviewed during the internship.

However, with regard to the rice sub sector, the high annual increase rate compared to the other products can be attributed firstly to higher percentage use of fertilizer and secondly to the fact that more than 80 per cent of rice consumed is produced under the national irrigation schemes in Mwea. In addition, this augmented yield is explained through Governmental and Stakeholders' Interventions that are guided by the National Rice Development Strategy (NRDS) [9], [49], [56].

As a result, the respective sustainable feedstock surplus potential in 2020 and 2030 stemming from the respective residue types is estimated.



Graph 3-6: Illustration of the technical and sustainable potentials and consecutively the sustainable feedstock surplus biomass potential originating from the agricultural sector at present and until 2030.

The future situation in the agricultural sector under the BAU scenario for 2020 shows a decrease by 7, 6 and 5 PJ for the three different types of biomass potential respectively. Despite the fact that the yields of coconut, sisal, rice and coffee grow in a short term, the respective yield decrease of sugarcane eventually led to this 2 PJ drop of the total sustainable feedstock surplus potential by 2020 compared to the current situation. Specifically, bagasse and sugarcane stalks & leaves accounts for 70 per cent of the total technical potential in the current situation, implying that any change incurred in their corresponding parameters (yield, RPR, LHV, sustainability criteria and domestic demand) can significantly affect the aggregated picture of the agricultural sector.

Given that sugarcane is a major determinant factor of the future biomass potential available in agriculture, no much has changed in the medium term as well. In particular, as noted before sugarcane yield from 2020 until 2030 is considered to be constant. Thus, the slight increase of the total sustainable feedstock surplus is attributed to the corresponding yield increase of the remainder feedstocks resulting to a total 27 PJ herbaceous sustainable feedstock surplus potential.

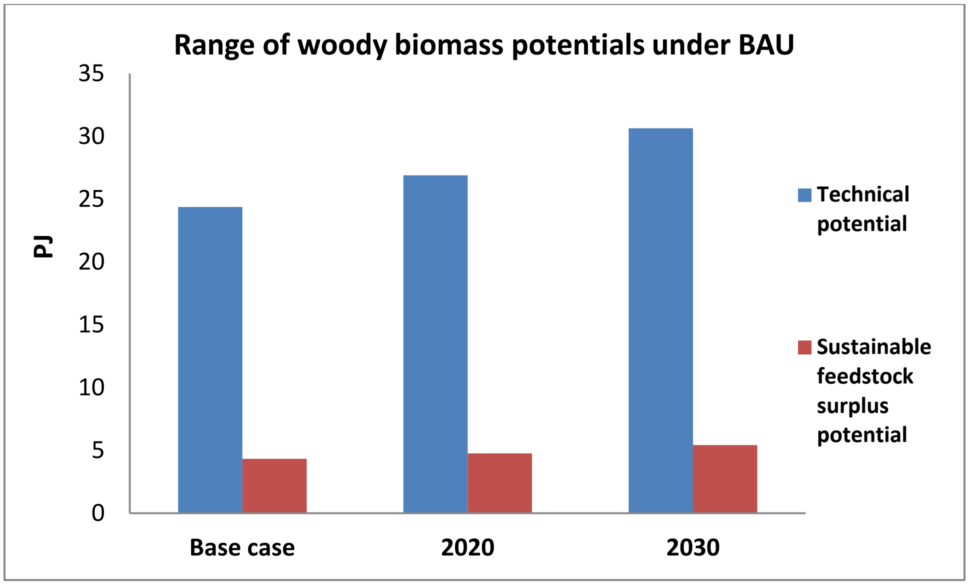
Forestry

With the view to forecasting the sustainable feedstock surplus in the forestry sector until 2030, the projections, as estimated by KFS, are used [7]. In fact, these projections were compared with a past trend of ten year time period (2003 to 2013) from FAOstat and they both concerned the supply potential of timber until 2030. This is done only for timber, since the investigated of woody biomass residues are generated from timber processing. The data presented in the following table are selected from the national report due to both the national report and FAOstat were showing similar trends (2.6 and 3.0 per cent respectively).

Increase/decrease %	Timber
Annual	2.6
2020	10.3
2030	25.6

Table 3-10: Annual and projected rates in 2020 and 2030 of timber supply.

The increasing trend of timber supply estimated by KFS is attributed to forecasted climate change and increased reforestation rates [44].



Graph 3-7: Illustration of the technical and sustainable feedstock surplus potentials that stem from the forestry sector at present and until 2030.

Accordingly, the results indicate a steady increase by 2020 and 2030 for both the technical and the sustainable feedstock surplus potential compared to the base case. This incremented supply of timber regarding the technical potential originates from off-cuts & chips and sawdust and amounts to 26.9 and 30.6 PJ for short and medium term respectively. Consecutively, the sustainable feedstock surplus potential depending solely on sawdust, owing to the eliminated potential of off-cuts & chips by domestic demand, amounts to 4.7 and 5.5 PJ for 2020 and 2030 following the same order.

3.3.2. Biomass potential under Optimistic scenario

This sub task examines the miscellaneous biomass potentials in short and medium term under more optimistic estimations on the feedstock yields. The analysis is carried out for 2020 and 2030. Yields of the different feedstocks are projected on the basis of the following assumptions:

- Technological adoption-high (increased fertilizer and pesticide use, improved seeds, higher percentage of irrigated land);
- Farming practices-no till+double cropping;
- Soil quality-of high and medium potential;
- Deforestation levels-lower than BAU due to higher achieved yields [7], [46], [48], [49].

In order to use these assumptions a number of national policies and regulations are taken into account. Namely,

Policies:

- Vision 2030 → Aim for increasing agricultural land area, and domestic supply of forestry and agricultural products to meet domestic demand through fiscal incentives and R&D expenditures;

- Forest Policy, 2014 → All forest resources shall be managed sustainably to yield social, economic and ecological goods and services;
- Agricultural Sector Development Strategy 2010-2020 → Increase productivity through enhanced irrigation and reduced costs of farming inputs.

Regulations:

- Crop Act, 2013 → Accelerate the growth and development of agriculture by enhancing productivity through the promotion of production, processing, marketing, and distribution of crops in suitable areas of the country;
- Forest Conservation and Management Act, 2014 → Target to sustainable forest conservation and management.

Agriculture

In the optimal case a number of assumptions regarding the yield, area and production increase capacity of the investigated crops are used. That is, through these assumptions the incremented yields and harvested areas of the different crops are examined and subsequently the future situation is built on the respective current yields and harvested areas.

Increase/Decrease	Area %			Yield %			Production %		
Crops	Annual	2020	2030	Annual	2020	2030	Annual	2020	2030
Coffee	1.0	7.5	19.1	3.2	24.3	70.0	4.2	39.2	110.0
Coconut	1.0	7.5	19.1	8.2	177.3	284.5	9.2	133.5	358.0
Rice	5.6	160.4	155.4	3.2	29.0	64.3	8.6	235.0	320.0
Sisal	5.7	56.0	171.9	6.7	67.6	219.5	12.8	161.2	768.0
Sugarcane	1.0	7.5	19.1	2.5	39.5	52.4	3.6	50.0	81.4

Table 3-11: Optimized parameters of the studied crops regarding the agricultural sector future situation.

With regard to sugarcane the yield increase is determined based on a study by KETS (Kenana Engineering and Technical Service Co.Ltd.) [46]. In fact, in this study population, GDP and price rates of sugar were used as input factors in order to assess the future indigenous consumption of the product. This was estimated to be approximately 1 million t in 2020. When comparing the current situation of total sugarcane production with the corresponding of total sugar consumption, a deficit of about 200 thousand t is noted[18], where the difference is covered through imports [34], [46]. Thus, by taking into account high technological adoption, improved farming practices and a good soil quality for the future, an increasing production capacity is assumed able to offset the gap between consumption and production from 2020 to 2030. In order

[18] In order to convert the amount of sugar into sugarcane a TC/TS (sugarcane crushed/sugar sold) ratio of 10 was applied [46].

to estimate sugar consumption by 2030, a trend from 2001 to 2020 was consulted to draw conclusion about the annual increase of sugar demand (211 thousand t). Subsequently, by knowing the respective sugarcane demand in 2020 and 2030 the required annual production increase of sugarcane production to meet indigenous demand derived (2.5 per cent). Furthermore, land area of sugarcane is also expected to increase. This is underpinned by the aim of Vision 2030, which is to exploit an additional land of 1 million ha suitable for crop cultivation by 2030 [49]. Given the fact that the current total land in Kenya under agricultural activities is approximately 6 million ha, the required annual land increase to achieve this target should be 1.0 per cent. Thus, the current land area for sugarcane is assumed to augment by 1.0 per cent annually. Subsequently, through the estimation of sugarcane annual production increase and area expansion, the corresponding annual yield was estimated to be 2.5 per cent. The resulting yields in 2020 and 2030 (84.1 and 91.8 t/ha respectively) are feasible when considering the increasing trend of sugarcane in Uganda, Ethiopia and Mozambique but also the current yield of sugarcane in Brazil (about 80.0 t/ha), where more contemporary means for managing the crop are used [57], [58].

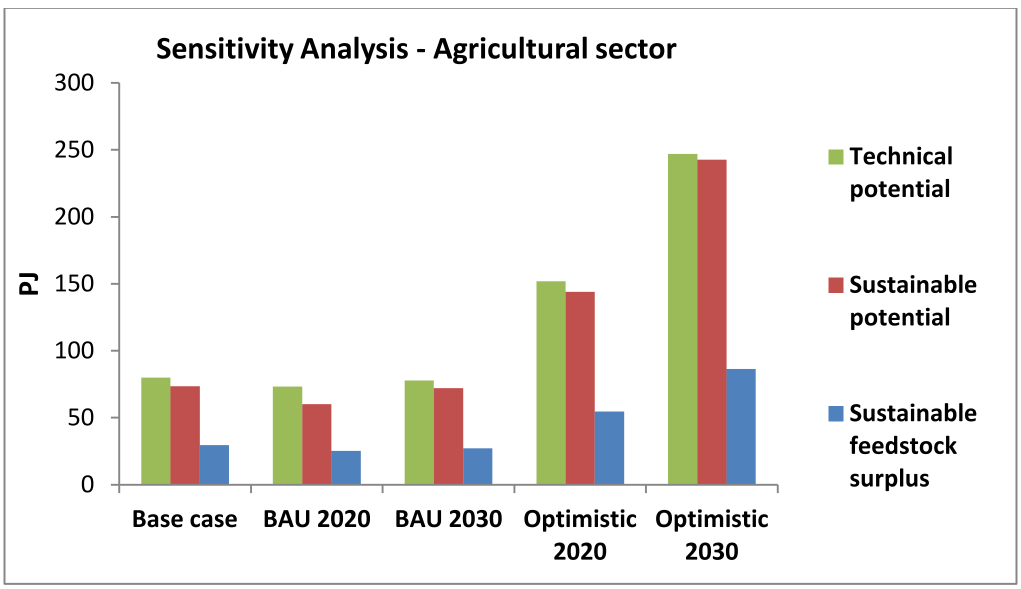
Sisal yield, area and production improvements are investigated based on a study by Zhao [59]. In particular, the study describes the potential of improving productivity of sisal plantations by discussing a specific case study in Tanzania. In fact, the case study concerned a big sisal plantation in Morogoro, where through modern applied technologies and management methods an area increase from 1,400 ha in 2000 to 3,000 ha by 2020 and a production volume increase of 2,000 t to 10,000 t accordingly for the same years were anticipated, given a fertile soil. As a consequence, owing to the fact that Tanzania is a neighboring country of Kenya and improved technological adoption and farming practices, as well as fertile soil are considered in the optimistic scenario, the different parameters of Kenyan sisal are based on this example. In fact, through the 20 year trend (2000 to 2020) applied in the case of Tanzania, the respective annual increasing production, area and yield rates were derived and applied accordingly on the Kenyan sisal sector (see Table 3-11).

According to Kenya Coconut Development Authorities (KCDA), farmers in Kenya growing coconuts are poorly managing their farms relying on the existing fertile soil of the coast area with a restricted use of fertilizer and pesticides and no irrigation systems. KCDA suggested that in an environment where modern farming technologies and farming practices are implemented, coconut yields might reach 11 t/ha in the future. Thus, considering the current average yield of coconut crops (3 t/ha), the annual yield increase required to achieve the 11 t/ha by 2030 was estimated. Regarding the increment in land area of coconuts, the same assumption with sugarcane is used. Thus, the annual increase of coconut cropland and yield affects the annual production volume, accordingly.

With regard to the rice sub sector, the assumption used to improve the different parameters is based on NRDS. The amount of rice consumed per capita was provided and through projections of the population rates in Kenya by 2020 and 2030 respectively, demand of rice at a national level for these years was estimated [45], [48]. Consequently, the annual production volume increase was determined under the scope of meeting domestic demand in a short and a medium term. Furthermore, NRDS indicates a 5 t/ha as the required yield in order to accomplish the goal of meeting domestic demand of rice by 2020. Thus, the annual yield increase of rice was estimated based on the required yield to meet domestic demand by 2020 and considered to maintain the same rate until 2030. Accordingly, a deeper insight into the harvested area of rice in the corresponding timelines was obtained. As can be seen from Table 3-9 and Table 3-11, the difference between the different yields concerning the BAU and the Optimistic scenarios is minor. This is normal considering the current status of the rice sub sector in Kenya, which is relatively well managed, by holding the biggest share in fertilizer inputs and irrigated land, hence leaving less potential for further improvements.

According to the Coffee Board of Kenya and to the Vision 2030 plan, through the promotion of improved seeds, reduced fertilizer costs and production techniques, the increasing small holder yields might lead to a 76 per cent rise in coffee production by 2030. Thus, annual production increase was estimated. Regarding the land increase, the same assumption with sugarcane and rice are applied and hence yield was able to be estimated as well.

With respect to the field residues, an additional assumption is used. Due to the fact that farming practices are considered to have been improved, this may involve a shift from conventional tillage to no till + double cropping farming practices. Thus, less residue is required for the 2 per cent SOC maintenance (see Appendix 8.2 and Table 8-10).



Graph 3-8:Comparison between the present and the future situation of total herbaceous biomass potential in Kenya under BAU and Optimistic scenarios.

Apparently, from an optimistic perspective the technical, sustainable and sustainable feedstock surplus potentials show a significant increase. In a short term, the technical and sustainable potential note an increase of 90 and 96 per cent respectively compared to the base case. The technical potential growth on the other hand, can be justified through the increased yields and areas. Similar to the technical potential, the increase of the sustainable potential can be explained not only by the increased yields and areas but also through the assumption of improved management practices (no till + double cropping), which in turn resulted to lower residue requirements. Taking these parameters into account the respective sustainable feedstock surplus in 2020 was estimated to be around 55 PJ. As a consequence, in the medium term the increase of the miscellaneous residue potentials is more intense with an augmented sustainable feedstock surplus at about 86 PJ.

Alike to the base case and the BAU scenario, the major contributors of the total sustainable feedstock surplus in 2020 and 2030 are bagasse and stalks & leaves possessing an average of about 65 per cent.

All in all, the sustainable feedstock surplus potential originating from the agricultural sector under the BAU and the Optimistic scenarios is projected to range from:

- 25 to 55 PJ → Short term;
- 27 to 86 PJ → Medium term.

