BioTrade2020plus

Supporting a Sustainable European Bioenergy Trade Strategy

Intelligent Energy Europe
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Assessment of Sustainable Lignocellulosic Biomass Potentials from Kenya for export to the European Union 2015 to 2030

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The BioTrade2020plus Project

Objectives

The main aim of BioTrade2020plus is to provide guidelines for the development of a **European Bioenergy Trade Strategy for 2020 and beyond** ensuring that imported biomass feedstock is sustainably sourced and used in an efficient way, while avoiding distortion of other (non-energy) markets. This will be accomplished by analyzing the potentials (technical, economical and sustainable) and assessing key sustainability risks of current and future lignocellulosic biomass and bioenergy carriers. Focus will be placed on wood chips, pellets, torrefied biomass and pyrolysis oil from current and potential future major sourcing regions of the world (Canada, US, Russia, Ukraine, Latin America, Asia and Sub-Saharan Africa).

BioTrade2020plus will thus provide support to the use of stable, sustainable, competitively priced and resource-efficient flows of imported biomass feedstock to the EU – a necessary pre-requisite for the development of the bio-based economy in Europe.

In order to achieve this objective close cooperation will be ensured with current international initiatives such as IEA Bioenergy Task 40 on "Sustainable International Bioenergy Trade - Securing Supply and Demand" and European projects such as Biomass Policies, S2BIOM, Biomass Trade Centers, DIA-CORE, and PELLCERT.

Activities

The following main activities are implemented in the framework of the BioTrade2020plus project:

- Assessment of **sustainable potentials of lignocellulosic biomass** in the main sourcing regions outside the EU

- Definition and application of sustainability criteria and indicators

- Analysis of the **main economic and market issues of biomass/bioenergy imports** to the EU from the target regions

- Development of a dedicated and **user friendly web-based GIS-tool** on lignocellulosic biomass resources from target regions

- **Information to European industries** to identify, quantify and mobilize sustainable lignocellulosic biomass resources from export regions

- **Policy advice on long-term strategies** to include sustainable biomass imports in European bioenergy markets

- **Involvement of stakeholders** through consultations and dedicated workshops

More information is available at the BioTrade2020plus website: **www.biotrade2020plus.eu**

About this document

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RE	Restricted to a group specified by the consortium (including the Commission Services):	
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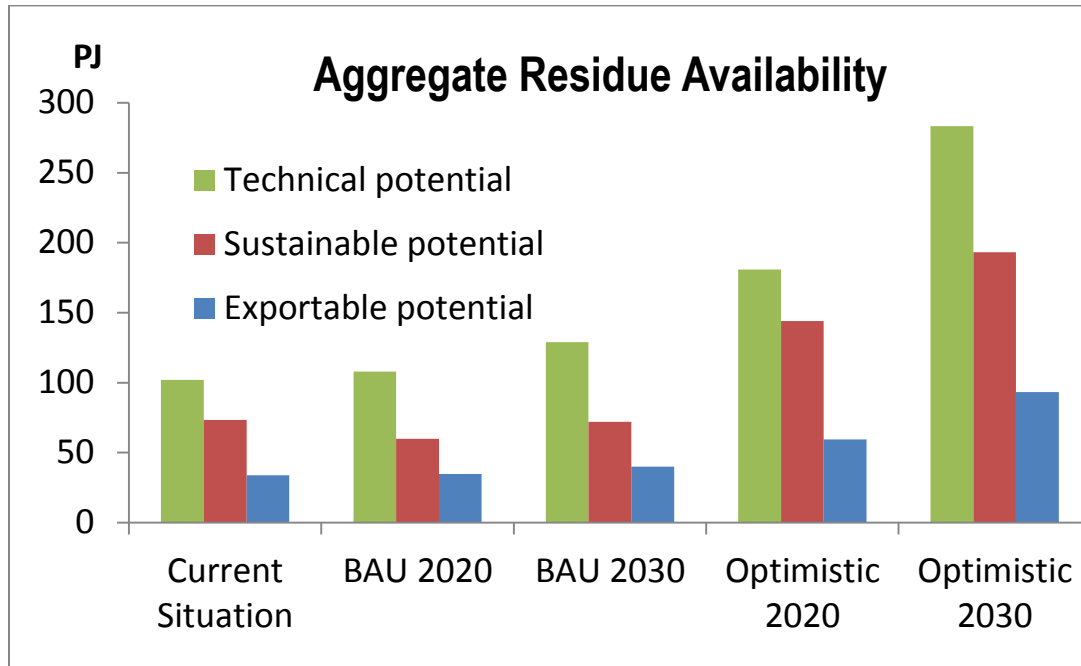| Version	Date	Reason for modification	Status
0.1	09/02/15	Consultation and advices from project partners & AB members	Draft
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Summary

In order to meet its demand of biomass for bioenergy purpose as biomass production in the continent might not be sufficient; European Union is in search of identifying international sourcing countries to import biomass resource while ensuring that resource satisfies sustainability criteria up until 2030. Kenya is selected as a promising sourcing country as a number of stakeholders have indicated that the country might have surplus potentials to be exported. Therefore this report aimed to investigate biomass potentials in Kenya that stem from herbaceous, woody and lignocellulosic biomasses and subsequently assess their suitability and availability for export to the EU for the time being up until 2030. This goal was achieved primarily through an internship in Kenya of Aristeidis Dardamanis, MSc student in Utrecht University to discover where the most promising feedstocks and the counties of production are, where these feedstocks are present in term of residues availability and their change in the future. In fact, the selected counties were considered as studied areas in order to determine local demand and other related drivers (e.g. farming practices, technological adoption) which were in turn applied to the other counties where the selected feedstocks are being produced. Thus, regarding the present situation in Kenya the technical, the sustainable and finally the sustainable feedstock surplus potentials for each feedstock were estimated on a county level and subsequently summed up to reach the aggregate biomass potentials. Accordingly, the costs and GHG emissions generated 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. In order to estimate possible future ranges of the total sustainable feedstock surplus potential in Kenya, two scenarios (BAU[1] and Optimistic[2]) were developed providing a sensitivity analysis with a moderate and a more optimistic situation under different drivers for 2020 and 2030.

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[1] *The business-as-usual (BAU) scenario reflects biomass production and consumption at current and predicted paces. They are built based on the reports and review of national statistics, FAO reports, scenarios presented in the World Energy Outlook 2012 and 2013 that set the normal development in the studied sectors in the studied countries. The BAU scenario is built on current and expected policies in energy, climate and environmental etc. which are already come into effect in the EU, in the sourcing regions and possible in other world regions.*

[2] *The Optimistic scenario explores options under which larger volumes of sustainably produced biomass might become available for export. These may include an assessment of possibilities to increase the yields of both dedicated biomass production for energy, agricultural and forestry yields in general, effective land management and subsequent additional land availability for biomass production; it also envisages more vigorous policy developments in energy, climate and environment sectors. The optimistic scenario is built amongst other inputs of national statistics, FAO reports, scenarios presented in the World Energy Outlook 2012 and 2013 that sets out an energy pathway consistent with the goal of limiting the global increase in temperature to 2°C by limiting concentration of greenhouse gases in the atmosphere to around 450 parts per million of CO2.*

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

Aggregate Residue Availability

PJ

- Technical potential
- Sustainable potential
- Exportable potential

Graph 0-1: 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:

- 33 to 60 PJ → In a short term;
- 34 to 84 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 15 €/GJ and 23 kg CO_2/GJ respectively, while for 2020 and 2030 the respective total amount under the two scenarios will be 13 €/GJ with more than 90 per cent of total biomass at 21 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 therefore was found. This situation may remain the same until 2030 considering the last 10 year trends however regarding interviews with local policy makers and the Crop Act 2013 to increase the growth and development of agricultural crops, the decreasing trend of agricultural yield supposed to stop in three year time and more investments will be carried out, particularly for fertiliser increase to booth agricultural productivity.

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, off-cuts and chips, 100 per cent were used. Subsequently, sugarcane stalks & leaves and bagasse were found to be the most significant sources of solid biomass in Kenya considering 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 11 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 total biomass potentials were taken into account. In details, 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 11 PJ at present to 33 PJ and 40 PJ respectively, under a BAU scenario and delivered at 14 €/GJ and 23 kg CO2eq/GJ for about 80 per cent of the total sustainable feedstock surplus.