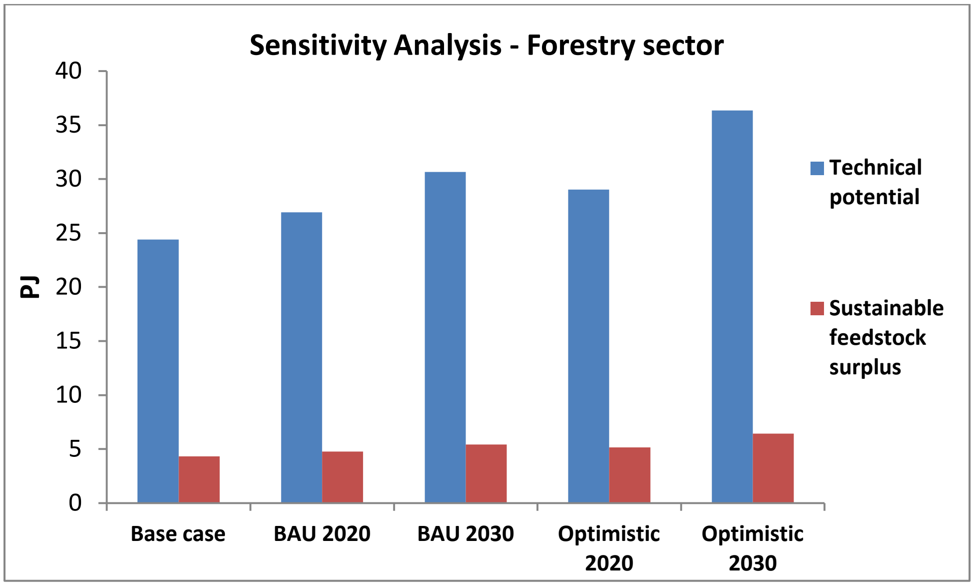
Forestry

The optimistic scenario of the forestry sector builds upon the projections carried out in a study by the KFS on woody products supply [7]. That is, as discussed in sub section 3.3.1 KFS has performed projections, suitable to be used in the BAU scenario, on timber, poles, charcoal and firewood by taking into account changes in climate and reforestation levels. However, in this study an optimum situation is also incorporated.

Timber	Increase %
Annual	2.7
2020	19.0
2030	49.0

Table 3-12: Optimum increasing rates of timber supply following KFS projections.

KFS indicates that forests have not yet reached the optimum yielding levels predominantly due to poor management techniques. Through the policies and regulations provided in the beginning of this section the optimum supply of forestry products can reach 43 million m^3 [7]. Given the fact that there is a high pressure on land acquisition between the agricultural and the livestock sectors and in conjunction with existing deforestation rates trying to be offset by reforestation rates, the forest area was assumed to remain stable. The forecasted national woody biomass supply was projected to be 36 million m^3 in 2030 considering current conditions, and through the optimum achievable level of 43 million m^3 an additional increase of 19 per cent is needed to reach the optimum level. Accordingly, a 19 per cent increase is applied in the primary amount of timber projected for 2030 (9.2 million m^3) so as to estimate the corresponding optimum amount for the same year. That is, through the 11.0 million m^3 of optimum timber supply by 2030 and the 7.3 million m^3 current supply, a clear idea regarding the annual growth of 2.7 per cent and the corresponding growths of 19.0 and 25.0 per cent in 2020 and 2030 respectively was acquired.



Graph 3-9: Comparison between the present and the future situation of total woody biomass potential in Kenya under BAU and Optimistic scenarios.

Similar to the previous results of the BAU scenario, these ones follow a linear increase as well. Again, regarding the technical potential, the highest amount of increase is attributed to off-cuts & chips, whereas due to domestic demand the slight increase of the sustainable feedstock surplus by 1 and 2 PJ for a short and a medium term respectively compared with the base case is attributed solely to sawdust.

Now that this task is accomplished the ranges of the possible sustainable feedstock surplus potential in 2020 and 2030 are provided:

- Short term: 4.8 - 5.1 PJ;
- Medium term: 5.4 - 6.4 PJ.

4. Supply chain of solid biomass feedstocks

This chapter elaborates on the steps from part 2 of the methodology, pointing out the range of the net sustainable surplus potential available for export to the EU-28 currently, in 2020 and 2030.

4.1. Biomass supply costs

This task examines the costs incurred at each step of the biomass supply chain as described in the methodology. With the view to estimating the total costs of a possible future range of residues potential available for export, the BAU and the Optimistic scenarios are also considered.

In order to draw the results a number of data were collected during the internship in Kenya but also through literature. Specifically, selection of the necessary data and the process of their treatment in order to construct the cost supply curves were decided based on Batidzirai's similar study on Mozambique [14].

The following analysis uses inputs from previous tasks, such as production volumes, yields and distances. Nevertheless, a number of new parameters implemented are determinant for the respective herbaceous and woody residues potential variation in the future.

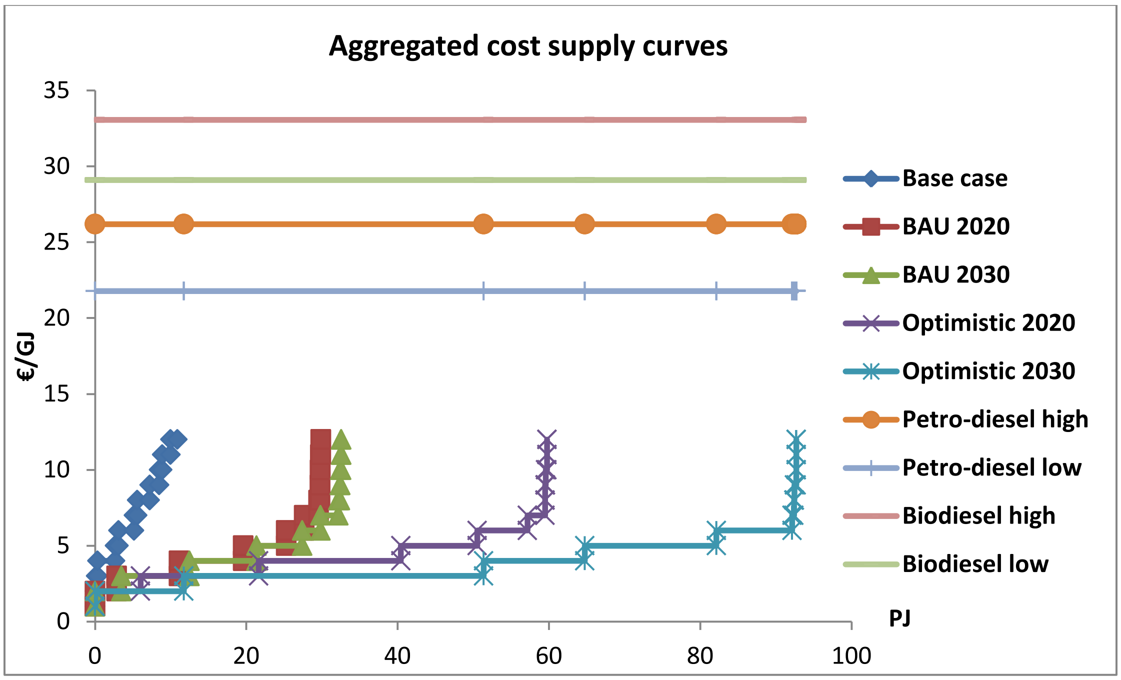
Scenarios/Parameters	30%Fertilizer cost reduction	Kisumu freight station openning[19]	Lamu port development	80% train costs reduction	Pre-treatment
Base case	N/A	N/A	N/A	N/A	N/A
BAU 2020	N/A	×	×	N/A	×
BAU 2030	N/A	×	×	N/A	×
Optimistic 2020	N/A	×	×	×	×
Optimistic 2030	×	×	×	×	×

Table 4-1: Determinant factors of the net sustainable potential under the three scenarios [49], [60], [61], [62].

The first parameter influences the harvesting costs of the field residues, since for every ton of residue removed a certain amount of nitrogen, phosphorous and potassium is depleted from the soil, resulting to additional costs for the farmer in order to compensate for the nutrient loss [63]–[65]. The Kisumu freight station release concerns the bulk of residues lying in the west part of Kenya; due to the fact that currently there is no freight station connecting these areas with the port of Mombasa, transportation of biomass from those areas in hardly feasible. Currently, the port of Lamu is not suitable for big scale shipping storage due to low capacity. However, according to Kenya Ports Authority (KPA) the port will have been developed by 2020 and large shipments for overseas transport may take place. Thus, through the development of the port of Lamu, new biomass sourcing points may become available for export. The Kenyan government claims that by 2020 the construction of the rail line connecting Mombasa, Kampala, Kigali and Juba might lead to reduced train transport costs by almost 85 per cent [60], [66]. That would

[19] According to Mr. D. Hunda the Head of the Railway Division in Kenya, the freight station in Kisumu will open by 2020 .

result in a significant reduction of the total logistic costs for long distances. Finally, for the current situation, the different feedstocks were considered to be transferred at their raw form, raked and balled. This has a huge impact on the logistic costs, since the respective bulk and energy densities of the residues in their raw form are low resulting to more trips needed by truck and train. Thus, biomass pre-treatment facilities were assumed, in order to increase the different residues bulk densities in a short and a medium term. In fact, depending on biomass availability at each different sourcing point a pre-treatment plant of 100 kt and 10 kt for counties with high and low biomass potential respectively was applied [14]. As a consequence, despite the additional costs of this new step in the biomass supply chain, through the grinding, drying and pelletizing process, the logistic costs drop leads to cheaper and final biomass delivered.



Graph 4-1: Illustration of the national sustainable feedstock surplus with incorporated costs throughout the entire biomass supply chain and comparison between costs of alternative fuel uses.

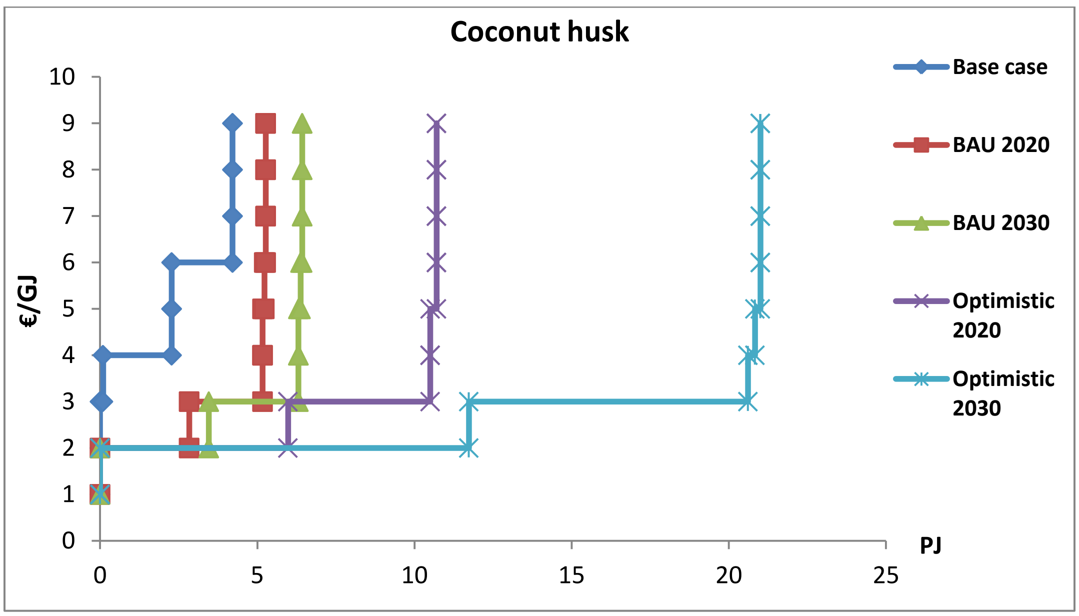
In Graph 4-1 the total sustainable feedstock surplus originating from sugarcane stalks & leaves, bagasse, sisal ball, rice husk, rice straw, coffee husk, coconut husk and sawdust is depicted together with the costs incurred from the respective sourcing points to the port for export. Furthermore, low and high price levels of petro-diesel (22 and 26 €/GJ) and biodiesel (29 and 33 €/GJ) respectively are used to provide an indication on economic viability of the shares of the sustainable feedstock surplus potential. The prices of the competing uses were retrieve by Batidzirai's study [22]. Thus, at first seems that in each case all biomass delivered can potentially be an economic viable solution. However, in Graph 4-1 primary and secondary energy carriers are illustrated and in order to enable the comparison between them, primary energy losses of about 30 per cent and additional costs due to ship transportation and conversion process

(Fischer–Tropsch) are considered[20] [22]. In fact, at the moment 100 percent of solid biomass is delivered at a cost of 9 €/GJ, when for the remainder scenarios from 7 to 6 €/GJ. With the primary energy loss and additional transport and processing costs considered the costs may increase from 9 to 30 €/GJ for the base case and from 7 to 23 €/GJ and from 6 to 20 €/GJ in the BAU and the Optimistic scenarios. Thus, shares of the sustainable feedstock surplus might not be economically viable to export when incorporating costs from 7 €/GJ and higher.

As an overview of the possible potentials, currently only 50 per cent of the total sustainable feedstock surplus may be deemed suitable for export with 6 €/GJ and more than 90 per cent in for the remainder scenarios.

The different feedstocks are analyzed in order to understand and show separately the respective biomass potential costs with the view to estimating the possible net sustainable surplus potential correspondingly.

Coconut husk



Graph 4-2: Supply costs of coconut husk throughout the entire biomass supply chain at present, in 2020 and 2030.

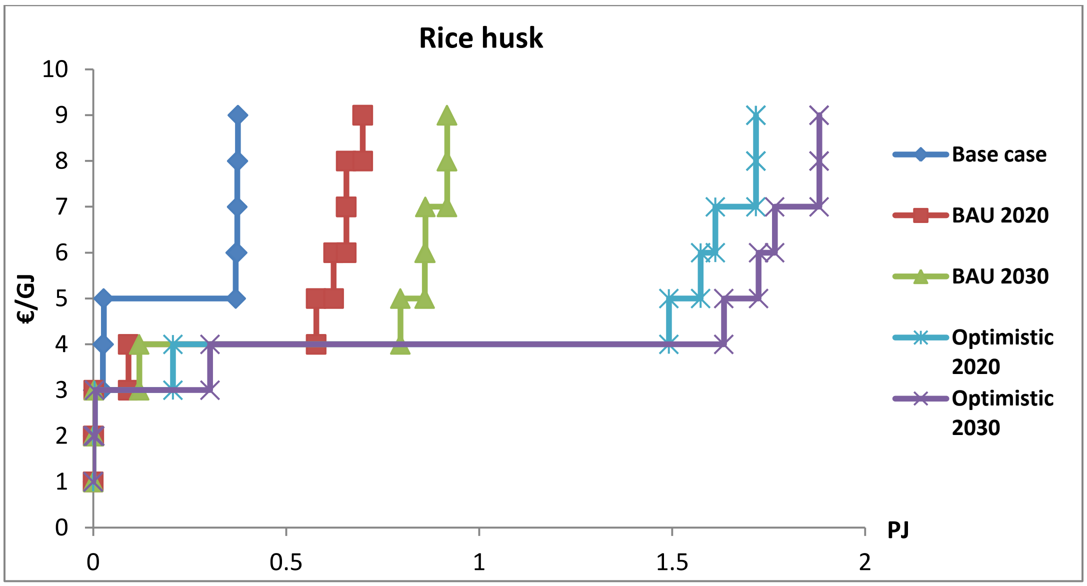
With regard to 2020, under the BAU and Optimistic scenarios coconut husks from all regions are delivered on average with 2.5 €/GJ and 2.3 €/GJ respectively, whereas in the base case with 5 €/GJ[21]. About 50 and 60 per cent of coconut husks in the BAU and Optimistic scenarios respectively are delivered at 2 €/GJ, while currently 50 per cent is supplied at 4 €/GJ. The situation varies accordingly in the medium term as well. The differences in costs between the three scenarios lie on the higher yields of coconuts in 2020 and 2030 correspondingly but also on

[20] Primary energy losses and additional costs due to shipping transport and conversion process are assumed by comparing solid biomass deliverance from Brazil to the Netherlands (source: Batidzirai chapter 6)

[21] Weighted average cost of biomass from all regions.