Accordingly, in an optimal case through more positive and vigorous changes on the related parameters (crop yields and timber supply) coupled with the expansion of assumed annual harvested areas, reduced logistics (train costs from 0.16 to 0.056 €/km) [90] and fertilizer costs (30 per cent reduction), the total net biomass available at the main port may increase from the 10 to 60 and 89 PJ in 2020 and 2030 correspondingly and 80 per cent of these amounts delivered at 21 €/GJ and 5 and 5 kg CO2eq/GJ respectively. 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 whole biomass supply chain. The shares of sustainable feedstock surplus are possibly available for exportation to the EU when compared with studies in other neighbouring countries in terms of supply chain costs and GHG emission reduction rates.

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.   Country perspective on biomass potential

Kenya is 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[3] 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]. As a result, agriculture and forestry sectors indicate that large amounts of residue are generated due to their harvesting and processing activities. And as a consequence, these residues can create a new market branch of bio-energy production in the country,

Figure 1-1: Location of Kenya on Earth.

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 at present and in the future that would add to the bio-energy potential of Kenya [5], [9].

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 demand feedstocks for the production of bio-products and for bio-energy generation. This is an indication of the fact that in the Climate and Energy package, European targets have been set by 2020 suggesting 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

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

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 potentially importing biomass from other international sourcing countries [11]. Therefore, it is of importance to provide more information 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. EU has taken action by initiating the project BioTrade2020+ "Supporting a Sustainable European Bio-energy Trade Strategy" where several universities and institutions participate in seeking innovative solutions to overcome this challenge [12]. The project aims at the development of a European Bio-energy Trade Strategy up to 2030 while taking into account sustainability constraints, giving priority for local uses as well as considering 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.   Studied focus

The bio-energy potential accumulated from solid biomass in Kenya is currently unexplored. Therefore, the main 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 has to be examined. Biomass potential stemming from these three different sources depends on a number of factors. Consequently, to analyse 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 in agricultural and forestry sector;
- 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), sustainability criteria (GHG emissions, soil erosion control & soil organic carbon maintenance) and subsequently quantity available for the market to be capitalized. However, the local demand aspect capturing all the possible competing uses and when that happened were not completely analysed by the aforementioned studies.

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 sustainability 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 uses of the selected agricultural and forestry products?
4. What is the prospective potential of land availability 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 an agregate one. The potential counties were selected during the internship;
- An estimation of the spatial distribution of initially technical and subsequently sustainable potentials regarding the selected agricultural & forestry lignocellulosic feedstocks and energy crops is essential;
- An analysis of the biomass supply chain costs 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 and sustainability criteria;
- A calculation of the GHG emissions released during the biomass delivery 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 methodological approach illustrated in Figure 2.1 is implemented. The different steps included in the approach 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 setup of this stage leads to the estimation of the biomass potential available currently, in 2020 and 2030 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. Step 4, Market potential is not taken into account due to the market immature in Kenya; however it is mentioned in Chapter 5 and 6 for further investigation. 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.
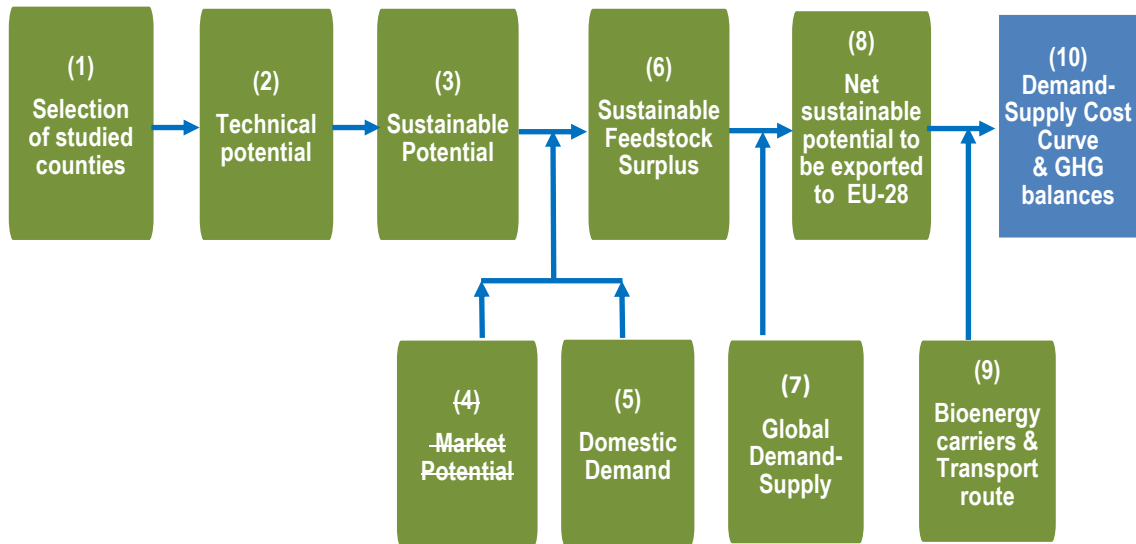
Figure 2-1: Visualization of the research planning and the different tasks to be carried out in order to answer the research questions.

2.1.   Part 1: Assessment of 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 were identified through the implementation of a number of criteria as

described below. Subsequently, after the identification of the most promising feedstocks, the counties indicating 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 for animal feed and provide a general indication on the biomass availability at a county level. Secondly, a number of sustainability criteria combined with the first one are used 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 regarding 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;
LHV$_i$:	The lower heating value of a residue type;

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.

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

$$Sustainable\ feedstock\ surplus\ = sustainable\ potential - domestic\ demand$$

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. Global demand and supply of biomass

Global trade of biomass feedstock and energy carriers expands swiftly as a   result of policy implementation on energy and climate aiming to promote the diversity of energy resources, mitigate climate change impacts and reduce greenhouse gas emissions as well as augment the usage of biofuels and bioenergy in a high number of countries particularly the European Union.

In the landscape of biomass trade worldwide, European Union plays an important role as the main import region. According to the study of Eurelectric [91], biomass imports to fulfil the gap of biomass supply to demand are about 60-90 Mtoe in 2020. If interpolating this quantity for

2030, the import would be enlarged to 81-122 Mtoe. Therefore the need to access to a gigantic amount of biomass from various sourcing regions to the European Union is clarified.

Besides Canada and the United States, Eastern European countries (Russia, Ukraine), South America regions (Brazil, Argentina), in consideration with statistics from FAOSTAT and Eurostat indicated that South East Asia and Africa are becoming other potential importers of biomass to the European Union. In the future when torrefaction and pyrolysis technologies will be more matured and commercialised whilst the economies of scale are equally considered, torrefied pellets and pyrolysis oil might be highly competitive in the global trade. Equally, there are new trade routes possibly developed from potential supply regions, hence scenario analysis needs to take into account this perspective.

Aim: to understand the biomass demand and supply at global level

Method: to consult external resources and data in particular the IEA World Energy Outlook 2012 and 2013 for Renewable Energy, IEA Technology Perspective 2014 and estimation of global biomass demand by models Timer, POLES and GFPM.

Data requirements and data sources: aggregate production, import and export of biomass at global scale; data sources: IEA World Energy Outlook 2012 and 2013 for Renewable Energy, IEA Technology Perspective 2014 and estimation of global biomass demand by models Timer, POLES and GFPM

2.2.2. Analysis of biomass supply chain cost

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).
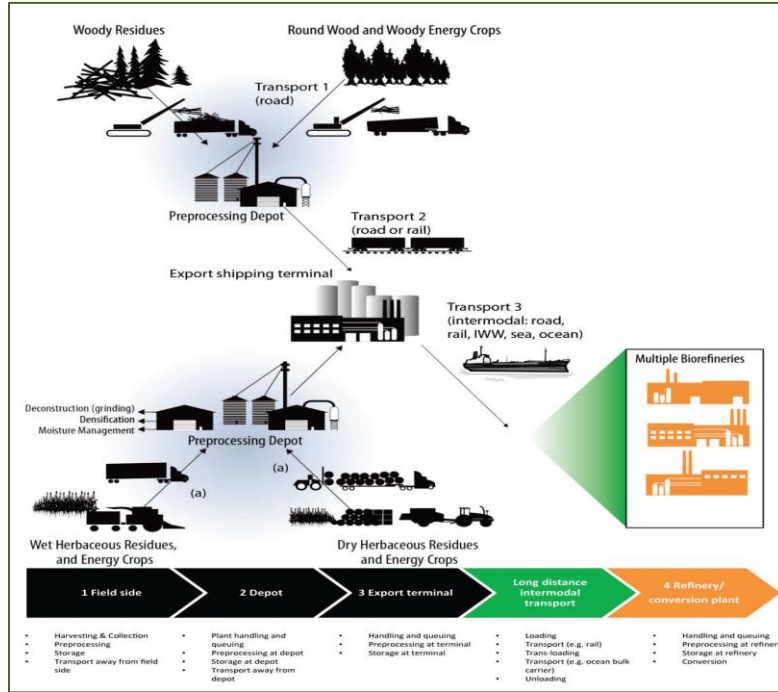
Figure 2-2: Breakdown of the biomass supply chain[4] [19].

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
Nutrient compensation costs	€/GJ

---

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

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.

2.2.3. Biomass supply chain GHG emissions analysis

Aim: Analysis of GHG emissions concerning the selected feedstocks which are released throughout the supply chain and the respective shares of biomass that meet sustainability criteria in term 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.
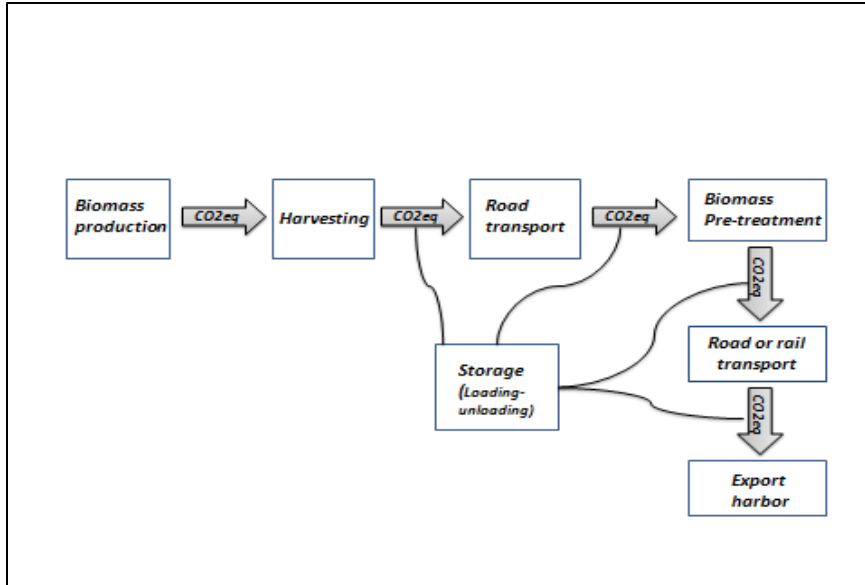
Figure 2-3: Illustration of the biomass supply stages, where GHGs emissions are released[5].

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$_{residue\ harvested}$
Fuel emission factor	CO2$_{kg}$/GJ
Electricity usage	MWh/t$_{residue}$
Electricity emission factor	CO2$_{kg}$/MWh

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

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

Scenarios play a key role in all the mentioned tasks. 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 on e.g. energy, climate and environmental targets which have already come into effect in the EU, in the sourcing regions and in other possible world regions.

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 increased annual yields and expanded land areas for cultivation are derived through three approaches based on data availability.

Regarding the yields, the first approach already carried out projections on consumption and production volumes until 2030 consulted from national reports 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 consulted yield is set as a target yield until 2030 and the respective optimum annual yield increase is estimated. Finally, the third approach based on national reports, indicated optimum yield levels for specific crops are considered and set again 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 similar to the yield increase, different case studies from neighboring countries are used. In the second approach through national reports projections on additionally 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 in 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 analyses 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[6].

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 indicating 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 provides results of 3.1.1 and 3.1.2 sub sections, 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

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

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 rejected based on their production volume (t) at an 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 studies on biomass waste from agricultural residues in Kenya together with consideration of expert opinions were deemed necessary in order to identify the first 15 prominent agricultural products in terms of residue availability [17], [18], [25]. Therefore, maize, mangoes, bananas, sugarcane, irish potatoes, beans, coffee, sisal, wheat, cassava,

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[6] 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.

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 significant potential in the agricultural products in term 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. G. 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 indicated 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 an aggregate level and based on negative indications of previous reports regarding their availability, then 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 is that households are directly involved in agricultural activities including all food & horticultural products under investigation, 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, in term 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 experts of ILRI (International Livestock Research Institute) and of the Ministry of Livestock[7].

The analysis, for identifying which 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 distribution of livestock

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[7] 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.

population 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. By this way, an indication of the residue availability concerning the different residue types was investigated. The calculations are provided in more detail in the Appendix 8.1.

As can be seen from the Table 8-8, there is a total deficit of 105 PJ. Thus, it was unlikely that there was 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 main sustainability constraints since biomass when transported by truck for such distances is not economically viable [27].

As a result, sugarcane, sisal, coffee, rice, and coconut were selected because of the reason that they are 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 (reliable information indicated that they are not possibly used for livestock), 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 then 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[8]	0.05	0.05	0.84	N/A

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

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 as a result of conversion efficiencies of each process. Due to the fact that timber waste, accruing from sawing, accounts for 86 per cent of the 6 million m3 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 aggregate waste, 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 different stakeholders, interviewed during the internship, considered them as one identical 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 and domestic demand concerning each different residue type, the corresponding sustainable feedstock surplus is obtained.

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[9] - 4.70	14.40 - 15.30
Sisal bogas	19.80	14.85	15.60[10] - 24.00	14.40 - 15.30
Coffee husk	0.24	14.10	0.23[11] - 0.25	12.20 - 16.00
Coffee pulp	2.42	0.01	3.40[12]	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 an aggregate one. Regarding the investigated feedstocks, the 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).

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[9] 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.
[10] The lower limit of sisal bogas RPR is provided again by Real Vipingo's estate measurements.
[11] This value is retrieved from the data sets of Kofinaf (coffee mill) in Kiambu County during the internship.
[12] Similarly to coffee husk RPR, it is retrieved from the data sets of Kofinaf.

Aggregate technical potential of agricultural residues

Legend:
- Coconut husk
- Sisal ball
- Sisal bogas
- Molasses
- Sugarcane stalks & leaves
- Bagasse
- Rice straw
- Rice husk
- Coffee husk
- Coffee pulp

Values shown: 0.6 PJ, 0.2 PJ, 0.0 PJ, 4.0 PJ, 7.2 PJ, 1.6 PJ, 7.8 PJ, 2.0 PJ, 32.8 PJ, 23.8 PJ
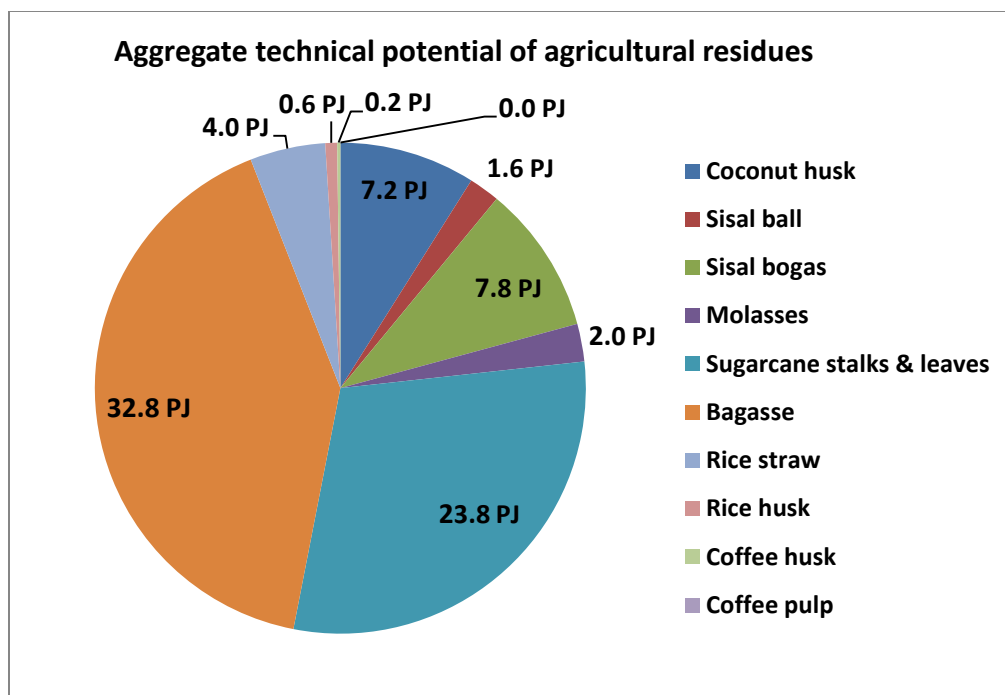
Figure 3-2: Breakdown of the total technical potential originating from the agricultural sector.

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[13] (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 dependent predominantly on the net residue availability of the sugarcane subsector. The figures used to draw the conclusions at an aggregate level are provided in the Appendix 8.2.