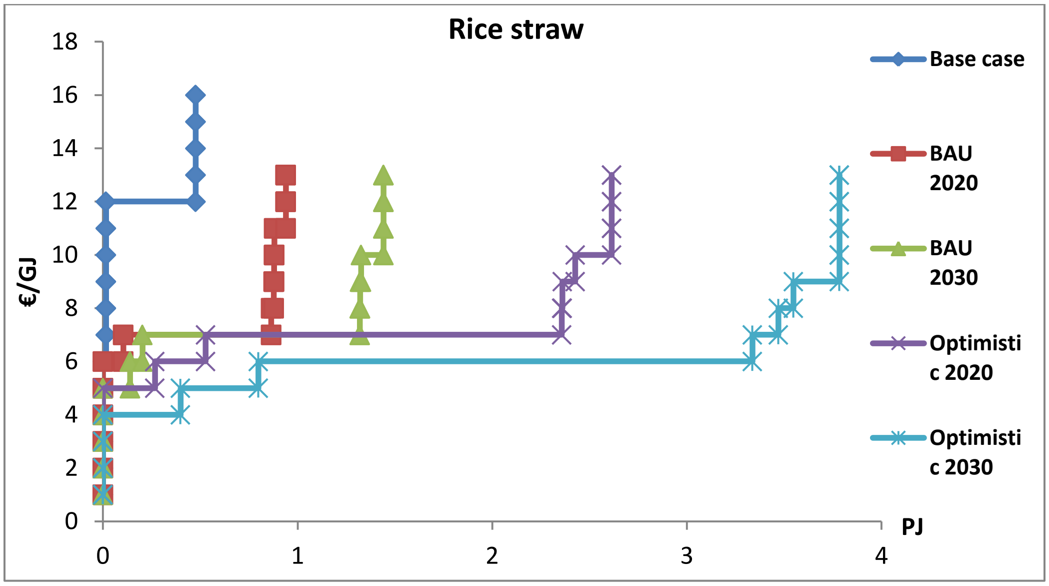
the pre-treatment of biomass. That is, higher and more dense amounts of husks transferred result to reduced logistic costs per GJ. Logistic costs effects are more influential in the case of feedstock, as transfer of biomass is almost entirely realized by truck due to the close proximity of the biomass sourcing points to the port of Mombasa. The main bulk of husk transferred originates from Kwale and Kilifi counties and accounts for 90 per cent of the national coconut husk potential and hence the final supply cost is directly dependant on the characteristics (distance, yield and area harvested) of the two areas. For instance, at present, Kwale amounts to 123 thousand t of husks, while Kilifi amounts to 110 thousand t. Furthermore, Kwale abstains 33 km from the port of Mombasa, when Kilifi abstains for 60 km. These factors have contributed to the two district steps in each scenario. In conclusion, 100 per cent of coconuts indicate promising sustainable feedstock surpluses for export.

Rice residues



Graph 4-3: Supply costs of rice husk throughout the entire biomass supply chain at present, in 2020 and 2030.

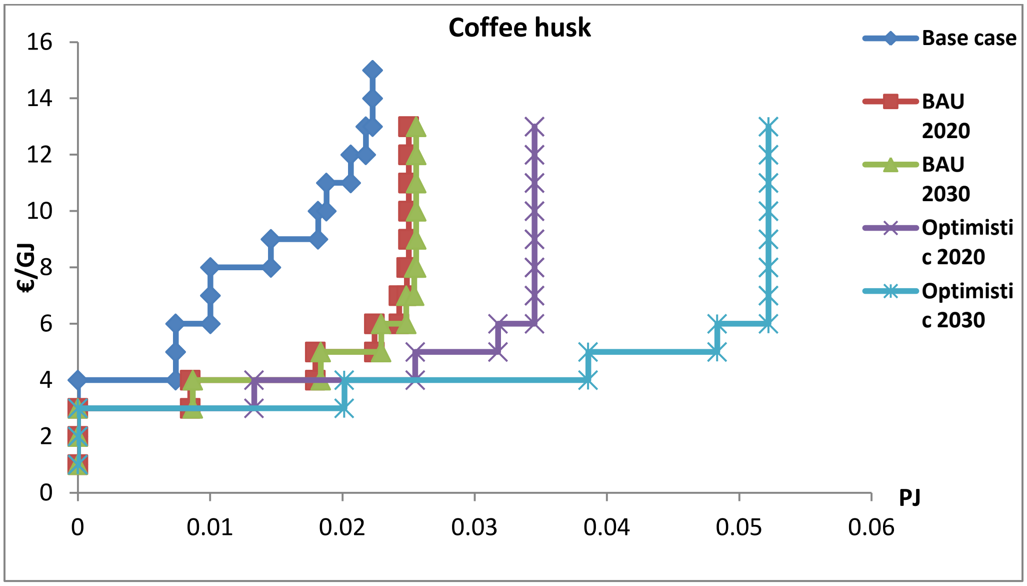
The weighted average for the rice husk supply are 4.8, 4.3, 4.3, 4.2 and 4.2 €/GJ at present, the BAU 2020 and 2030 and the Optimistic scenarios for 2020 and 2030 respectively. It is important to mention that there are only slight differences in the supply costs due to minor differences in the yield assumed regarding each scenario but also the low RPR of rice husk. As a result, rice husks costs are predominantly affected by the pre-treatment costs. The main volume of rice husk potential appearing in all the scenarios stems from Kirinyaga county. In fact, Kirinyaga accounts for more than 60 per cent of total rice husk produced in Kenya and hence rendering its further transportation from the sourcing points more economically viable. At present, the negligible aspect of the total husks, which in the short and medium terms becomes more discreet due to improved yields, stem from counties close to the port of Mombasa and are subsequently feasible to transfer at lower costs. Furthermore, as discussed in the beginning of 4.1 task, the additional amount of rice husk appearing in the short and the medium term is omitted in the description of the current situation due to the fact that Kisumu freight station is not currently available, rendering unfeasible the transportation solely by truck from remote areas. Finally, based on the costs estimated more than 80 per cent of rice husk sustainable feedstock potential might become available for export.



Graph 4-4: Supply costs of rice straw throughout the entire biomass supply chain at present, in 2020 and 2030.

With regard to rice straw, residues today are delivered at a price of 12 €/GJ. This cost is largely affected by the low density of straw and the high logistic costs (7.5 €/GJ). In the BAU scenario for 2020 and 2030 the average costs are 7.0 and 6.8 €/GJ, respectively. Through the grinding, drying and pelletizing process the energy density of rice straw increased by almost five times resulting to this sharp decrease in the supply costs. Similarly, in the optimistic scenarios the pre-treatment process is the major factor for this steep decline in the supply costs, as well. However, both of the optimal cases are differentiated from the rest predominantly due to the cheaper rail costs (0.14 to 0.02 €/km). In particular, the optimal case in 2030 is shown, highlighting an even lower cost relative to the short term (4.0 to 4.5 €/GJ) because of the 30 per cent of fertilizers costs reduction, resulting to lower farm gate costs. As a result, only under the Optimistic scenario more than 80 per cent of rice straw show promising potential for export. In the rest of the cases about 90 per cent is considered possibly unattractive to export.

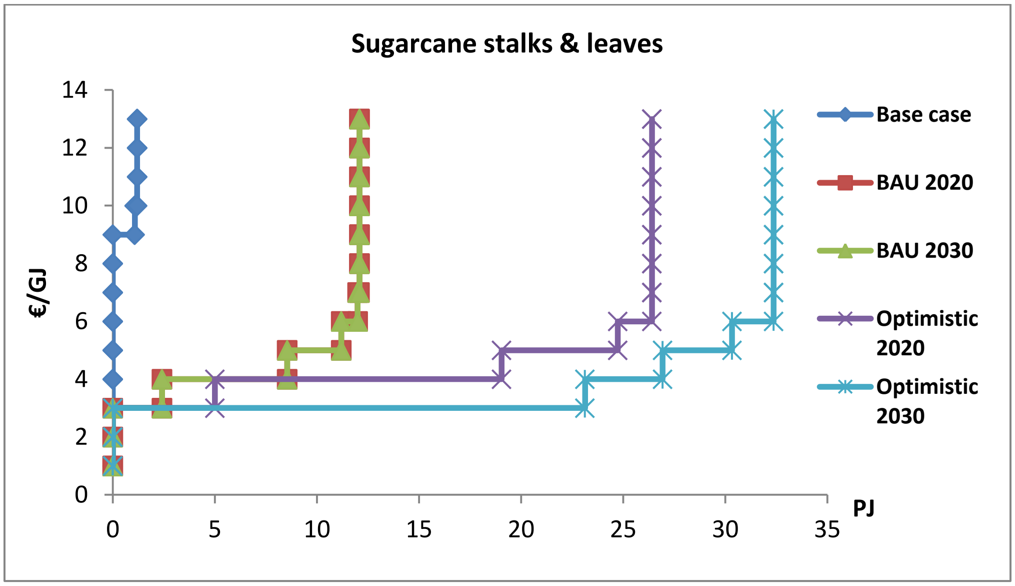
Coffee husk



Graph 4-5: Supply costs of coffee husk throughout the entire biomass supply chain at present, in 2020 and 2030.

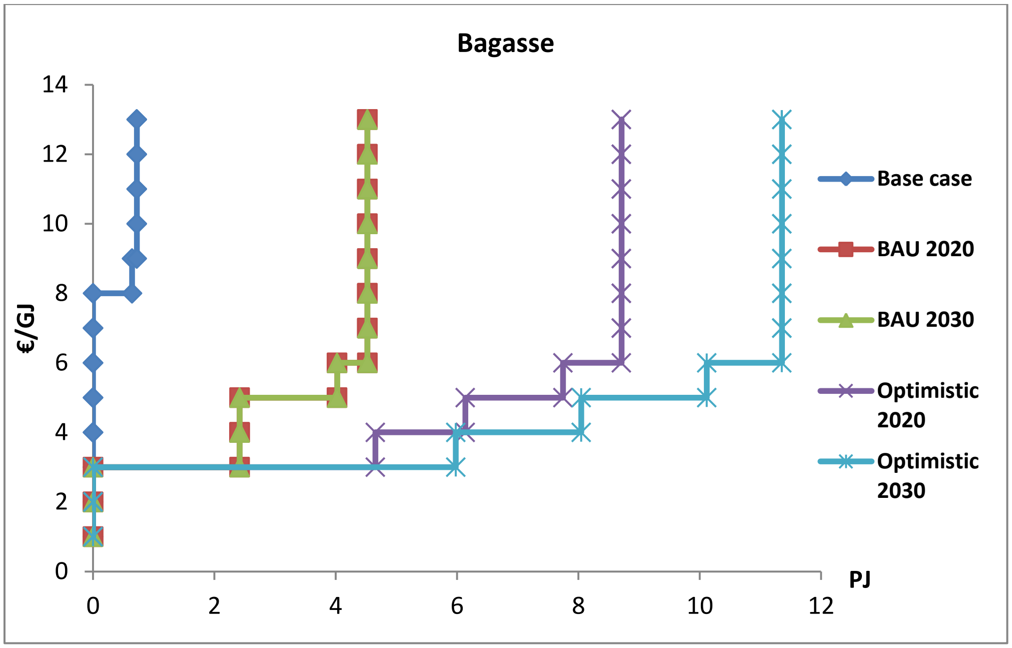
At present, coffee husk is estimated to be available at the port of Mombasa for export on average at about 7.1 €/GJ. The multiple steps of the graph are attributed to numerous counties, where coffee production takes place and hence becomes available at different costs. The respective costs for biomass supply in 2020 and 2030 under the BAU scenario are almost the same and amount to approximately 4.4 €/GJ on average each. The costs are similar due to the very low annual yield increase suggesting that no more biomass might become available at lower costs in the medium term compared with the short term. In contrast, under the scope of a more optimistic point of view, and hence higher yields, the supply costs are reduced further (3.9 €/GJ) with more coffee husk available at lower costs from 2020 to 2030. In conclusion, currently only about 40 per cent of coffee husk is deemed likely available for export. With regard to the rest of the scenarios 100 per cent is considered possibly available.

Sugarcane residues



Graph 4-6: Supply costs of sugarcane stalks & leaves throughout the entire biomass supply chain at present, in 2020 and 2030.

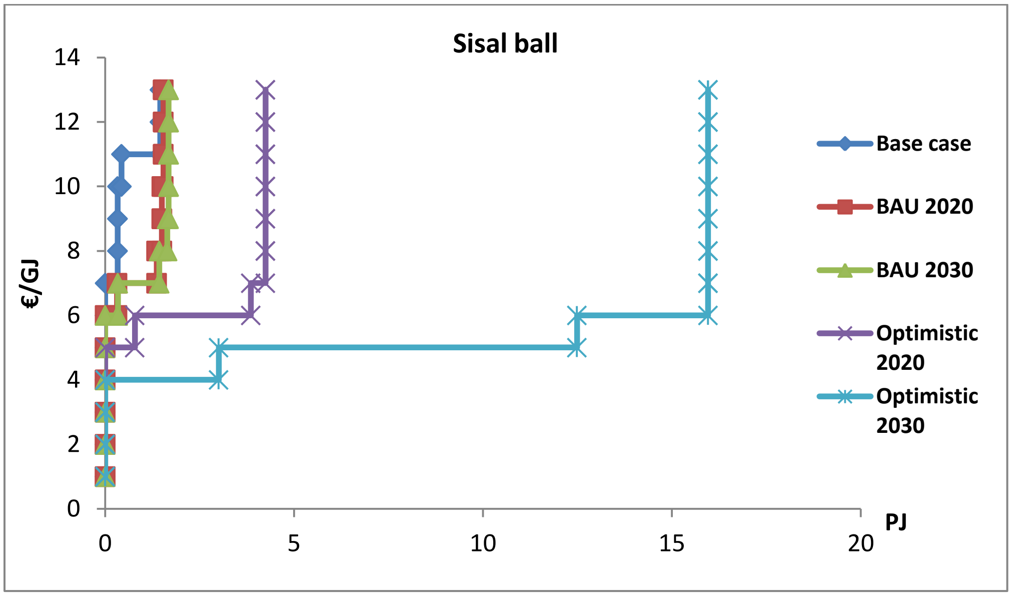
The sugarcane sector is centered in the west part of Kenya, approximately 900 km far from the main port of Mombasa indicating that any transfer of sugarcane residues is potentially economically viable only through rail transport. In particular, from the 16 PJ sustainable feedstock surplus potential estimated for the current situation in the preceded tasks, only 1.2 PJ may become available at a cost of 9.0 €/GJ. With regard to the BAU scenario in a short and a medium term, the supply average costs are identical (4.2 €/GJ) due to both timelines share the same assumptions and yields. However, the decrease in costs is explained mainly through the pre-treatment process, which has caused a sharp decrease in the logistic costs owing to the longer distances needed to be covered. In the Optimistic scenario about 60 per cent of the total residues potential becomes available in 2020 and 2030 at 4 and 3 €/GJ respectively because of the lower rail costs and the increased yields. Thus, at present no solid biomass potential from stalks & leaves is deemed possibly available for export, whereas in the future the entire amount might become available.



Graph 4-7: Supply costs of bagasse throughout the entire biomass supply chain at present, in 2020 and 2030.

As expected, bagasse supply cost curve shares similar characteristics with the one of stalks & leaves. Almost the entire amount is presently delivered at 8 €/GJ. The difference in costs between stalks & leaves and bagasse largely lies on the farm gate costs, since process residues are less labor intensive, concerning their collection, and without considering any additional expenditures for nutrient compensation. Thus, in 2020 and 2030 the averages supply costs amount to approximately 4.5 €/GJ regarding the BAU scenario, whereas for the same timelines under the Optimistic scenario comes to about 4.0 €/GJ. As a result, is difficult to become available at present for export to the EU, when the entire amount of the respective sustainable feedstock surplus is deemed possibly available in the future.