When 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

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

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, contribute 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 counties, where sisal, sugarcane and rice are produced, are investigated based on the basis of their average annual rainfall and temperature and on 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, the average value of the proper maize and wheat residues requirements from Table 8-10 in the Appendices are used. It considers conventional tillage as 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 the Appendix 8.2.
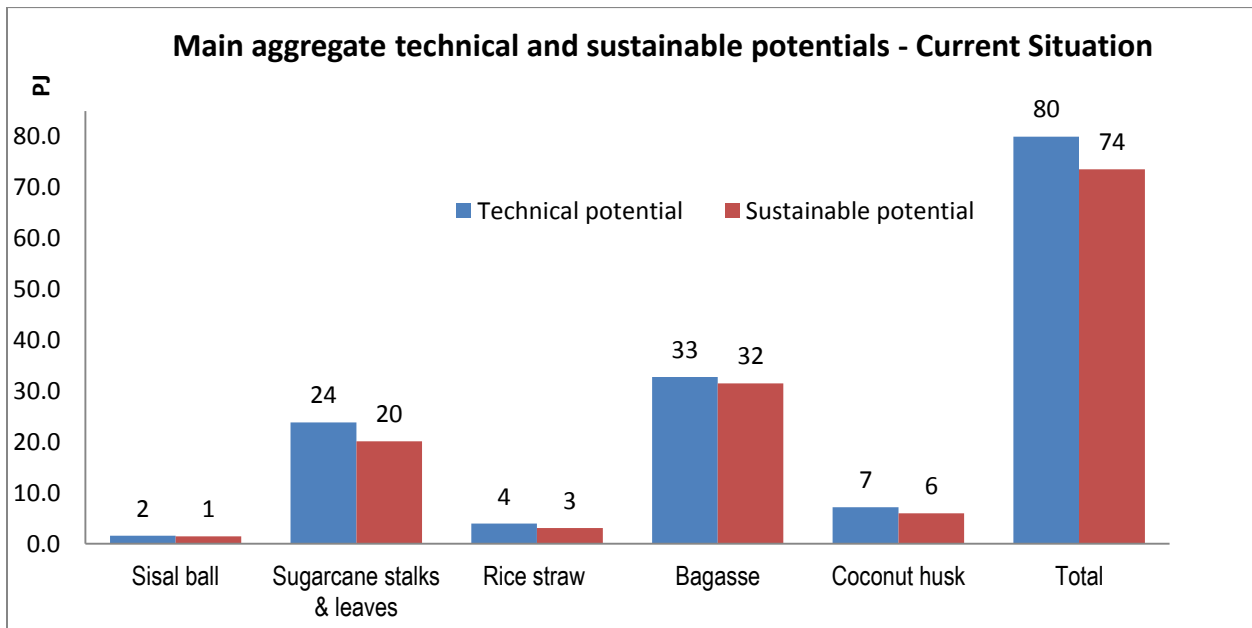
Graph 3-1: Amounts of herbaceous residues required to set aside for soil erosion control and 2% SOC maintenance.

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 74.0 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[14] (%)			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

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.

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[14] 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.

Stalks & leaves

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

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

Picture 2: Bagasse stored in Mumias deposited point.

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.

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 Kenya15, 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 costs incurred by fertilizer application.

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

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

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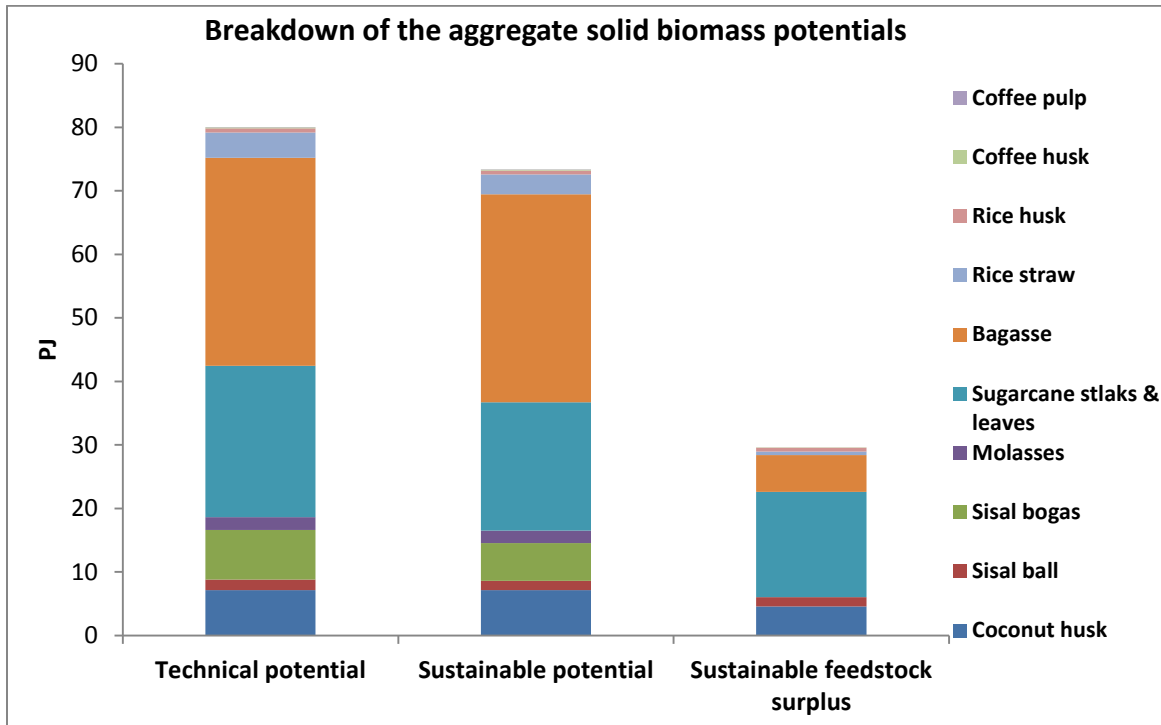
Graph 3-2: Aggregated technical, sustainable and sustainable feedstock surplus potentials originating from the agricultural sector.

All in all, the sustainable feedstock surplus that stems from herbaceous residues, is estimated approximately 30 PJ (Equation 2-6). That is achieved mainly through the intensive internal use of sisal bogas and bagasse, 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 an aggregate one (see the Appendix 8.2).
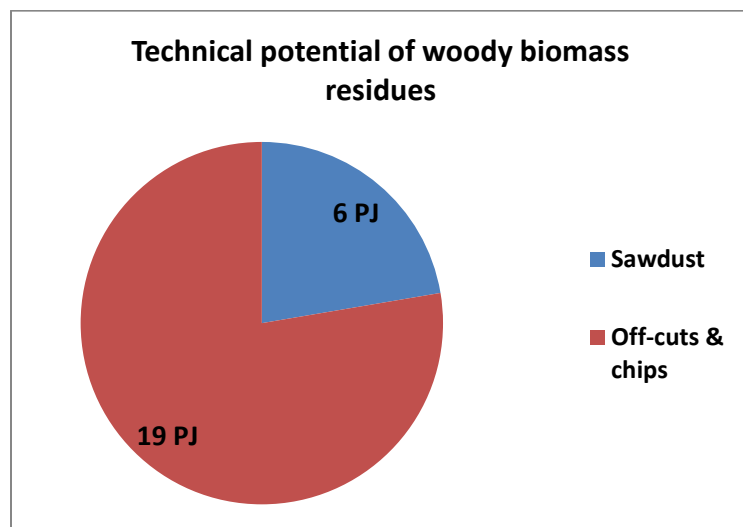
Figure 3-3: Breakdown of the total technical potential originating from process residues of woody biomass.

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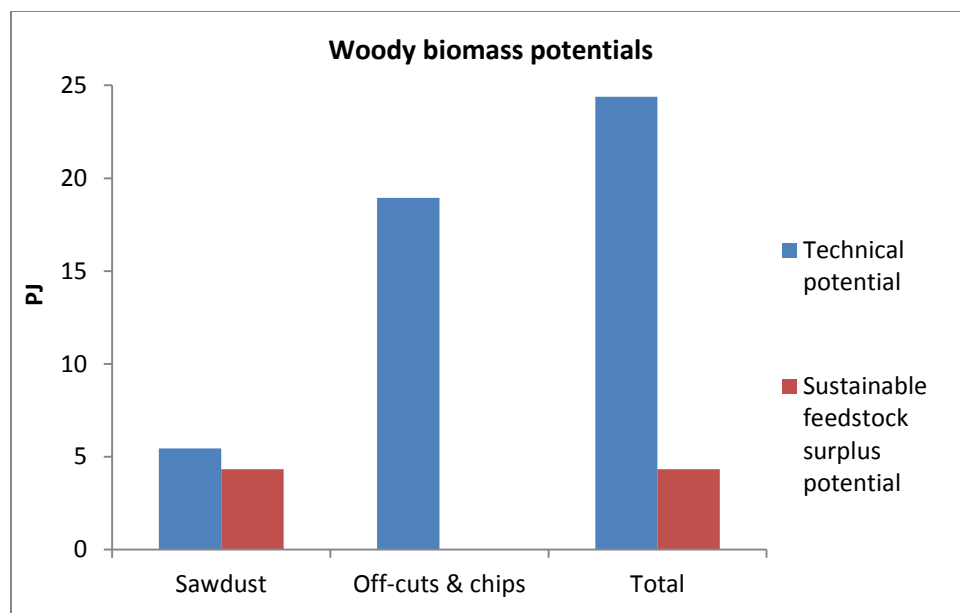
Graph 3-3: Technical and sustainable feedstock surplus potential of woody biomass at present.

Technical potential of woody biomass has been taken into account sustainability constraints; therefore the step of assessing sustainable potential is skipped. 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 be 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 indicate no territory for energy crop production even in the future.
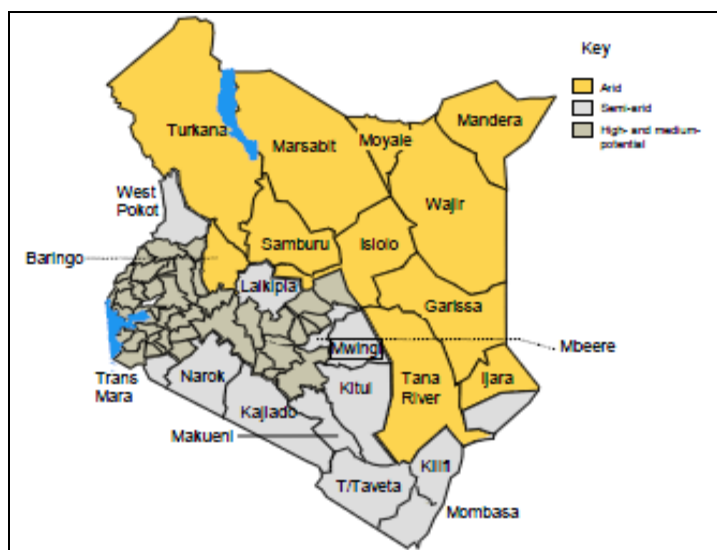
Figure 3-4: Land status of Kenya regarding arid (yellow), semi-arid (light grey) and high potential (dark grey) areas [49].

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[16]. 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.
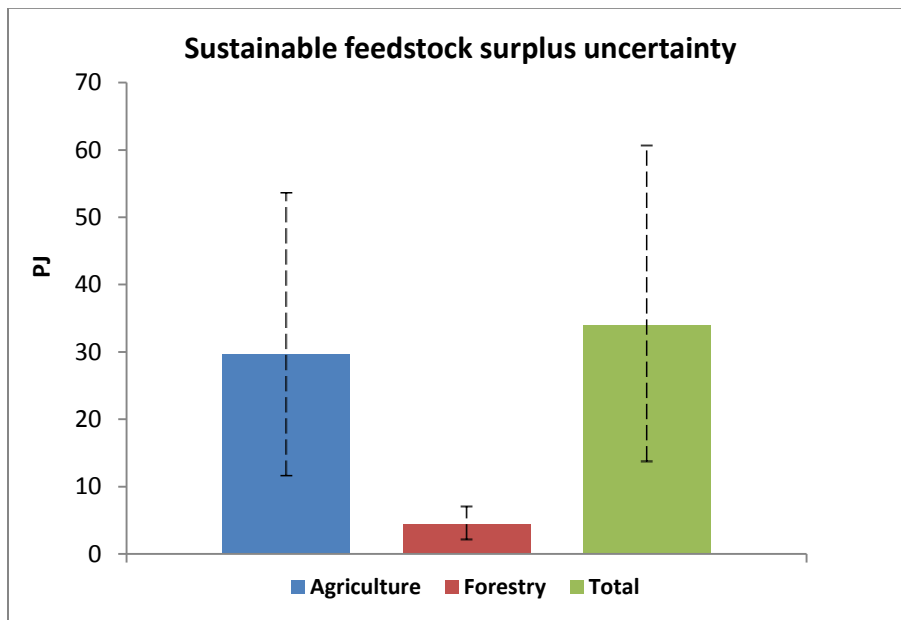
Graph 3-4: Illustration of the uncertainties incorporated in the final results of the current situation.

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

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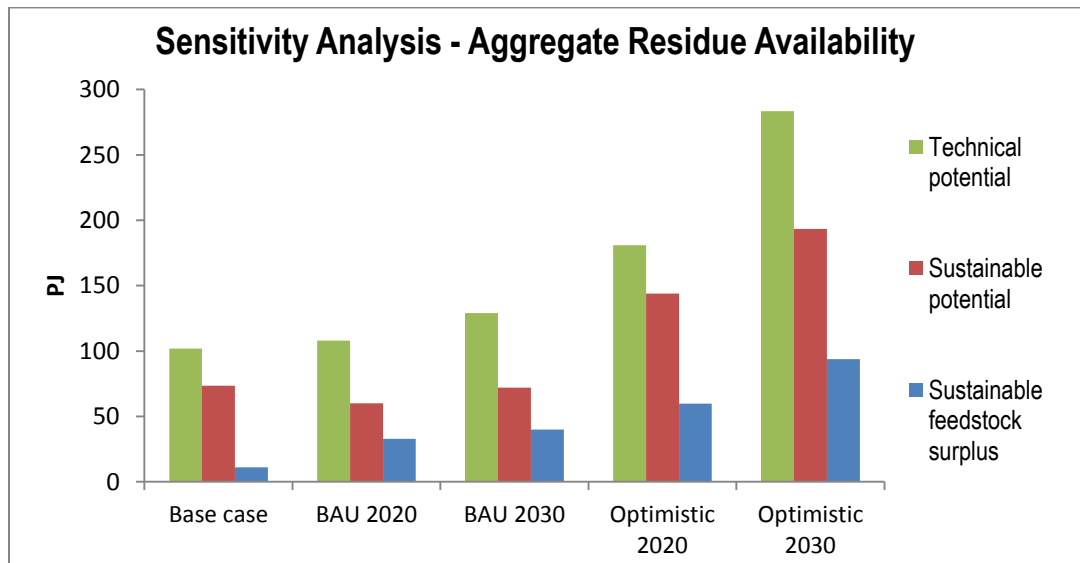
Graph 3-5: Projections of the different types of biomass residues potentials in a short and a medium term under the BAU and the Optimistic scenarios.

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:

- 33 to 60 PJ → In a short term;
- 34 to 84 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 impacts 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[17] (limited fertilizer and pesticides use, no irrigation-6 per cent of total cropland is irrigated) [26], [49];
- Farming practices: conventional tillage;
- Soil quality: of high and medium potential[18] [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

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[17] 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.
[18] The soil quality concerns the areas, where the majority of each of the aforementioned crops lies.

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[19].

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	6.1
Sugarcane	- 3.5	-12.0	10.5

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 were acquired during the internship concerning the current farming practices, technological adoption and soil quality underlying the five feedstocks.

All the products, except 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 rain-fed 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 2018, while with minimal or no investments in soil improvement nutrient depletion is unavoidable, resulting to decreasing yields. However, the resulting yield of sugarcane from 2018 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.

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[19] 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].