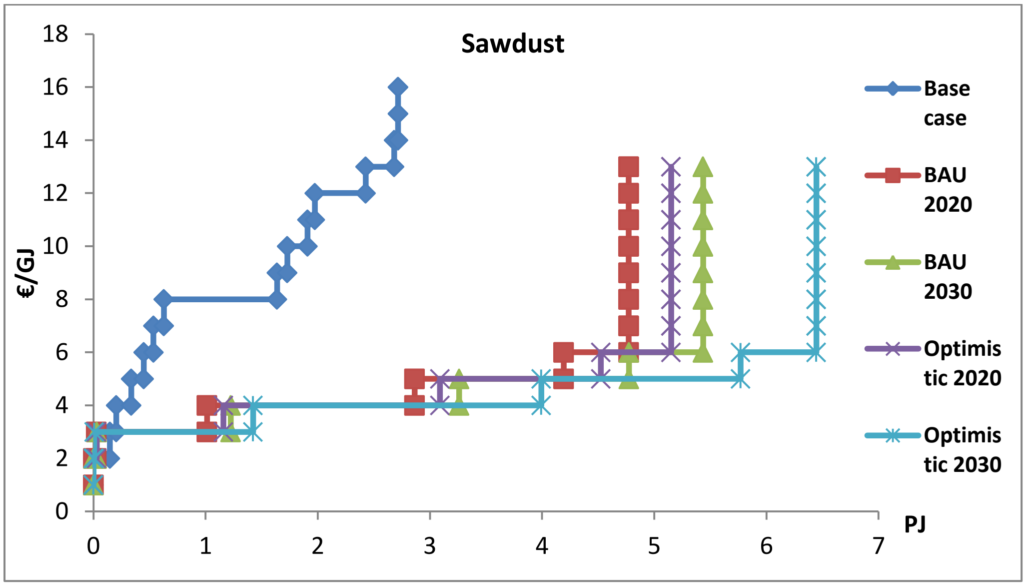
Sisal ball



Graph 4-8: Supply costs of sisal ball throughout the entire biomass supply chain at present, in 2020 and 2030.

With respect to sisal ball, intensive differences are noted between the base case, BAU and Optimistic scenarios. Due to the fact that biomass availability of the respective feedstock and energy density are low, high transport costs resulted to 11 €/GJ supply costs on average. Accordingly, in the future under the two scenarios through the pre-treatment process the average costs have dropped significantly. The further reduction in a more optimistic situation is attributed to the higher yields compared with the BAU scenario, which resulted to 6 and 7 €/GJ for 2020 and 2030 compared with the 7 €/GJ of the total biomass delivered for both the same timelines. Therefore, only in the Optimistic scenario sisal ball might become entirely available, while in the remainder cases no potential is deemed economically viable for export.

Timber sawdust



Graph 4-9: Supply costs of sisal ball throughout the entire biomass supply chain at present, in 2020 and 2030.

Similar to the previous products, the pre-treatment of sawdust and plantations yield improvements have resulted to increased biomass potential disposable at lower costs. Specifically, more than 80 per cent of total sawdust in 2020 and 2030 regarding the BAU and the Optimistic scenarios can be delivered at 5 €/GJ. Thus, when looking at the current situation only about 30 per cent of the sawdust sustainable potential is considered likely suitable for export, whereas in the remainder scenarios 100 per cent might become available.

4.2. Biomass supply GHG emissions

This task elaborates on GHG emissions left due to biomass deliverance from the harvesting point to the main port for export.

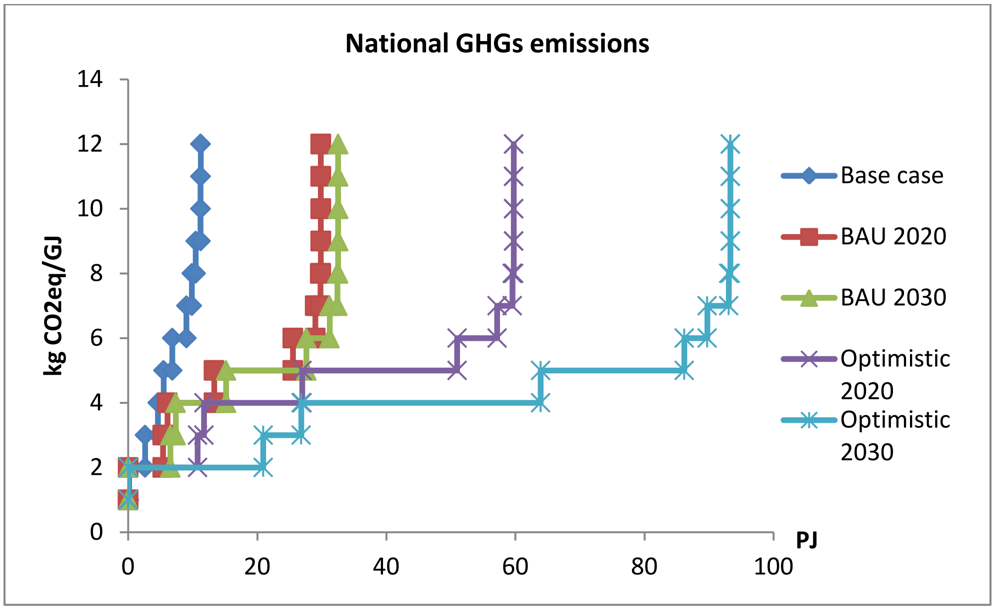
In order to carry out this analysis new data through literature review combined with inputs from task 4.1 are used.

Parameters/Emission factor[22]	kg CO2eq/km	kg CO2eq/$t_{residue\ harvested}$	Kg CO2eq/KWh
Truck	1.3	N/A	N/A
Sisal ball	N/A	19.8	N/A
Sugarcane stalks & leaves	N/A	18.9	N/A
Rice straw	N/A	28.9	N/A
Electricity	N/A	N/A	0.3

[22]Truck emission factor was calculated based on diesel consumption, and the fuel's emission factor. Train emission factor used was 0.02 kg CO2eq/t-km for a 1000 t train. The emission factors of sisal ball, sugarcane stalks & leaves and rice straw were estimated through the corresponding nutrient contents of each feedstock and the kg CO2eq emitted for every t of N, PO2 and KO2 produced.

Table 4-2: Emission factors of the elements contributing to the GHGs released throughout the entire supply chain [2], [22], [27], [67], [68].

The emission factors presented in Table 4-2 were used and according to equation 2-8, provided in the methodology, GHGs emissions for each feedstock were estimated (kg CO2eq).

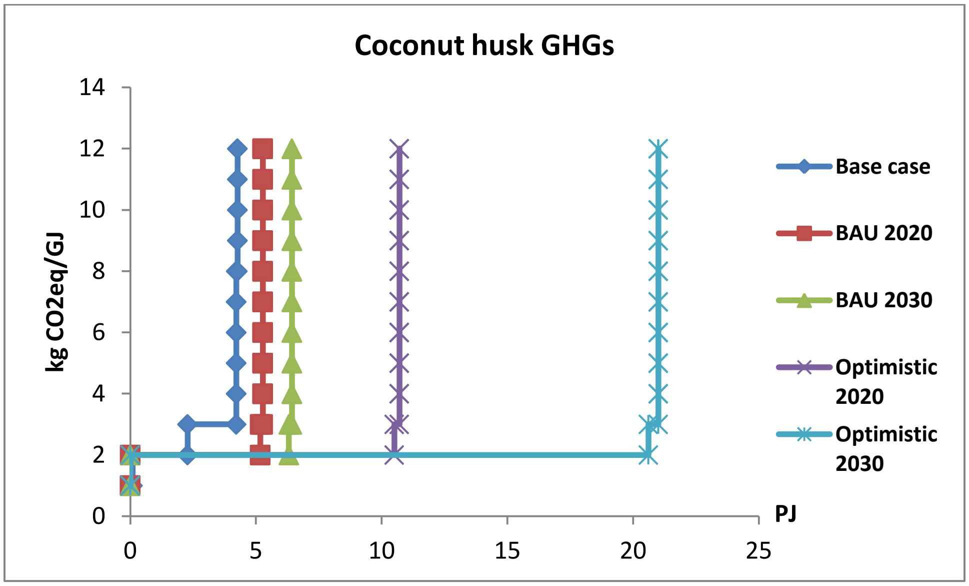


Graph 4-10: Aggregated GHG emissions released throughout the biomass supply chain originating from the selected feedstocks.

In Graph 4-10 the total GHGs incorporated in the entire biomass supply chain are shown. It can be seen that in the base case more than 90 per cent of solid biomass is delivered at 6 kg CO2eq/GJ. In the BAU scenario respectively more than 90 per cent of the total sustainable feedstock surplus is delivered at 5 kg CO2eq/GJ for 2020 and 2030 correspondingly. In the Optimistic scenario regarding the same timelines, about 90 per cent of total biomass is delivered again at 5 kg CO2/GJ. Thus, when looking a similar study from Batidzirai, assessing the GHG emissions across a solid biomass supply chain starting from Brazil and ending to the Netherlands useful indications can be derived. That is to say, in that study, for the same biomass supply chain steps considered in this research, the GHG emissions released were estimated at about 9 kg CO2eq/GJ. This level of emissions resulted, including the entire steps involved in the biomass trade and utilization process, to a 77 per cent on average emission reduction based on oil reference prices. Thus, it is indicated that the carbon footprint of Kenyan solid biomass is likely to meet any sustainability requirements.

An analysis on how the GHGs emissions per feedstock are released follows, in order to show how this promising national sustainable feedstock potential in terms of low GHG emissions is formed.

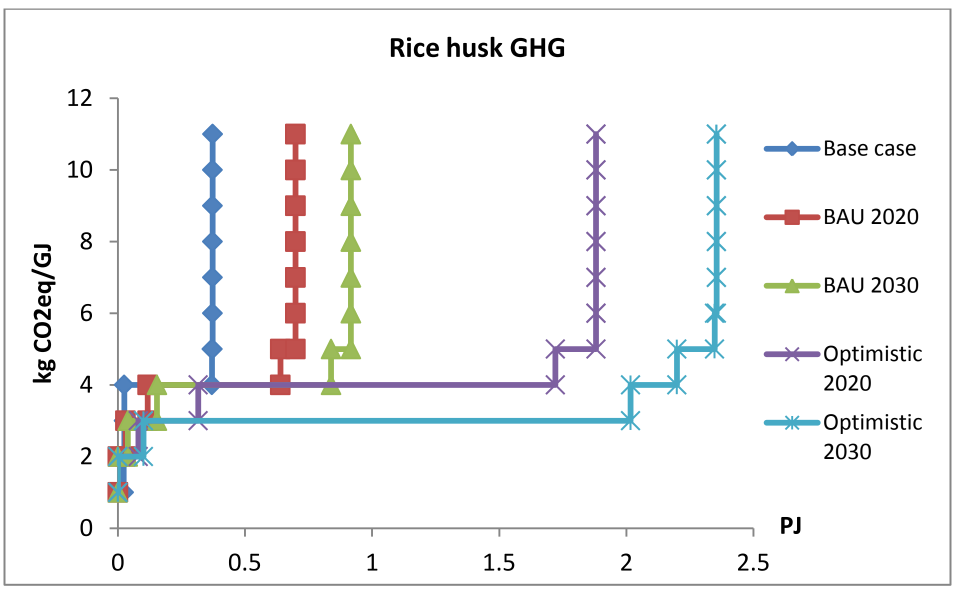
Coconut husk



Graph 4-11: Carbon footprint registered owed to the coconut husk supply process.

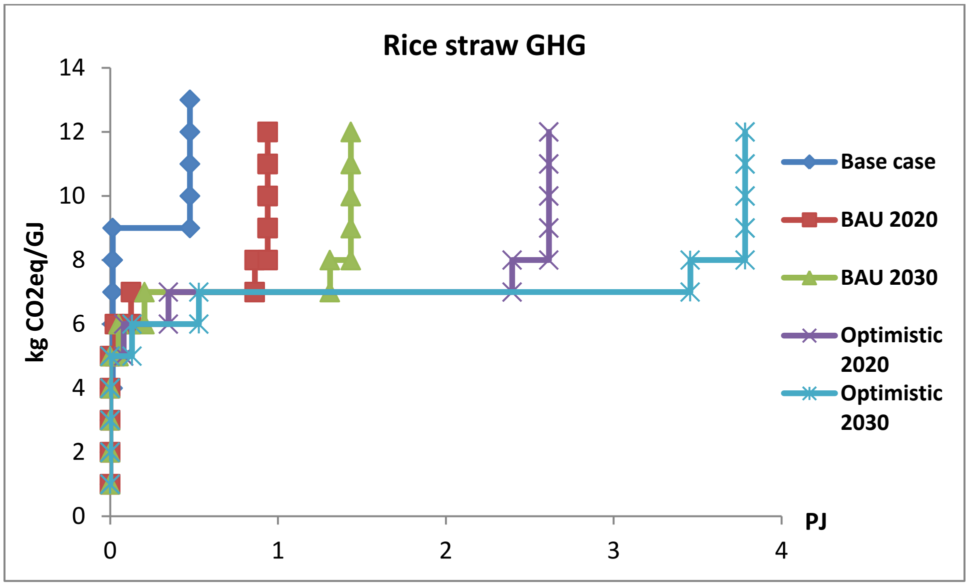
With respect to coconut husk, 4 PJ can be delivered with 3 kg CO2eq/GJ. In 2020 and 2030 GHGs are reduced by 1 kg CO2eq/GJ due to the increased yields, indicating less GHGs emitted in the pre-treatment and transportation process. About 50 per cent of the carbon footprint is caused by the pre-treatment process.

Rice residues



Graph 4-12: Carbon footprint registered owed to the rice husk supply process.

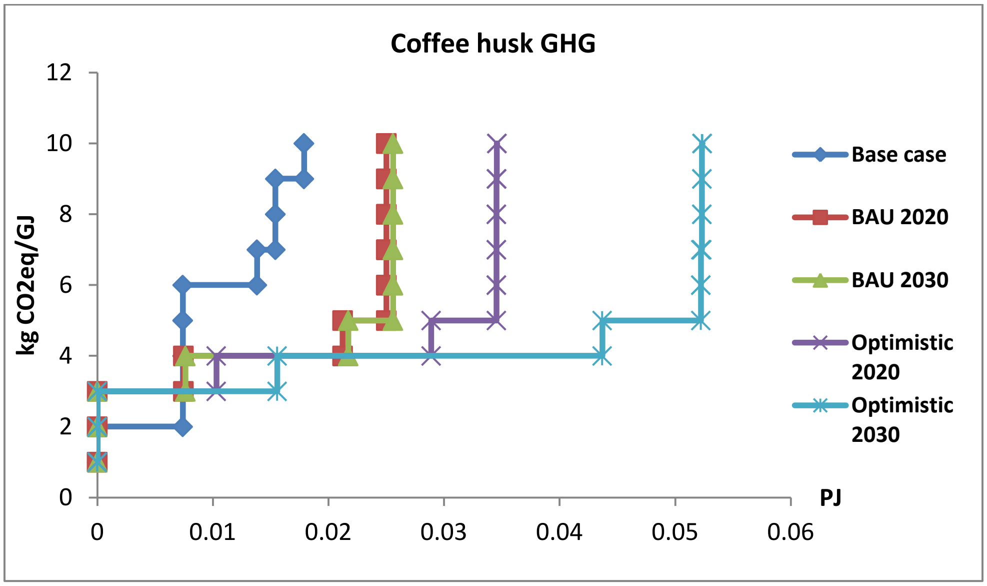
At present, rice husk becomes almost entirely available at 4.0 kg CO2eq/GJ. In the short term 0.7 and 1.8 PJ are delivered with 4.0 kg CO2eq/GJ respectively, and by 2030 the carbon footprint of rice husk ranges from 4.0 to 3.0 kg CO2/GJ. This drop is explained through the higher amounts of husks generated, and thus leading to less GHG per biomass supplied. Similar to coconut husk, the basic parameter affecting the environment through GHG quantity is the pre-treatment process accounting for approximately 50 per cent of total emissions.



Graph 4-13: Carbon footprint registered owed to the rice straw supply process.

It is apparent from Graph 4-13 that the rice straw supply process exerts greater impact to the environment than rice husk. The difference lies in the additional emissions produced by fertilizer compensation, which are considered solely for the field residues analysis. Approximately 1.0 to 2.8 PJ in the short term are estimated to be delivered with 8 kg CO2eq/GJ, whereas 1.5 to 4.0 PJ of rice straw in the medium term with 8 kg CO2eq/GJ as well. An overall decrease by 1 kg CO2eq/GJ is projected in the future compared with the present.