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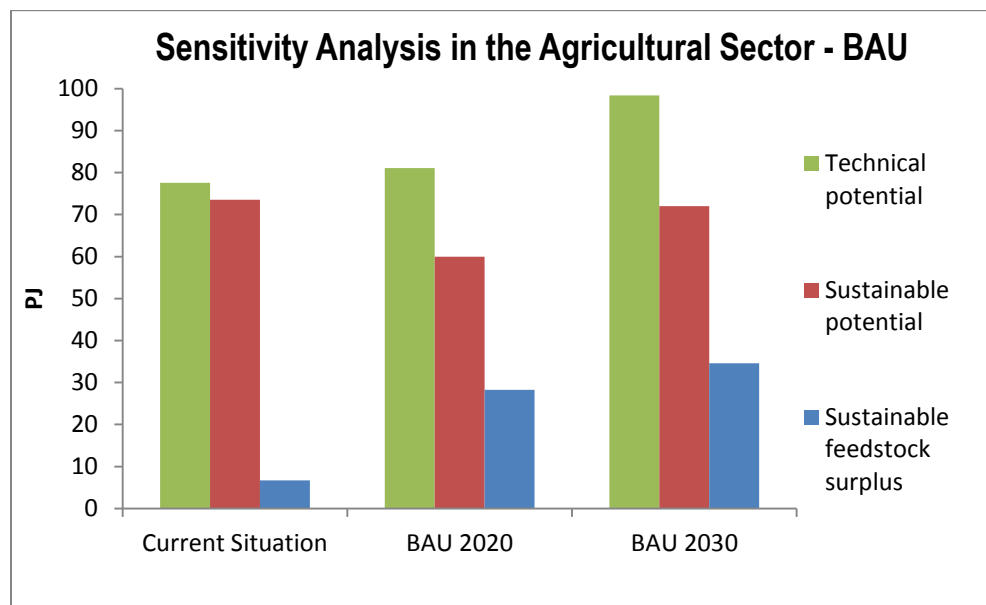
Graph 3-6: Illustration of the technical and sustainable potentials and consecutively the sustainable feedstock surplus biomass potential originating from the agricultural sector at present and until 2030.

The future situation in the agricultural sector under the BAU scenario for 2020 shows a slightincrease by 3, 6 and 12 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 sugarcane decrease until 2018 eventually increase after suppose due to intervention of government and industry to the sector which lead to a higher aggregate amount of 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 crop of the future biomass potential available in agriculture, there is positive change in the medium term. In particular, as noted before sugarcane yield from 2020 until 2030 is considered to be improved. Thus, the higher increase of the total sustainable feedstock surplus is attributed to the corresponding yield increase of the remainder feedstocks resulting to a total 20 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].
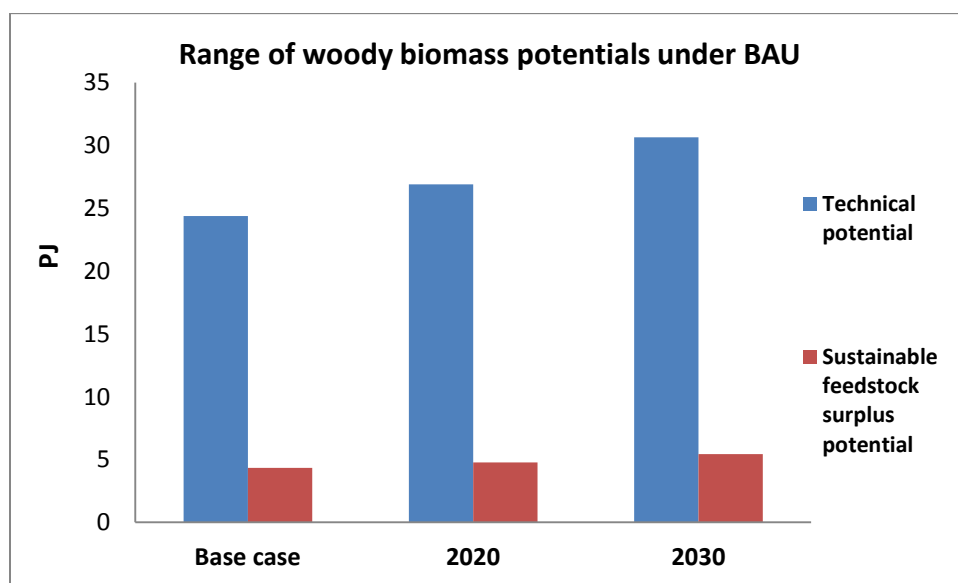
Graph 3-7: Illustration of the technical and sustainable feedstock surplus potentials that stem from the forestry sector at present and until 2030.

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

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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. 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 tonnes in 2020. When comparing the current situation of total sugarcane production with the corresponding of total sugar consumption, a deficit of about 200 thousand tonnes is noted[20], 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 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 tonnes). 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 annual production increase and area expansion of sugarcane crop, 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 tonnes to 10,000 tonnes accordingly for the same years were anticipated, given a fertile soil. As a consequence, owing to the fact that Tanzania is a neighbouring country of Kenya and

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

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, 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, fewer residues are required for the 2 per cent SOC maintenance (see the Appendix 8.2 and Table 8-10).
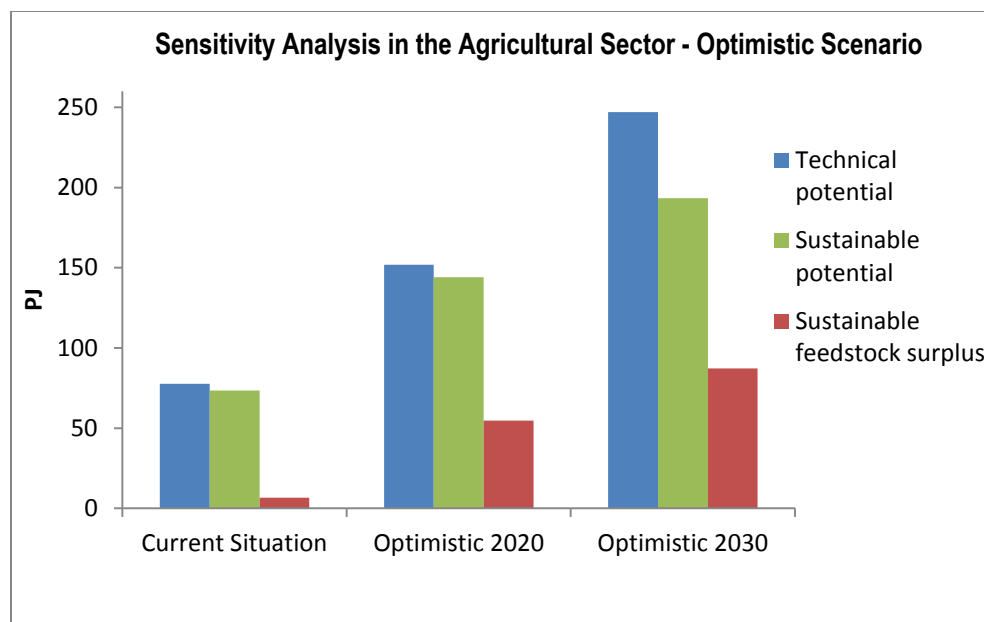
Graph 3-8:Comparison between the present and the future situation of total herbaceous biomass potential in Kenya under Optimistic scenario.

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.

Similar 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:

- 7 to 55 PJ → Short term;
- 28 to 87 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	25.0

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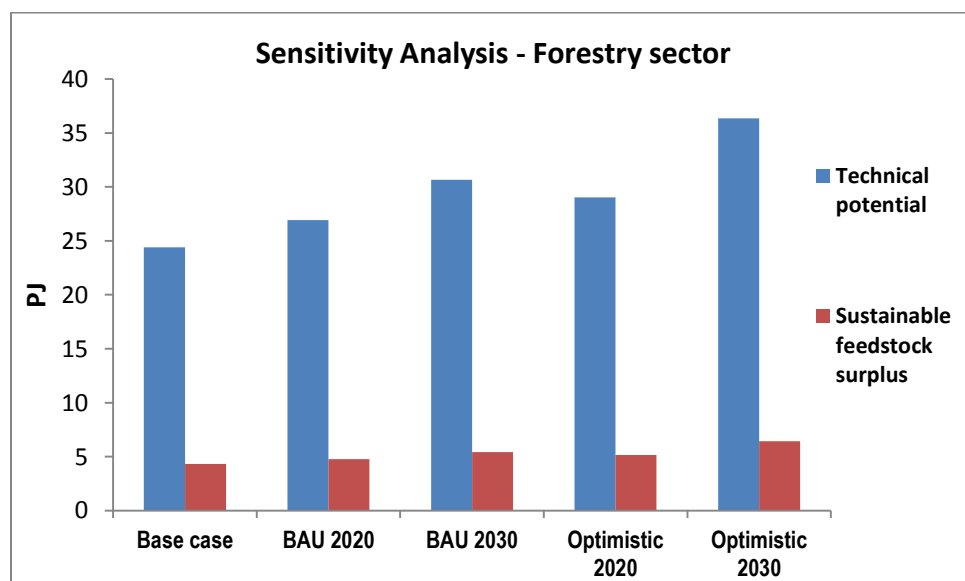
Graph 3-9: Comparison between the present and the future situation of total woody biomass potential in Kenya under BAU and Optimistic scenarios.