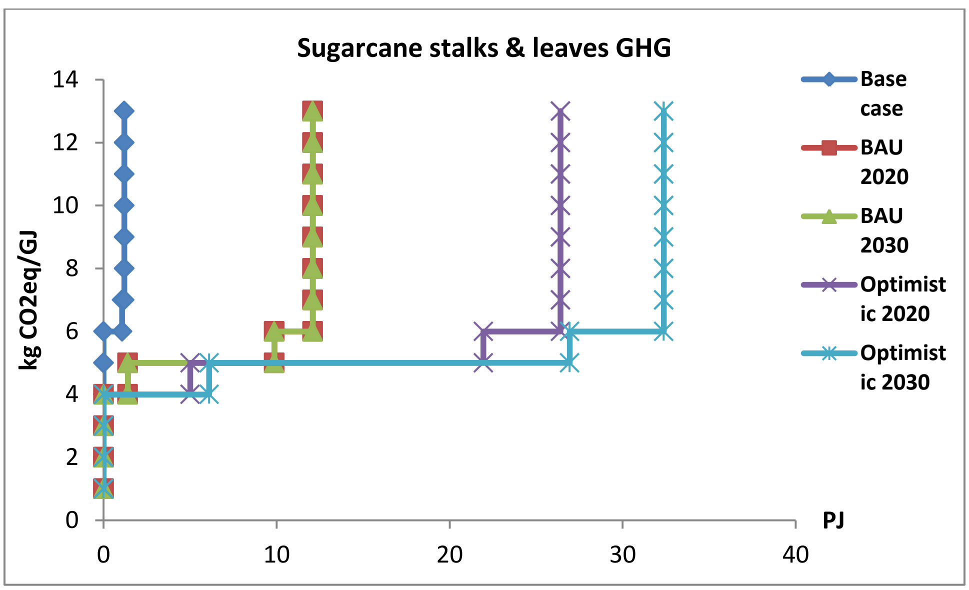
Coffee husk



Graph 4-14: Carbon footprint registered owed to the coffee husk supply process.

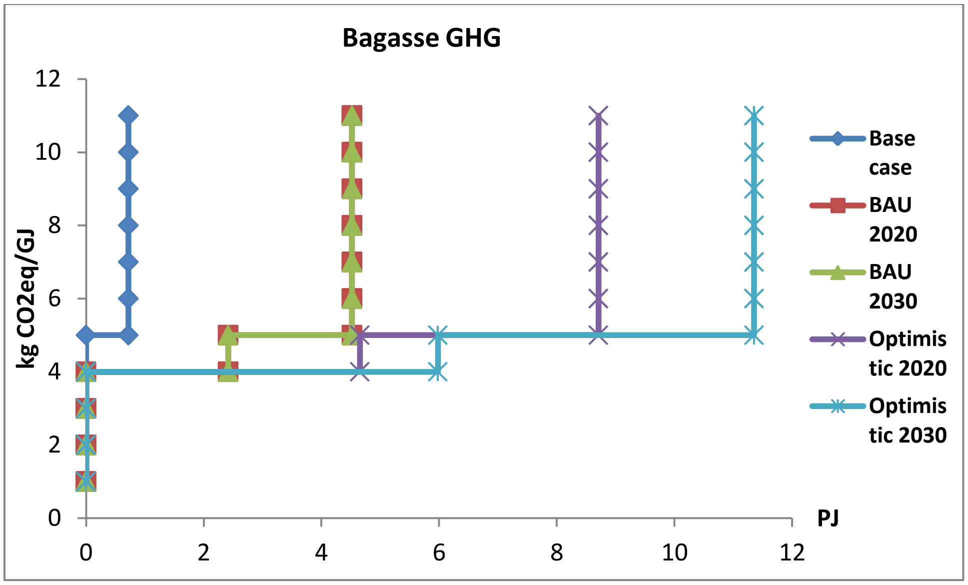
Regarding coffee husk the overall GHGs drop by 5 kg CO2eq/GJ in the future compared with the base case. The low bulk transferred by train has currently resulted to this high carbon footprint. The situation improves in the future due to advanced pre-treatment process, through which higher bulk of residues are transported by train.

Sugarcane residues



Graph 4-15: Carbon footprint registered owed to the sugarcane stalks & leaves supply process.

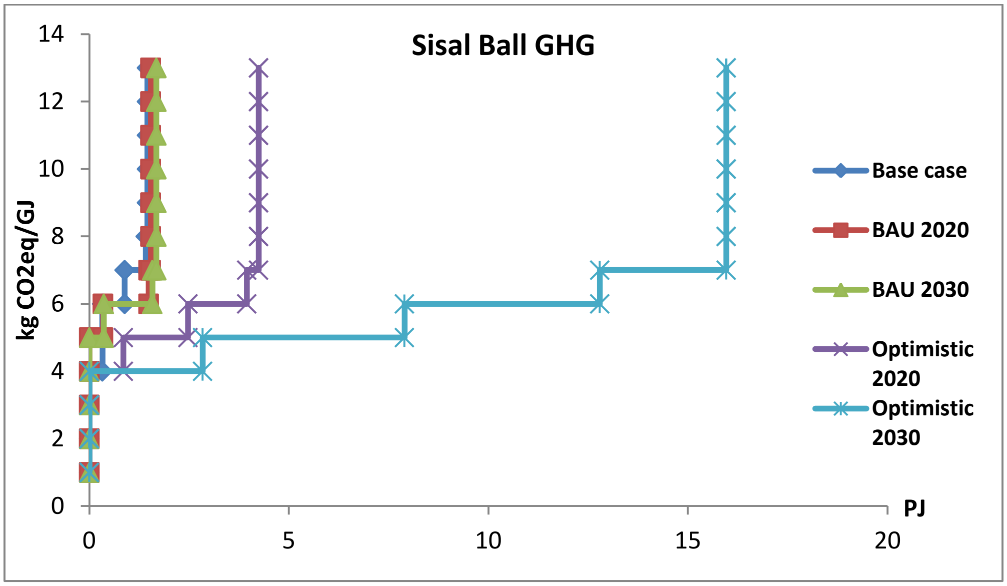
As discussed in the supply cost curve of stalks & leaves in the base case the majority of the counties standing for sugarcane production do not appear in the graph due to the absence of a freight station in those areas. Furthermore, the yield from 2020 to 2030 was assumed to be constant as was the case with the carbon footprint in the BAU scenario. In the optimistic scenario, due to higher and differentiated yields more biomass can be delivered more sustainably with on average 5.0 kg CO2eq.



Graph 4-16: Carbon footprint registered owed to the sugarcane stalks & leaves supply process.

Similar to rice straw and rice husk, bagasse is supplied at on average with 1.0 kg CO2eq less compared with stalks & leaves owing to the additional farm gate emissions of the latter.

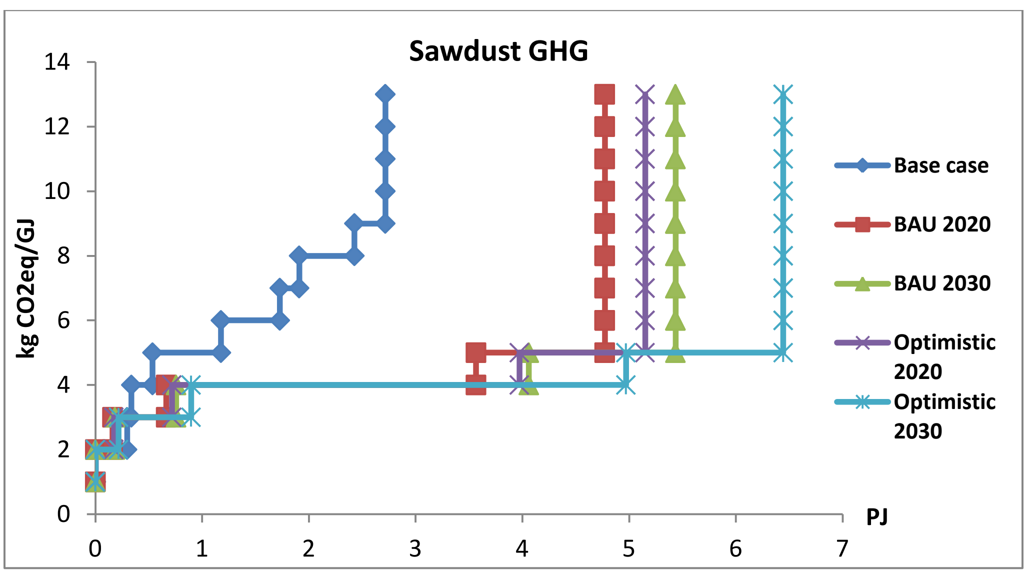
Sisal ball



Graph 4-17: Carbon footprint registered owed to the sisal ball supply process.

The sustainable feedstock surplus of sisal ball, in which GHG emissions and the supply costs can be reduced through scaling, is low in relation to other residue types. Thus, the situation improves drastically only in the Optimistic scenario, where more intense yield increases were assumed. In fact, in the base case 1.5 PJ are supplied with 7.0 kg CO2eq/GJ, whereas 4.0 kg CO2eq/GJ are released for the same amount of sisal ball delivered in the optimal case by 2030.

Timber Sawdust



Graph 4-18: Carbon footprint registered owed to the sawdust supply process.

With regard to sawdust, the major contributor of the GHGs is the logistics, since sawdust is collected from distant areas requiring two modes of transport. Thus, air pollution has increased through the pre-treatment process; however, the augment in sawdust energy density resulted in lower emissions released during transportation. Currently, about 3.0 PJ are delivered with 9 kg CO2eq, while in present scenario by 2030 the same amount can be delivered with 4 kg CO2eq.

5. Discussion

The aim of this research was to assess Kenya's solid biomass potential under the scope of exporting it to the EU-28 at present and until 2030. In fact, this study investigates the potential of biomass originating from herbaceous, woody and lignocellulosic biomass feedstocks, adhering to certain sustainability criteria and how this might vary in the future.

Results-methods

The findings of a four month internship carried out in Kenya in 2014 were used as key inputs, with the view to developing the analysis of this research. Specifically, in this internship the most prominent agricultural and forestry feedstocks in terms of residue availability were identified, combined with the respective counties holding the highest share of these feedstocks. Subsequently, vital information for a further analysis in this study was retrieved regarding each of the selected herbaceous and forestry residue types. That is, production volumes, harvested areas and yields, for each county where the selected products are being produced, ongoing and forthcoming policies concerning the selected feedstocks were collected. Furthermore, the selected counties were investigated with the aim of building case studies for each feedstock of both the agriculture and forestry sectors on predominantly domestic demand, but farming practices and technological adoption as well. Thus, residues stemming from coconut, sugarcane, rice, coffee, sisal and timber were examined further in this study. In contrast, the analysis on land availability was approached predominantly through literature review. Due to the fact that detailed information on land availability for lignocellulosic biomass production was not found during the internship, the further analysis was based on indications from literature and to some lesser extent information from stakeholders interviewed in Kenya (e.g. woody biomass balance).

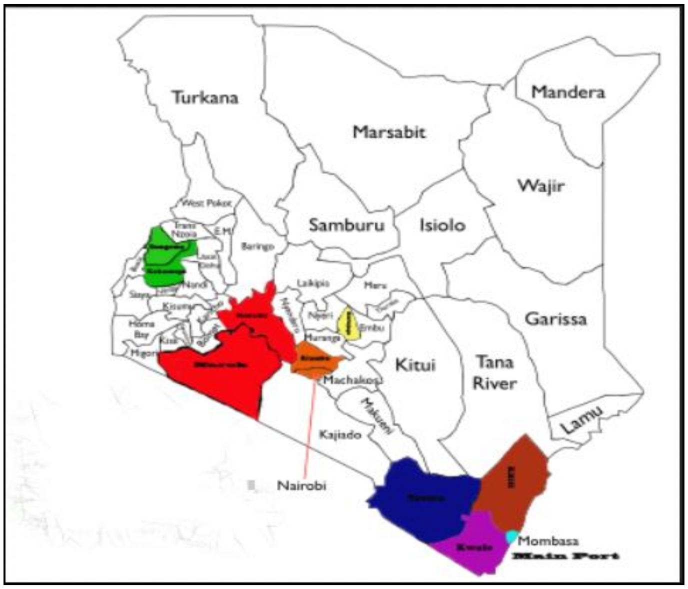


Figure 5-1: Areas visited during the internship for the development of herbaceous and woody biomass case studies.

The research set up was separated into two parts with 4 and 2 tasks each, by which the net sustainable surplus potential of solid biomass was determined. All of the tasks apart from the first one were initially carried out for the current situation in Kenya and subsequently for 2020 and 2030.

Agriculture & Forestry sectors

With regard to the present condition of the solid biomass potential in Kenya, the completion of the first task (2.1.1) enabled the estimation of the technical potential regarding herbaceous and woody residues feedtocks. That is, through the different production volumes and areas obtained, the respective RPR and LHV retrieved from literature were applied and resulted to the estimation of the technical potential of the miscellaneous feedstocks at present. The third task (2.1.3) of part 1 of the research focused on determining the share of the technical potential (sustainable potential) of the field residues, such as sugarcane stalks & leaves, sisal ball and rice straw, which should be set aside for soil erosion control and soil organic carbon maintenance. Data were not available for these specific crops in Kenya, and hence the findings of Valk's study on maize, wheat and sugarcane residues required for these specific applications were used [23]. In the fourth and last task (2.1.4) of part 1 the share of the sustainable biomass potential stemming from coconut, rice, sugarcane, sisal and coffee residues, which is consumed in a number of indigenous applications , was estimated. For this task inputs predominantly from the internship in Kenya were used. That is to say, a number of companies and farmer unions in Nakuru, Narok, Taita Taveta, Kakamega, Bungoma, Kirinyaga, Kwale, Kilifi and Kiambu counties were interviewed in order to among others identify and quantify the domestic demand for the investigated agricultural and forestry feedstocks. The first two concerned timber, Taita Taveta and Kilifi sisal, Kakamega and Bungoma sugarcane, Kirinyaga rice, Kiambu coffee and Kwale and Kilifi coconuts. Thus, based on the findings from these interviews separate case studies were built for each feedstock respectively. The different competitive applications of the residues identified were animal use, households, local industries and residue streams which were capitalized internally by the same stakeholders producing a certain feedstock. Thereinafter, by applying the different shares of domestic demand on the corresponding sustainable potentials of the investigated residue types, the sustainable feedstock surplus was derived.

With regard to the second part of the research analysis two tasks were conducted. In fact, the costs and GHGs emissions incurred during the supply of biomass from the miscellaneous sourcing points to the main port of Mombasa were estimated. In order to estimate the costs, the methodology followed in a similar case study conducted in South Africa by Batidzirai was adopted [14]. Data on harvesting costs of biomass comprised by labor, fuel, nutrient compensation and machinery costs (Typical scenario of a maize farmer using a square baler). For the transport process, truck and train capacities ($m^3$and t) were used. Furthermore, densities of the different residue types, when raked and balled combined with the distances from a specific sourcing point (county) to the nearest freight station and/or the port of Mombasa, were considered. Finally, total train and truck costs per km (including fuel costs, loading-unloading costs, profit margin) at current rates for given distances, and all the port charges were taken into account. Data for this analysis were retrieved from the aforementioned study, Damco, a logistic company in Kenya , Kofinaf, a coffee mill in the same country and through further literature review [27], [63]–[65], [69], [70]. Subsequently, the GHGs emissions released through the same process were estimated based on diesel, fertilizer and electricity emission factors, of the elements composing the biomass supply chain [22], [68], [71]. Thus, through the estimation of the costs and the GHGs incorporated in the supply chain of each of the examined feedstocks, the realization of the respective costs and GHGs supply curves was achieved. In fact, through these supply curves the corresponding shares of the sustainable feedstock surplus potential of the different residue types hold specific information on costs and GHGs about the biomass delivered to the port, by which the assessment on the share's suitability for export can be conducted.

In the framework of providing a sensitivity analysis for the future situation of the sustainable feedstock surplus and subsequently the respective costs and GHGs emissions induced by the deliverance of biomass (€/GJ and kg CO2eq/GJ respectively), the BAU and the Optimistic scenarios were developed. Both scenarios were developed upon the present situation. However, the BAU scenario considered a moderate development of the current situation based on existing farming practices, technological adoption, soil quality and deforestation rates, without considering additional policies in place. Thus, past trends from national and FAOstat data on production volumes and harvested areas were compared and used accordingly in order to derive annual yield increases or decreases and make projections for 2020 and 2030. With respect to timber a study by KFS was used in which projections on timber supply, based on climate change, reforestation and deforestation rates, until 2030 were performed [7]. In the Optimistic scenario given a fertile soil in the areas where the selected crops were being cultivated new policies and regulations were considered and more optimistic yields were applied, based on optimum yield levels and projected national domestic consumption rates from national reports regarding the different crops [6], [46], [48], [49]. Furthermore, considering a higher technological adoption and an increased market share harvested area was considered to increase as well. Alike to the BAU scenario regarding timber supply the study by KFS was used to carry out the projections for the Optimistic scenario. In fact, this report provided the optimum achievable yield level of forested areas under proper land management, through which the optimum timber supply level by 2020 and 2030 was estimated. Finally, both scenarios considered pre-treatment facilities for the construction of herbaceous and wood pellets with the view of reducing costs and GHGs emissions at the end of the supply chain. Thus through the different assumptions made in the two scenarios the outcomes of the different task were influenced accordingly. That is, in the BAU scenario the change in time of yield levels, affected the residue availability and hence the technical, the sustainable, the sustainable feedstock surplus potential and combined with the implementation of the pre-treatment facilities (lower transport costs and GHGs due to scaling) the net sustainable surplus potential. Similarly the Optimistic scenario considered higher yields, which together with assumptions on better farming practices (no till + double cropping), pre-treatment facilities, lower logistic and farm gate costs (reduced rail costs from 0.16 €/km to 0.02 €/km, 30 per cent fertilizer costs reduction), the different biomass potentials were affected as well [14], [27], [49], [60].

As, a result at present the different national sustainable feedstock surplus potentials were estimated to be approximately 30 PJ and 4 PJ respectively. The sensitivity analysis carried out provided the lower limits of 25 and 27 PJ and the higher ones of 55 and 87 PJ for 2020 and 2030 respectively of the total sustainable feedstock surplus potential.

The emerging question is, how much satisfying is this amount of biomass for exportation?

The findings of Batidzirai's study on South Africa maize and wheat residues potential estimated a total amount delivered to the conversion plant of Secunda ranging from approximately 100 to 200 PJ for a moderate and an optimistic case [14]. It can be seen that South Africa's residue potential only from maize and wheat residues can be up to four times higher. That would initially suggest a low biomass potential available for export in Kenya. However, it is important to assess the environmental and economic characteristics of this potential. In fact, at present in Kenya only 10 PJ may become available at about 9 €/GJ. This stems from the fact that a huge part of the sustainable feedstock surplus comes from sugarcane residues (70 per cent) and lies in the west part of Kenya, where at the moment there is no freight station available to transfer the biomass at the port of Mombasa. In the future this situation changes, as through the new freight station construction in Kisumu these amounts may become available through much lower logistic costs. In fact, in the short and the medium term through increased biomass availability and lower logistic costs predominantly owed to the pelletization process the costs are reduced. From 2020 to 2030 about 90 per cent of the sustainable feedstock surpluses indicated above can be delivered from 5 to 4 €/GJ for the BAU and the Optimistic scenarios respectively. As it is discussed in section 4.1 any sustainable feedstock surplus potential with supply costs of less than 7 €/GJ are deemed to be possibly suitable for export, implying that 90 per cent of the total sustainable feedstock surplus in 2020 and 2030 respectively is promising for export to the EU-28. That is supported also from the fact that for similar amounts of biomass in Kenya and South Africa, the first indicates similar or even lower costs compared with the latter (4-5 against 4-7 €/GJ). Accordingly, at present Kenya is not suggested as worthwhile country to import biomass due to its low potential available but also high supply costs compared with the respective biomass potential and costs 3 €/GJ (for the same amount) of the case study in South Africa but also the higher than 7 €/GJ costs (9 €/GJ).

Similarly, the GHGs emitted throughout the biomass supply chain leave a carbon footprint from 6 kg CO2eq/GJ currently to 5 kg CO2eq/GJ in 2020 and 2030 regarding more than 90 per cent of the total herbaceous and woody biomass delivered to the port of Mombasa. As discussed in section 4.2 these emission rates in each timeline indicate promising emission reduction potentials when comparing a similar study by Batidzirai, where for 9 kg CO2/GJ of solid biomass delivered until the coast of Brazil to be further transported to the Netherlands, 77 per cent emission reduction was achieved [3]. Thus, the total sustainable feedstock surplus potential is likely to be deemed suitable for export in terms of sustainability requirements.

Dedicated energy crops

At present, the biomass potential originating from energy crops was estimated based on different land use types, such as forest areas, and croplands, the respective pressure upon them and their location. In fact, Kenya faces a supply wood deficit and together with the high pressure on extra land for food crop production eliminates any potential land available for energy crops production in the high and medium potential and semi arid areas [26], [50]. Any possible marginal or degraded land available in the arid regions was also excluded due to the fact that they are located in the North part of Kenya which is remote and not connected with the port of Mombasa.

With respect to lignocellulosic biomass potential in 2020 and 2030 a separate analysis was carried out based on projections of a number important parameters related to land availability. In particular, projections on maize yield, woody biomass deficit, livestock feed needs and food demand were performed for 2020 and 2030 based on national data and KFS report [4], [7], [48].

The results for lignocellulosic feedstock production indicated that there is no potential for the time being but in a short and a medium term as well. The decreasing yield of maize combined with the increasing woody biomass deficit, the augmented food demand and livestock nutritional requirements resulted to the conclusion that there is no potential for energy crop cultivation in Kenya owing to the expected adverse competition on land. Regarding arid regions, where marginal and degraded lands lie and a possible potential of land for energy crops may exist, they were discarded due to these areas are abstain relative to the main port for export and no plans are into consideration with the view to connecting them until 2030 with the port of Mombasa or Lamu. The conclusion that Kenya is not a suitable country for energy crop cultivation is also supported by a failed attempt for biofuel production from jatropha in the Tana Delta area in Kenya in 2009, which was due not only to the aforementioned reasons, but also to the resistance from the local NGOs, personal conflicts between locals and governmental corruption [72].

Thus, through the results and process of this study important guidelines are provided for the development of a European Bio-energy Trade Strategy beyond 2020, ensuring that imported bio-resources are sustainably sourced and used in an efficient way, while avoiding distortion of other (non-energy) markets in Kenya.

Limitations-Uncertainties

In order to derive the results of this study a number of assumptions and data were used. That is, for the estimation of the technical potential RPR and LHVs were retrieved from literature and applied to the different yields of the investigated feedstocks. This process incorporates significant uncertainties due to the fact that the average values were used. Furthermore, in order to estimate the sustainable potential the average values of wheat and maize residues required for soil erosion control and soil organic carbon regarding sisal ball and rice straw were used and applied accordingly. Finally, the miscellaneous shares of domestic demand that were applied on the sustainable potentials of the examined residue types were obtained during the internship. In fact, during the interviews carried out at site concerning each feedstock a number of stakeholders indicated different shares of residue uses for households, local industries, animal feed or internal use. In some occasions, such as bagasse quantified information was not available and hence through literature review the respective ranges of the shares were derived. Thus, by taking into account the lower and the upper limit of these ranges an uncertainty of 43 per cent and 70 per cent for the lower and higher possible values respectively of the sustainable feedstock surplus potential were estimated.

A key point of the study's results is the strong dependence of the national sustainable feedstock surplus with the sugarcane residues potential. Sugarcane stalks & leaves and bagasse account for more than 50 per cent in each scenario. In particular, if an adverse negative impact occurred in the sugar sector due to a number of reasons, such as drastic climate change, sharp and steady increase in farming inputs costs and or a serious natural disaster, then the national sustainable feedstock surplus potential would be significantly reduced resulting to no promising solid biomass amounts available for export. Specifically, in the BAU scenario analysis of sugarcane residues through the past trends retrieved from national and FAOstat a decreasing annual yield was estimated, which based on a number of arguments (sub section 3.3.1) was assumed to stabilize from 2020 and onwards. If however the sugar sector doesn't manage to stabilize the decreasing yield, then the residue stream which now constitute the largest share of biomass residues possibly available for export may suddenly stop to be produced thereby posing a significant risk for any future project aiming to mobilize such residues for export. Another key issue - week point of the research is that due to lack of information on dependencies between domestic demand and parameters (e.g. primary energy needs, feed demand) it was assumed that domestic demand remains unaffected in 2020 and 2030. Thus, the actual situation in the future could be significantly altered because of different shares in domestic demand, entailing the need for further research in this aspect.

6. Conclusions-Recommendations

This MSc thesis has been developed with consideration of a joint methodology in BioTrade2020plus project to ensure consistency between other existing case studies in order to exploit the findings effectively, assess the potential of biomass originating from herbaceous, woody and lignocellulosic feedstocts that could be suitable for export to the EU. These were achieved through the implementation of certain sustainability criteria, advices and information provided by local stakeholders, project partners and external experts with the view to providing indications on the possible ranges of the result in 2020 and 2030, through the development of two scenarios, BAU and Optimistic.

Agriculture

Sugarcane, sisal, coconut, rice and coffee were found to be the most promising crops by indicating the higher amounts of field-based and/or process-based residues possibly available. The analysis of these feedstocks derived in total on a national level 80.0, 73.5 and 30 PJ of technical, sustainable and sustainable feedstock surplus potential regarding the current situation. The most adverse competing uses of the agricultural residues were found to be the internal uses. In fact, 100 per cent of sisal bogas is consumed internally for fertilizing purposes. Sugarcane stalks & leaves and bagasse are deemed the most significant sources of solid biomass considering that they account for approximately 70 per cent of the total biomass potential. This is also indicated through the determination of the biomass supply costs and GHG emissions, where currently more than 90 per cent of sugarcane residues are not available due to the lack of access to a freight station in close proximity (<300 km). In fact, only 10 PJ are feasible to be delivered and 80 per cent of this amount are set at 7 €/GJ and 6 kg CO2eq/GJ respectively. However, in the short and the medium term a number of parameters were taken into account, which significantly affect the total potentials at present condition. Through the opening of the Kisumu freight station by 2020, the entire sugarcane residues volumes will become available. As a result, the final biomass supplied to the main port of Mombasa for export in 2020 and 2030 may increase from 10 PJ at present to 25 PJ and 27 PJ respectively, under a BAU scenario and delivered at 4 €/GJ and 5 kg CO2eq/GJ for about 80 per cent of the total sustainable feedstock surplus. The additional parameters causing this change are the increased annual yields and the assumed pre-treatment facilities through which bulk and energy densities of the investigated feedstocks are also increased, resulting to lower logistic costs and GHGs emissions released throughout the biomass supply chain. The sugarcane residues have substantial impact to the final result due to the fact that annual yield rates were assumed to remain constant from 2020 until 2030 no difference in costs and GHG emissions occurred. Accordingly, through more positive vigorous changes on the same parameters (yields) plus assumed annual harvested areas ito be expanded, reduced logistic and fertilizer costs in an optimal case the total net biomass available at the main port may increase from the 10 PJ to 55 and 87 PJ in 2020 and 2030 correspondingly and 80 per cent of these amounts delivered at 5 and 4 €/GJ and 5 and 4 kg CO2eq/GJ for the same timelines. The same amounts of solid biomass with those in the BAU scenario can be delivered with lower costs and GHG emissions. Thus, the shares of sustainable feedstock surpluses holding these costs and GHG emissions are deemed to be likely available for export to the EU when comparing with alternative competing fuels (biodiesel and petro-diesel) in terms of costs and emission reduction rates.

Forestry

Timber was recognized as the most promising product in terms of residue potential among poles, firewood and charcoal. Sawdust, off-cuts & chips were investigated. Although off-cuts & chips indicate about 88 per cent of the total technical potential, owing to the intensive and multiple domestic demand applications, such as fencing and firewood, the sustainable feedstock surplus potential is solely formed by sawdust. Currently, a total technical potential of 24 PJ through the different competing uses results to about 4 PJ sustainable feedstock surplus. This solid biomass is delivered from multiple sourcing points through all over the country and about 80 per cent of this amount was estimated to be supplied at the main port of Mombasa at 10 €/GJ and 8 kg CO2eq/GJ. These high values are attributed to the low residues volumes in certain counties, which resulted to more intensive use of transport modes (trucks, trains). However, alike to the agricultural sector different parameters were considered, through which the net sustainable surplus potential of sawdust increased. That is, the BAU and the Optimistic scenarios considered annual timber supply increases through which more sawdust became available. Furthermore, the pre-treatment facilities assumed in the herbaceous case were also considered applicable for sawdust. All these parameters influenced the total net sustainable surplus potential through the reduced logistic costs and GHGs emissions. Specifically, the sustainable feedstock surplus will be increased from 4.0 to 4.8 and 5.4 PJ in 2020 and 2030, respectively. Under the BAU scenario it is assumed that there will be moderate changes, such as from 4.0 to 5.1 and 6.4 PJ in a short and a medium term and under the Optimistic scenario there will be more vigorous changes in the timber annual increase supply. These changes in the different sustainable feedstock surpluses will cause also changes in the respective costs and GHGs incurring throughout the biomass supply chain of sawdust. As a result, about 80 per cent of the total sustainable feedstock surplus in the BAU scenario can be delivered at 5 €/GJ and 5 kg CO2eq/GJ in 2020 and 2030, whereas in an optimal case can be delivered at 4 €/GJ and 5 kg CO2eq/GJ in 2020 , and 4 €/GJ and 4 kg CO2eq/GJ in 2030. In conclusion, the costs and GHG emissions estimated for the present situation are not considered likely suitable for export due to their high costs (10 €/GJ) compared to the acceptable cost level (less than 7 €/GJ) against the alternative fuel uses. In contrast, the costs in conjunction with the GHG emission levels estimated for 2020 and 2030 regarding both the BAU and the Optimistic scenarios indicate promising potential shares of the respective sustainable feedstock surplus.

Dedicated energy crops

Through the analysis carried out on assessing land availability for lignocellulosic biomass production, no land available was found. The high pressure on land use indicated by the high woody biomass deficit (10.3 million m^3) and the high demand by livestock and agricultural activities. Furthermore, in the arid regions where possible potential areas (marginal and degraded) could be utilized for biofuel production are not accessible due to the absence of rail lines connecting these areas with the main port of Mombasa. However, based on a number of determinant parameters on land availability in Kenya, a future situation was assessed. In fact, maize yield rate, food demand, livestock nutritional needs and the woody biomass deficit were estimated for 2020 and 2030. The decreased yield of maize (58 per cent) in 2020 and 2030, in conjunction with the increased food demand (32, 75 per cent), the increased livestock nutritional needs (50, 150 per cent) and the increased woody biomass deficit (10, 24 per cent) for the same years implied no potential for energy crops cultivation. Regarding the arid regions no plans exist , where these areas might be accessed by rail and even with the development of Lamu port by 2020 the potential for biofuel production and export to the EU in 2020 and 2030 is deemed to be very limited.

Recommendations

With regard to task 2.1.1 carried out during the internship in Kenya, due to the fact that there was no quantified information on the respective production systems of livestock, only the agricultural residues were considered as a feed. This means biomass potential originating from the aforementioned feed-stocks, when taking into account only livestock is certainly higher as there are also other production systems (semi-intensive and extensive) in which agricultural residues are not consumed, or are partly consumed. Furthermore, there is a slight additional potential coming from the rest of the products which were discarded owing to their low production volumes and other criteria described in this task. Therefore, taking also into account that maize accounts for more than 40 per cent of the total food crops productions with an average yield of 1.7 t/ha and that was one of the agricultural products which was excluded in the feedstock selection process more information on maize are needed. In fact, the current average yield of maize is deemed to be very low when also considering other average yields of maize, such as the 4.3 t/ha in South Africa and 9.2 in the US [14]. In general the low yield levels in Sub-Saharan Africa are caused predominantly by lack of water, soil loss, and land degradation. Thus, through proper farming practices this current average yield could increase. This is also supported by a case study in Western Kenya, where recommended fertilizers were used and maize yield increased more than threefold [73]. Such an improvement in current maize yield would result to a serious increase in residues generation. Thus, it is highly recommended for a similar study to be conducted and focus on the opportunities for maize yields improvements and what the possible suitable residues potentials from maize harvesting and processing are until 2030. This study should emphasize in any prospective strategies, policies and regulations oriented on the maize sub sector and through them identify the possibilities for yield increases in the future. Furthermore, a detailed analysis on domestic demand of maize residues should be conducted through which the different domestic demand shares can be assessed in the future.