Similar to the previous results in the BAU scenario, these results also indicate a linear increase. 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.

When 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 study on Mozambique which is similar to this case study [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[21]	Lamu port development	80% train costs reduction	Pre-treatment
Current situation	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 lying in the west part of Kenya indicates concerns of the bulk of residues due to the fact that currently there is no freight station connecting these areas with the port of Mombasa and 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 be 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

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

Juba might lead to reduced train transport costs by almost 85 per cent [60], [66]. That would 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 bulk densities of different residues 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.
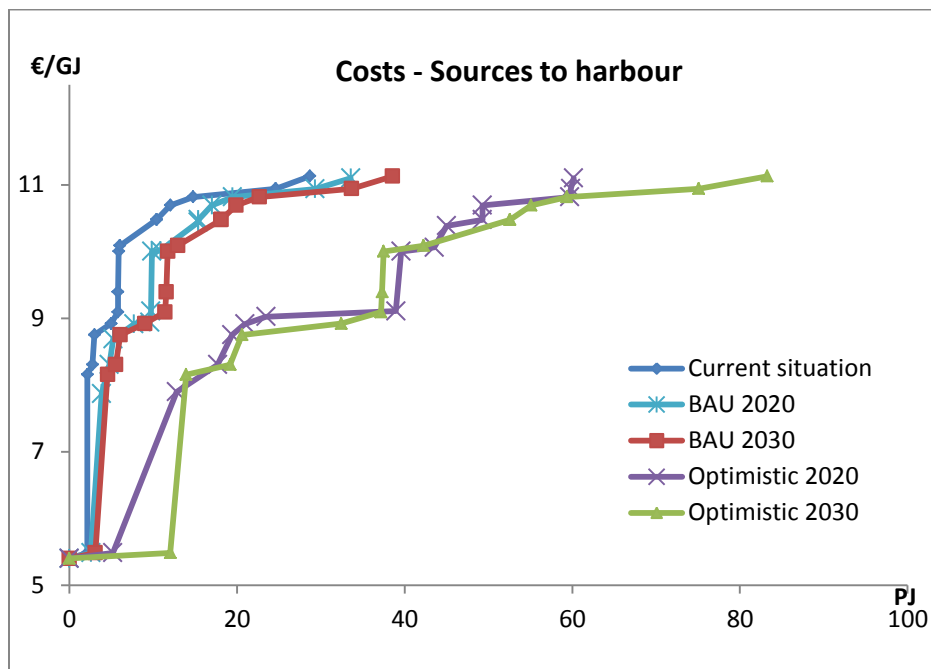
Graph 4-1: Illustration of the aggregate export potentials to Mombasa harbour

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. The prices of the competing uses were considered and applied from Batidzirai's study [22]. Thus, it seems that in each case all biomass delivered can potentially indicate an economic viable solution. However, if primary energy losses of about 30 per cent and additional costs due to ship transportation and conversion process are considered then the situation is changed[22] [22]. In fact, at the time being, 100 percent of solid biomass is delivered at a cost of 10.6 €/GJ, when for the

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[22] 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)

remainder scenarios from 5 to 10.6 €/GJ. In the future scenarios, there is more biomass to be mobilised and thanks to the economy of scale, total costs are cheaper.

4.2. GHG emissions in the biomass supply chain

This task elaborates on GHG emissions released due to biomass delivery 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[23]	kg CO2eq/t*km	kg CO2eq/t$_{residue}$ harvested	Kg CO2eq/KWh
Freight train 1625t	0.36	N/A	N/A
Truck, 21t	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

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).
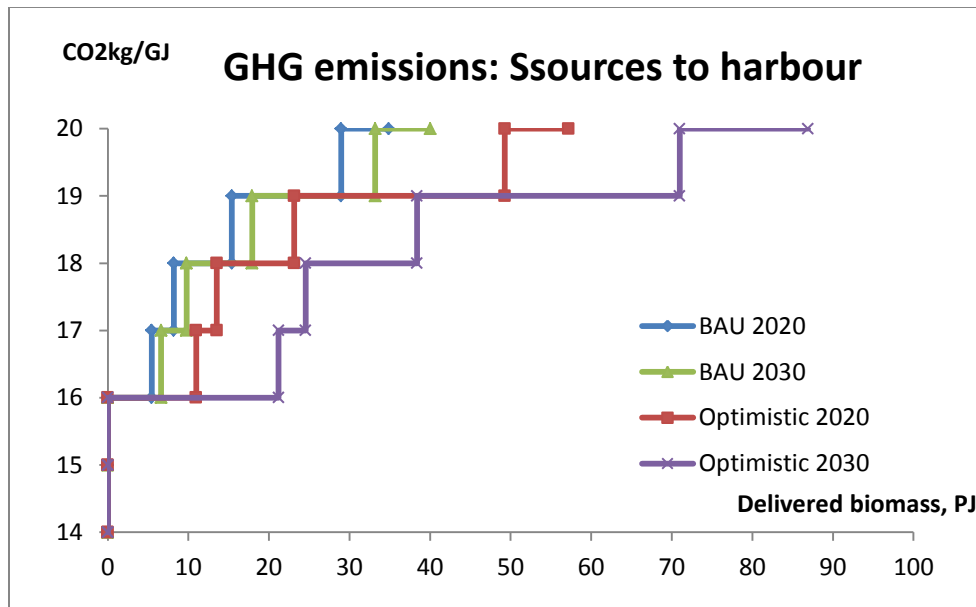
Graph 4-2: Aggregated GHG emissions throughout the supply chain sources to harbour

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[23] Train and truck emission factors were calculated based on diesel consumption of the same, and the fuel's emission factor. 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.

In Graph 4-10 the total GHGs incorporated in the entire biomass supply chain are shown. For example, it can be seen that in the base case more than 90 per cent of solid biomass is delivered at 19 kg CO2eq/GJ while at the same emission levels, more biomass to be mobilised in the Optimistic scenario again thanks to the economy of scale, better infrastructure and better harvest management.

5. Discussion

The aim of this research is 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 investigateed 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 – data collection
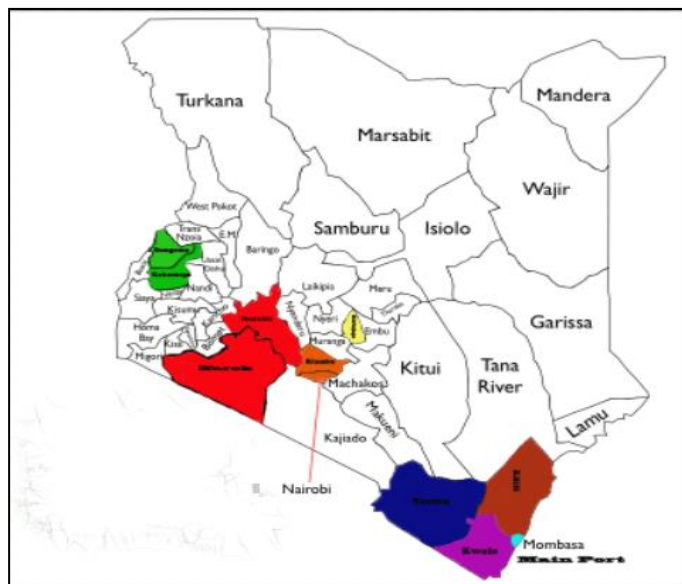
Figure 5-1: Areas visited during the internship for the development of herbaceous and woody biomass case studies.

The methodological approach used to assess the sustainable surplus of biomass potentials in Kenya to be exported to the EU was consulted with project partners, particularly experts of Wp2 and Wp3. Therefore, the four month internship carried out in Kenya in 2014 was to collect as much as possible the data and information needed to achieve the results of 10 steps in the project methodological approach.