The findings of this research showed a strong dependence between the total sustainable feedstock surplus and the sugarcane sub sector, which accounted for 70 per cent of the current total sustainable feedstock surplus. In the analysis of the future situation of the sugarcane sub sector, the projections for the BAU scenario considered the decreasing annual yield at current pace to stabilize from 2020 until 2030. If that won't be the case and the decreasing yield is not stabilized or increased (as assumed in the Optimistic scenario) then the biomass potential suitable for export may be reduced dramatically resulting to high risk investments. Thus, a supplementary study is recommended in which the entire sugarcane sub sector in Kenya will be investigated through detailed assessment of the different factors (retail prices per company, farming practices per county, technological adoption per county, farming costs and inputs per county, soil quality per county, additional policies, regulations and national strategies related to the sugar sector development) affecting its performance. Furthermore, due to the fact that this study doesn't elaborate domestic demand for 2020 and 2030, more credible insights on a future situation are needed. In conclusion, this supplementary study should also focus on identifying the interrelations between the different parameters (primary energy needs, food demand, poverty levels ect.) affecting the different shares, as provided in this research, of domestic demand.

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Acknowledgments

I feel the need to thank all the people who have helped through the process of writing this report. Therefore, I would like to express my gratitude to Dr. H.M. Junginger and Ms. T. Mai-Moulin, my two supervisors from the University of Utrecht, who provided me with their guidance. Furthermore, Bothwell Batidzirai is a person who I would also like to express my gratitude due to his eagerness to readily share his insights and data with me whenever deemed necessary. Furthermore, most of the crucial data used as input in this study were collected throughout my internship in Kenya. I therefore feel grateful to the Ministries of Livestock, Agriculture and Transport, the Kenya Forest Research Institute, the Kenya Forest Service, the Kenya Sugar, Coffee & Sisal Boards, the Kenya Coconut Development Authority, the International Livestock Research Institute, Chardust LTD, DAMCO, the National Irrigation Board, Kofinaf, Real Vipingo, Kilifi plantations, Biashara, Mumias and the Kenya Forest Service Conservancy in Nakuru for providing me with their insights and data. Last but not least I would like to express my unreserved gratitude to my parents, Maria Konstanti and Mathew Dardamanis, who have stood next to me in all of my life.

8. Appendices

8.1. Feedstock and case studied areas selection

Products	RPR		LHV(MJ/kg)	
	Field	Process	Field	Process
Bananas	1.90		16.00	
Beans	1.10		16.00	
Cassava	0.58		17.50	
Coconut	0.60	1.00	17.40	18.62
Coffee		2.10		12.69
Irish potatoes	0.36		17.50	
Maize	2.70	1.60	12.46	15.46
Mangoes	2.00		16.61	
Pigeon & Cow peas[23]	1.10		15.00	
Rice	2.20	0.28	13.45	16.01
Sisal	4.70	24.00	15.00	15.00
Sorghum	4.20		12.38	
Sugarcane	0.20	0.22	16.60	12.93
Sweet Potatoes	0.36		17.50	
Wheat	1.50		17.00	

Table 8-1: Biomass properties for the different residue types generated by the 15 most promising agricultural products [13], [35]–[37], [74]–[79].

The respective technical potentials of the residues derive through the miscellaneous RPR and LHVs shown in this table. However, these figures serve solely the purposes of the internship in Kenya and are only considered in the first section of this study.

Agricultural products	Technical potential of residues in mass and energy					
	Field thousand t	Process thousand t	Total thousand t	Field PJ	Process PJ	Total PJ
Maize	10,037	6,026	16,063	125	93	218
Mangoes	5,562	0	5,564	89	0	89
Bananas	2,649	0	2,649	42	0	42
Sugarcane	1,165	1,252	2,416	19	16	35
Irish potatoes	1,050	0	1,050	18	0	18
Beans	1,123	0	1,122	18	0	18
Coffee	0	1,029	1,029	0	13	13

[23] The residues produced by pigeon and cowpeas were considered to have the same properties and as a result, they were taken into account as the same product.

Sisal	131	669	800	2	10	12
Wheat	654	0	654	11	0	11
Cassava	518	0	518	9	0	9
Sorghum	692	0	692	8	0	8
Pigeon & cow peas	380	0	380	6	0	6
Sweet potatoes	310	0	310	5	0	5
Rice	277	35	312	4	0.	4
Coconut(shell&husk)	72	121	193	1	2	3
Total	24,619	9,132	33,750	359	135	494

Table 8-2: Breakdown of the total technical potential in Kenya stemming from the 15 most prominent agricultural products in terms of residue potential.

In order to acquire the total amount of residues generated per product in tones, the technical potential was estimated by multiplying the production volume of each product with the respective sum of the RPR coefficients for field and process residues. Then, in order to obtain the energy potential of the residues, the previous result was multiplied with the respective sum of the LHVs for field and process residues of the same product.

Counties	Cattle in thousand	Sheep in thousand	Goats in thousand	Pigs in thousand	Poultry in thousand	Total population in thousand
Bungoma	342	873	88	29	2,167	3,498
Busia	167	68	108	49	634	1,027
Homabay	659	361	376	35	2,051	3,482
Kakamega	152	70	345	9	642	1,218
Kiambu	315	124	119	40	2,498	3,096
Kilifi	331	43	306	2	1,500	2,182
Kirinyaga	107	15	64	10	649	845
Kisii	271	33	90	1	1,265	1,660
Kwale	236	82	294	0.	447	1,060
Machakos	225	102	287	5	1,252	1,871
Makueni	318	118	629	1	678	1,744
Meru	359	207	317	19	1,032	1,935
Migori	267	121	148	7	1,748	2,292
Murang'a	275	46	150	33	799	1,303
Nakuru	316	266	193	11	1,122	1,908
Nandi	303	121	36	0.	609	1,070

Narok	1,228	1,134	752	0.	671	3,786
Nyamira	99	16	37	0.	557	709
Nyandarua	344	320	86	2	396	1,148
Siaya	316	133	245	13	862	1,569
Tharaka	84	44	130	11	505	775
Trans Nzoia	186	77	27	5	740	1,034
Uasin Gishu	409	162	80	12	615	1,278
Total population	7,309	4,538	4,909	251	19,092	30,188

Table 8-3: Livestock population distribution per county and livestock unit for the year 2013[24].

Agricultural residues	Metabolizable energy GJ/tn
Maize Cobs	8.8
Maize Stover	7.4
Banana leaves	9.7
Wheat straw	42.0% (TDN)[25]
Soyabean stover	8.5
Cassava straw	50.0% (TDN)
Irish potatoes leaves	14.0% (TDN)
Mangoes leaves	9.7

Table 8-4: Nutritional value of the agricultural residue types shown in the table [80].

Type	Livestock units	GJ/year Metabolizable energy
350-400 kg	Cattle	15.1
60kg ewe	Sheep	2.1
50kg	Goat	1.3
70kg	Pigs	13.1
1,18kg	Poultry	0.5

Table 8-5: Nutritional energy needs for the 5 most common livestock units in Kenya [81]–[86].

To describe energy fractions in the animal system, it was essential to include abbreviations. Specifically, Gross energy (E) or heat of combustion can be defined as the energy released as heat after an organic substance has been fully oxidized to carbon dioxide and water. E which is correlated to chemical composition does not provide any information regarding availability of that energy to the animal. Therefore, E is a negligible factor in evaluating a particular diet or dietary ingredient as an energy source for the animal. E of the food, subtracting the energy lost in

[24] Source: Mrs. Judy Gachora, production officer of the Ministry of livestock.

[25] The percentages represent the share of the total digestible nutrient content of the respective residue types.

the feces, is defined as digestible energy (DE). DE is significant in this research for feed evaluation as it illustrates diet digestibility and can be gauged with relative ease. However, DE fails to identify significant losses of energy related to digestion and food metabolism. Consequently, DE overvalues high-fiber feedstuffs ,namely hays or straws relative to low-fiber, highly digestible feedstuffs such as grains [81].

Metabolism energy (ME) is termed as E minus fecal energy (FE), urinary energy (UE), and gaseous energy (GE) losses, or ME=DE-(UE+GE). ME is an estimation of the energy available to the animal and signifies the process to evaluate food energy values and animal requirements. For most forages and mixtures of forages and cereal grains, the ratio of ME to DE is about 0.8 but can be subject to considerable variation on intake, age of animal, and feed source [81].

Therefore, the energy requirements of the livestock units above are based on metabolism energy as found through literature review.

Counties	Technical potential PJ	Nutritional value PJ
Bungoma	17.8	9.7
Busia	1.8	0.4
Homabay	6.1	3.5
Kakamega	12.2	7.7
Kiambu	0.6	0.2
Kilifi	13.4	8.1
Kirinyaga	5.9	3.4
Kisii	9.8	5.4
Kwale	11.6	7.0
Machakos	20.9	11.9
Makueni	19.5	11.6
Meru	14.3	7.0
Migori	11.8	6.0
Murang'a	4.7	2.6
Nakuru	24.1	11.2
Nandi	14.3	8.2
Narok	16.4	7.6
Nyamira	7.6	4.1
Nyandarua	5.3	0.4
Siaya	0.8	0.3
Tharaka-Nithi	5.0	3.0
Trans Nzoia	25.6	14.9
Uasin Gishu	14.9	8.7
Total	264.2	142.9

Table 8-6: Distribution at a county level of the technical potential and nutritional value originating from maize, mangoes, bananas, irish potatoes, beans, wheat and cassava residues.

Counties	Livestock energy requirements PJ				
	Cattle	Sheep	Goats	Pigs	Poultry
Bungoma	5.17	1.84	0.11	0.38	1.05
Busia	2.53	0.14	0.14	0.65	0.31
Homabay	9.97	0.76	0.49	0.46	0.99
Kakamega	2.30	0.15	0.45	0.12	0.31
Kiambu	4.77	0.26	0.15	0.53	1.21
Kilifi	5.01	0.09	0.40	0.03	0.73
Kirinyaga	1.62	0.03	0.08	0.12	0.31
Kisii	4.09	0.07	0.12	0.01	0.61
Kwale	3.57	0.17	0.38	0.00	0.22
Machakos	3.40	0.22	0.37	0.06	0.61
Makueni	4.81	0.25	0.82	0.02	0.33
Meru	5.43	0.44	0.41	0.24	0.50
Migori	4.04	0.26	0.19	0.09	0.85
Murang'a	4.16	0.10	0.20	0.43	0.39
Nakuru	4.78	0.56	0.25	0.15	0.54
Nandi	4.59	0.26	0.05	0.00	0.29
Narok	18.6	2.40	0.98	0.00	0.32
Nyamira	1.50	0.03	0.05	0.00	0.27
Nyandarua	5.20	0.68	0.11	0.03	0.19
Siaya	4.78	0.28	0.32	0.17	0.42
Tharaka-Nithi	1.27	0.09	0.17	0.15	0.24
Trans Nzoia	2.81	0.16	0.04	0.06	0.36
Uasin Gishu	6.19	0.34	0.10	0.16	0.30
Total	110.59	9.59	6.39	3.87	11.35

Table 8-7: Nutritional energy needs distribution of the five most common livestock units in Kenya at a county level.

Counties	Residue availability PJ
Bungoma	2.1
Busia	-13.8
Homabay	-15.7
Kakamega	6.9
Kiambu	-22.0
Kilifi	3.0
Kirinyaga	2.1
Kisii	1.0

Kwale	4.4
Machakos	12.7
Makueni	9.0
Meru	-0.1
Migori	1.2
Murang'a	-5.0
Nakuru	10.6
Nandi	5.2
Narok	-31.9
Nyamira	4.2
Nyandarua	-86.3
Siaya	-17.3
Tharaka-Nithi	1.8
Trans Nzoia	19.7
Uasin Gishu	2.8
Total	-105.4

Table 8-8: Indication of the residue availability emanating from maize, mangoes, bananas, irish potatoes, beans, wheat and cassava, when taking into account the demand for animal feed.

In order to create this table, the nutritional value of each of the above counties had to be evaluated. That could be feasible by taking into account the technical potential of the corresponding counties. Thus, through the production distribution volumes for each products as provided by the Ministry of Agriculture, and additionally by applying the corresponding biomass properties of Table 8-1, the technical potential on a county level, as presented in Table 8-6,was examined [9]. Then, the respective values from Table 8-4 were used in order to pinpoint the nutritional potentials. Consecutively, by considering the livestock population distribution as provided in Table 8-3 and the corresponding energy requirements per unit (Table 8-5), the total livestock energy needs per county for 2013 was calculated(Table 8-7).

Thus, data on the solid biomass available related to the seven agricultural products investigated (Table 8-9) were calculated as follows.

$RA_i = (NV_i - L_i) * TP_i / NV_i$

Where,

i	Represents a specific county;
RA	The amount of residues disposable when considering forage demand;
NV	The amount of nutritional value;
TP	The technical potential;

The livestock nutritional requirements.

8.2. Spatial distribution of herbaceous and woody biomass

The detailed data at a county level used to draw aggregated results concerning the different biomass potentials, are discussed. These are the Kenyan counties facing similar climatic conditions with specific South African provinces, the production volumes, harvested areas, yields and residues potentials of the miscellaneous feedstocks investigated.

Counties/ South Africa Kenya	KwaZulu	Free State	Gauteng	Mpumalanga	Eastern Cape	Limpopo	North west
Baringo	×						
Bungoma	×						
Busia	×						
Elgeyo	×						
Embu	×						
Garissa						×	
Homa Bay						×	
Kakamega	×						
Kericho	×						
Kiambu	×						
Kilifi			×				
Kirinyaga	×						
Kisumu	×						
Kwale					×		
Lamu					×		
Makueni							×
Meru	×						
Mingori					×		
Mombasa					×		
Muranga	×						
Nakuru	×						
Narok		×					
Nyeri	×						
Siaya	×						
Taita Taveta				×			
Tana River							×
Tharaka						×	

Table 8-9: Matching of Kenyan and South African counties sharing similar annual average rainfalls, temperatures and soil clay contents[26] [54], [87], [88].

South Africa	Maize t/ha		Wheat t/ha	
Provinces	Conventional tillage	No till+double cropping	Conventional tillage	No till+double cropping
Nothern Cape	5.8	3.9	6.7	4.5

[26] Additional sources are the national counties reports under Kenya vision 2030 (only hardcopies available).

Western Cape	4.6	3.1	5.4	3.6
Eastern Cape	4.2	3.0	4.8	3.4
KwaZulu-Natal	4.7	3.2	7.0	4.7
Free State	4.4	3.1	5.1	3.6
North West	5.8	4.1	6.7	4.7
Gauteng	4.4	3.1	5.0	3.5
Mpumalanga	4.1	2.8	4.6	3.1
Limpopo	5.3	3.7	6.0	4.2

Table 8-10: Maize and wheat residues required to maintain 2% SOC in the highlighted provinces of South Africa, as determined by the Rothamsted Carbon model under two different farming practices.

Year 2013	Production volume	Harvested area	Average yield	Residue yield	Residue yield
Coconut husk	thousand*t	thousand*ha	t/ha	t/ha	GJ/ha
Counties					
Kwale	175.7	92.1	1.9	2.1	37.0
Kilifi	155.9	60.7	2.6	2.8	49.9
Lamu	22.7	9.8	2.3	2.5	44.8
Mombasa	7.5	6.2	1.2	1.3	23.7
Tana River	3.0	4.8	0.6	0.7	12.4
Taita Taveta	3.9	3.2	1.2	1.4	24.0
Total	368.7	176.7	2.1	2.3	40.5

Table 8-11: Breakdown at a county level of basic data needed to derive the sustainable feedstock surplus of coconut husks [89].

Year 2012	Production volume	Harvested area	Average yield	Residue yield	Residue yield
Sisal ball	thousand*t	thousand*ha	t/ha	t/ha	GJ/ha
Companies (Counties)					
Alphega (Nakuru)	1.7	2.6	0.7	2.7	40.1
Banita group (Nakuru)	1.9	12.2	0.2	0.6	9.3
DWA (Makueni)	7.0	3.9	1.8	7.4	109.9
Kilifi Plantation Ltd (Kilifi)	0.4	0.4	1.0	4.2	62.1
Real Vipingo (Kilifi)	4.9	3.8	1.3	5.3	79.4
Taru (Kwale)	0.9	5.3	0.2	0.7	10.7
Teita (Taita Taveta)	9.3	9.6	1.0	3.9	58.4
Voi (Taita Taveta)	0.6	1.8	0.3	1.3	19.7
Total	26.7	39.6	0.7	2.8	41.0

Table 8-12: Breakdown at a county level of basic data needed to derive the sustainable feedstock surplus of sisal ball[27].

Year 2012	Production volume	Harvested area	Average yield	Residue yield	Residue yield
Sisal bogas	thousand*t	thousand*ha	t/ha	t/ha	GJ/ha
Companies (Counties)					
Alphega (Nakuru)	1.7	2.6	0.7	13.0	193.8
Banita group (Nakuru)	1.9	12.2	0.2	3.0	44.8
DWA (Makueni)	7.0	3.9	1.8	35.7	530.8
Kilifi Plantation Ltd.(Kilifi)	0.4	0.4	1.0	20.2	299.8
Real Vipingo (Kilifi)	4.9	3.8	1.3	25.8	383.4
Taru (Kwale)	0.9	5.3	0.2	3.5	51.6
Teita (Taita Taveta)	9.3	9.6	1.0	19.0	282.1
Voi (Taita Taveta)	0.6	1.8	0.3	6.4	95.2
Total	26.7	39.6	0.7	13.3	198.1

Table 8-13: Breakdown at a county level of basic data needed to derive the sustainable feedstock surplus of sisal bogas.

Year 2013	Production volume	Harvested area	Average yield	Residue yield	Residue yield
Sugarcane molasses	million*t	thousand*ha	t/ha	t/ha	GJ/ha
Companies (Counties)					
Butali (Kakamega)	0.4	6.7	62.6	2.2	18.6
Chemelil (Kisumu)	0.2	5.1	49.7	1.7	14.8
Muhoroni (Kisumu)	0.3	5.5	59.9	2.1	17.8
Mumias (Kakamega)	1,8	36.0	50.7	1.8	15.1
Nzoia (Bungoma)	0.8	13.1	56.6	2.0	16.8
Soin (Kericho)	0.	0.8	64.7	2.3	19.3
South nyanza (Migori)	0.7	7.8	86.8	3.0	25.8
Sukari (Kakamega)	0.4	4.4	78.2	2.7	23.3
Transmara (Narok)	0.4	4.5	89.4	3.1	26.6
West kenya (Kakamega)	1.0	24.9	41.1	1.4	12.2
Total	6.7	110.7	60.3	2.1	17.9

Table 8-14: Breakdown at a county level of basic data needed to derive the sustainable feedstock surplus of sugarcane molasses [34].

Year 2013	Production volume	Harvested area	Average yield	Residue yield	Residue yield
Sugarcane stalks & leaves	million*t	thousand*ha	t/ha	t/ha	GJ/ha

[27] Source: Data sets of sisal board in Kenya.

Companies (Counties)					
Butali (Kakamega)	0.4	6.7	62.6	13.5	224.7
Chemelil (Kisumu)	0.2	5.1	49.7	10.7	178.6
Muhoroni (Kisumu)	0.3	5.5	59.9	12.9	214.3
Mumias (Kakamega)	1,8	36.0	50.7	10.9	181.0
Nzoia (Bungoma)	0.8	13.1	56.6	12.2	202.0
Soin (Kericho)	0.	0.8	64.7	13.9	231.3
South nyanza (Migori)	0.7	7.8	86.8	18.7	310.1
Sukari (Kakamega)	0.4	4.4	78.2	16.8	279.4
Transmara (Narok)	0.4	4.5	89.4	19.2	319.2
West kenya (Kakamega)	1.0	24.9	41.1	8.8	147.8
Total	6.7	110.7	60.3	12.9	215.2

Table 8-15: Breakdown at a county level of basic data needed to derive the sustainable feedstock surplus of sugarcane stalks & leaves.

Year 2013	Production volume	Harvested area	Average yield	Residue yield	Residue yield
Sugarcane bagasse	million*t	thousand*ha	t/ha	t/ha	GJ/ha
Companies (Counties)					
Butali (Kakamega)	0.4	6.7	62.6	23.8	307.6
Chemelil (Kisumu)	0.2	5.1	49.7	18.9	244.2
Muhoroni (Kisumu)	0.3	5.5	59.9	22.7	294.0
Mumias (Kakamega)	1,8	36.0	50.7	19.2	248.8
Nzoia (Bungoma)	0.8	13.1	56.6	21.5	278.0
Soin (Kericho)	0.	0.8	64.7	24.6	317.9
South nyanza (Migori)	0.7	7.8	86.8	33.0	426.3
Sukari (Kakamega)	0.4	4.4	78.2	29.7	384.2
Transmara (Narok)	0.4	4.5	89.4	34.0	439.0
West kenya (Kakamega)	1.0	24.9	41.1	15.6	201.8
Total	6.7	110.7	60.3	*22.9*	*296.0*

Table 8-16: Breakdown at a county level of basic data needed to derive the sustainable feedstock surplus of sugarcane bagasse.

Year 2012	Production volume	Harvested area	Average yield	Residue yield	Residue yield
Rice straw	thousand*t	thousand*ha	t/ha	t/ha	GJ/ha
Counties					
Murang'a	0.6	0.3	1.9	4.2	57.1
Kirinyaga	80.0	13.6	5.9	12.9	173.8
Kilifi	0.4	0.5	0.7	1.6	21.9

Kwale	5.3	1.4	3.6	7.9	106.0
Lamu	0.2	0.7	0.3	0.7	10.1
Mombasa	0.	0.	3.0	6.6	88.4
Taita Taveta	0.9	1.2	0.8	1.7	22.6
Tana River	8.0	1.7	4.9	10.7	144.3
Embu	0.2	0.	3.6	7.9	106.0
Tigania	0.2	0.	2.9	6.4	86.0
Meru	0.2	0.	3.2	7.0	94.3
Tharaka Nthi	0.	0.	3.3	7.2	97.2
Garissa	0.3	0.	3.6	7.9	106.0
Homabay	1.3	0.3	4.2	9.2	123.7
Kisumu	14.6	3.3	4.3	9.4	126.7
Migori	0.8	0.2	3.6	7.9	106.0
Siaya	9.9	2.3	4.3	9.4	126.7
Elgeyo	2.7	0.8	3.4	7.4	100.1
Baringo	2.9	0.8	3.6	7.9	106.0
Bungoma	0.	0.	2.7	5.9	79.5
Busia	5.9	2.6	2.3	5.0	67.7
Kakamega	0.	0.2	0.2	0.4	5.7
Total	134.8	30.3	4.5	9.7	131.1

Table 8-17: Breakdown of basic data at a county level needed to define the sustainable feedstock surplus of rice straw [9].

Year 2012	Production volume	Harvested area	Average yield	Residue yield	Residue yield
Rice husk	thousand*t	thousand*ha	t/ha	t/ha	GJ/ha
Counties					
Murang'a	0.6	0.3	1.9	0.6	8.9
Kirinyaga	80.0	13.6	5.9	1.7	27.2
Kilifi	0.4	0.5	0.7	0.2	3.4
Kwale	5.3	1.4	3.6	1.0	16.6
Lamu	0.2	0.7	0.3	0.1	1.6
Mombasa	0.	0.	3.0	0.9	13.8
Taita Taveta	0.9	1.2	0.8	0.2	3.5
Tana River	8.0	1.7	4.9	1.4	22.6
Embu	0.2	0.	3.6	1.0	16.6
Tigania	0.2	0.	2.9	0.8	13.4
Meru	0.2	0.	3.2	0.9	14.7
Tharaka Nthi	0.	0.	3.3	0.9	15.2
Garissa	0.3	0.	3.6	1.0	16.6
Homabay	1.3	0.3	4.2	1.2	19.3

Kisumu	14.6	3.3	4.3	1.2	19.8
Migori	0.8	0.2	3.6	1.0	16.6
Siaya	9.9	2.3	4.3	1.2	19.8
Elgeyo	2.7	0.8	3.4	1.0	15.7
Baringo	2.9	0.8	3.6	1.0	16.6
Bungoma	0.	0.	2.7	0.8	12.4
Busia	5.9	2.6	2.3	0.7	10.6
Kakamega	0.	0.2	0.2	0.1	0.9
Total	134.8	30.3	4.5	1.3	20.5

Table 8-18: Breakdown at a county level of basic data needed to derive the sustainable feedstock surplus of rice husk [9].

In order to estimate the technical potential of the previously mentioned feedstocks from Table 8-11 to Table 8-18 at a county level, the corresponding areas need to be multiplied with the suitable figures of the last column. Subsequently, regarding the field residues, by subtracting the respective requirements for soil erosion control or 2 per cent SOC from the technical potential, the sustainable potential derives. The calculations are carried out based on the residue requirements shown in Table 8-10 for the proper counties depicted in Table 8-9. Thus, through the different shares of domestic demand, animal feed and internal use, insight into the sustainable feedstock surplus is acquired.

Year 2013	Production	Planted area	Residue production	Residue production
Coffee husk[28] Counties	thousand*t	thousand*ha	thousand*t	PJ
Kiambu	14.70	N/A	3.50	0.05
Nyeri	6.52	N/A	1.50	0.02
Kirinyaga	6.23	N/A	1.50	0.02
Muranga	3.17	N/A	0.75	0.01
Embu	2.85	N/A	0.68	0.01
Bungoma	2.53	N/A	0.60	0.01
Meru	2.46	N/A	0.58	0.01
Kericho	2.26	N/A	0.53	0.01
Machakos	2.06	N/A	0.49	0.01
Kisii	1.57	N/A	0.37	0.01
Total	49.48	N/A	11.78	0.17

Table 8-19: Breakdown at a county level of basic data needed to derive the sustainable feedstock surplus of coffee husk[29].

Year 2013	Production	Planted area	Residue production	Residue production
Coffee pulp	thousand*t	thousand*ha	thousand*t	TJ

[28] A number of counties are neglected due to their insignificant potential (in total an additional 0.01 PJ). The same counties are also neglected for coffee pulp.
[29] Source: Data sets of Coffee board.

Counties				
Kiambu	14.70	N/A	35.56	0.43
Nyeri	6.52	N/A	15.78	0.19
Kirinyaga	6.23	N/A	15.08	0.18
Muranga	3.17	N/A	7.68	0.09
Embu	2.85	N/A	6.91	0.08
Bungoma	2.53	N/A	6.14	0.07
Meru	2.46	N/A	5.95	0.07
Kericho	2.26	N/A	5.47	0.07
Machakos	2.06	N/A	4.98	0.06
Kisii	1.57	N/A	3.81	0.05
Total	49.48	N/A	11.78	1.40

Table 8-20: Breakdown at a county level of basic data needed to derive the sustainable feedstock surplus of coffee pulp.

Tables 8-19 and 8-20 show the residue potential of coffee husk and pulp, respectively. However, owing to lack of data regarding the harvested area of coffee, no yields could be identified. The last column of these two tables illustrates the technical potential for each county. When taking into account the different shares of domestic demand, animal feed and internal use, conclusions about the sustainable feedstock surplus can be reached.

Year 2013	Production	Residue production	Residue production
Sawdust (firewood surplus)	thousand*t	thousand*t	PJ
Counties			
Elgeyo	183.8	15.6	0.2
Kericho	187.8	15.9	0.3
Laikipia	76.8	6.5	0.1
Lamu	62.5	5.3	0.1
Nandi	127.9	10.9	0.2
Narok	394.1	33.5	0.5
Nyandaraua	156.3	13.3	0.2
Nyeri	189.2	16.1	0.3
Tana River	53.8	4.6	0.1
Tharaka	53.6	4.6	0.1
Uasin Gishu	163.0	13.8	0.2
West Pokot	164.3	13.9	0.2
Total	1,813.0	154.0	2.5

Table 8-21: Breakdown at a county level of data needed to define the sustainable feedstock surplus of sawdust. The depicted counties represent those with a firewood surplus potential [7].

Year 2013	Production	Residue production	Residue production
Sawdust (firewood deficit)	thousand*t	thousand*t	PJ
Counties			
Bomet	77.2	6.6	0.1
Bungoma	108.3	9.2	0.1
Busia	50.2	4.3	0.1
Embu	57.3	4.9	0.1
Homa Bay	102.4	8.7	0.1
Kajiado	86.9	7.4	0.1
Kakamega	143.4	12.2	0.2
Kiambu	138.5	11.8	0.2
Kilifi	110.5	9.4	0.1
Kirinjyaga	51.7	4.4	0.1
Kisii	45.1	3.8	0.1
Kisumu	58.6	5.0	0.1
Kitui	90.2	7.7	0.1
Kwale	66.4	5.6	0.1
Machakos	47.2	4.0	0.1
Makueni	91.0	7.7	0.1
Meru	199.0	16.9	0.3
Migori	76.8	6.5	0.1
Mombasa	5.6	0.5	0.0
Murang'a	90.1	3.8	0.1
Nairobi	29.9	2.5	0.0
Nakuru	258.3	21.9	0.3
Nyamira	41.1	3.5	0.1
Siaya	70.7	6.0	0.1
Taita Taveta	17.8	1.5	0.0
Trans-Nzoia	117.7	10.0	0.2
Vihiga	22.3	1.9	0.0
Total	2,254.0	187.6	3.0

Table 8-22: Breakdown at a county level of data needed to define the sustainable feedstock surplus of sawdust. The depicted counties represent those with a firewood surplus deficit [7].

Year 2013	Production	Residue production	Residue production
Off-cuts & chips	thousand*t	thousand*t	PJ
Counties			
Elgeyo	183.8	46.0	0.9

Kericho	187.8	47.0	0.9
Laikipia	76.8	19.2	0.4
Nandi	127.9	32.0	0.6
Narok	394.1	98.7	1.9
Nyandaraua	156.3	39.1	0.7
Nyeri	189.2	47.4	0.9
Tharaka	53.6	13.4	0.3
Uasin Gishu	163.0	40.8	0.8
West Pokot	164.3	41.1	0.8
Bomet	77.2	19.3	0.4
Bungoma	108.3	27.1	0.5
Busia	50.2	12.6	0.2
Embu	57.3	14.4	0.3
Homa Bay	102.4	25.6	0.5
Kajiado	86.9	21.8	0.4
Kakamega	143.4	35.9	0.7
Kiambu	138.5	34.7	0.7
Kilifi	110.5	27.7	0.5
Kirinjyaga	51.7	12.9	0.2
Kisii	45.1	11.3	0.2
Kisumu	58.6	14.7	0.3
Kitui	90.2	22.6	0.4
Kwale	66.4	16.6	0.3
Machakos	47.2	11.8	0.2
Makueni	91.0	22.8	0.4
Meru	199.0	49.8	1.0
Migori	76.8	19.2	0.4
Mombasa	5.6	1.4	0.0
Murang'a	90.1	22.6	0.4
Nairobi	29.9	7.5	0.1
Nakuru	258.3	64.7	1.2
Nyamira	41.1	10.3	0.2
Siaya	70.7	17.7	0.3
Taita Taveta	17.8	4.4	0.1
Trans-Nzoia	117.7	29.5	0.6
Vihiga	22.3	5.6	0.1
Total	3,950.9	989.4	18.9

Table 8-23: Breakdown at a county level of data needed to derive the sustainable feedstock surplus of off-cuts & chips [7].

The overall results reflecting the solid woody biomass potential available for a further supply cost and GHG emissions analysis are shown in Tables 8-21, 8-22, 8-23. The last columns of these tables represent the respective technical potential of sawdust and off-cuts & chips. Thus, by applying the different shares of domestic demand to the respective corresponding residue potential, the sustainable feedstock surplus is estimated.