The data and questionnaire list required by the project were however not fully fulfilled within the four month internship in the country due to a number of reasons:

➢ Communication with local stakeholders were not efficient: government officials were busy with their agenda and some of them did not response to the intern's requests and proposals; factories and companies in bioenergy production and provisions aimed to keep their information confidentially; local farmers did not have relevant knowledge and could only provide information by their experience, therefore information achieved were not identical;

➢ Cultural boundary and different work manner: The intern had difficulties to set up work plan and interviews with local stakeholders possibly due to different work manner and different ways of approaching people

➢ Not all information is available for developing scenarios in future timeline: the project aimed to look at technological advances to be applied into agricultural and forestry sectors but at the time of carrying out the internship, there were no relevant information applicable; a number of drivers and factors affecting the potentials of biomass production in the short and medium terms were neither achievable; policies in environment and energy having impacts on the

biomass production and consumption in the country were not fully attainable particularly for the future timelines 2020 and 2030
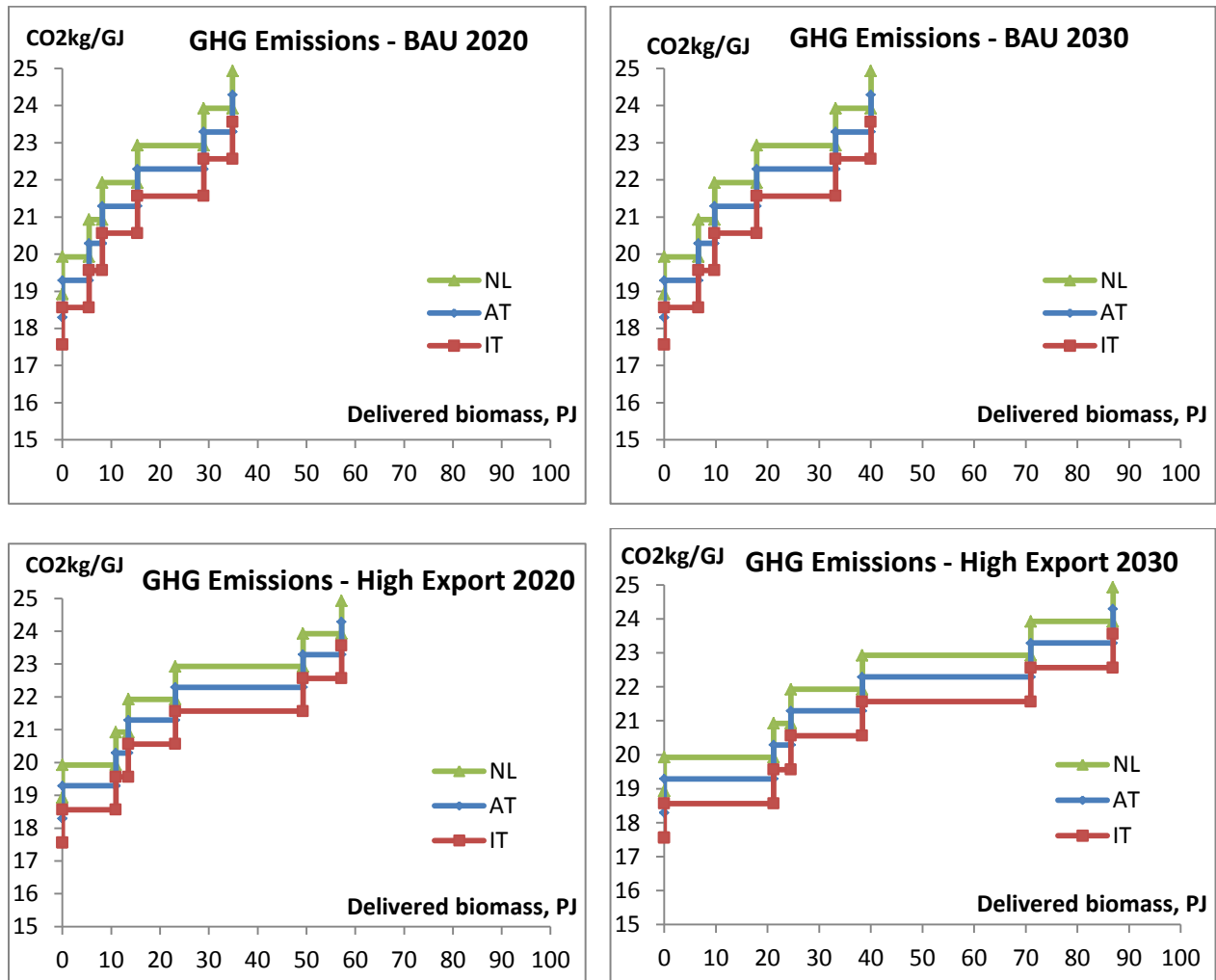
Figure 5-2: Total GHG emissions of biomass exported to the EU in various scenarios
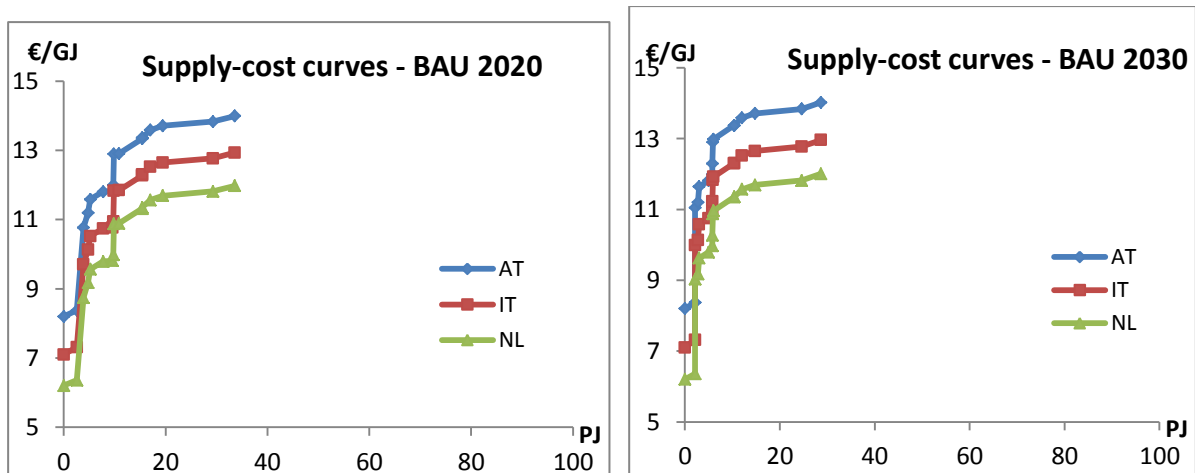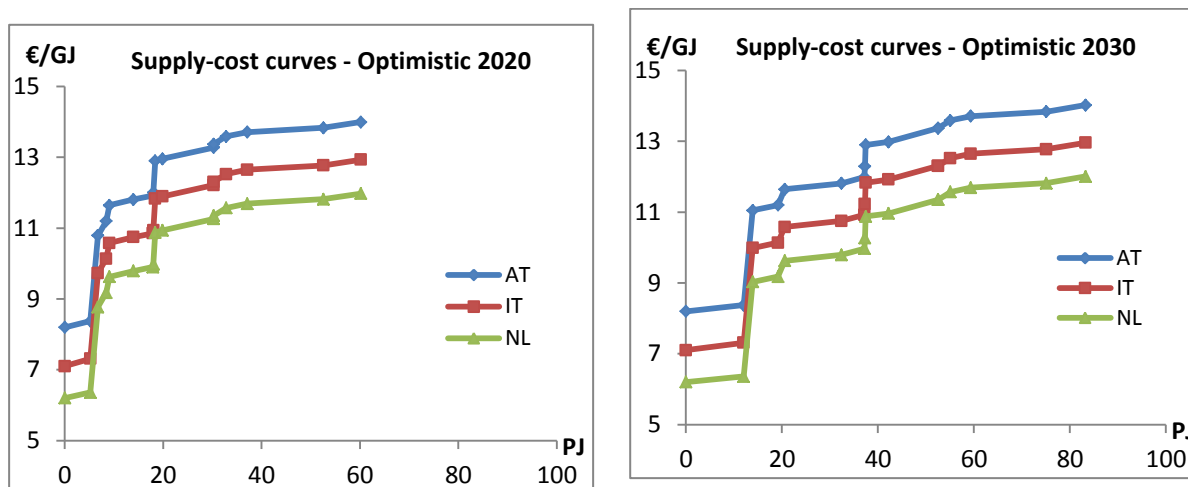
Figure 5-3: Total costs of biomass exported to the EU in various scenarios

Biomass potentials in agricultural & forestry sectors

With regard to the estimation of solid biomass potential in Kenya, the respective RPR and LHV retrieved from literature and field trip were applied and resulted to the estimation of the technical potential of the miscellaneous feedstocks at present. However, there were ranges of RPR and LHV values which lead to the fluctuation of aggregate values.

The aggregate biomass potentials might be decreased in consideration with the last 10 year trend - 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. 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. From discussions with local experts and review of the Kenyan Crop Act 2013, interventions from the Ministry of Agriculture and Forestry as well as further investments in the two sectors might soon happen which prevents firstly the decreasing trend of productivity and secondly improves further the crop yield which ultimately leads to higher biomass potentials even in the BAU of short and medium term. At present the different aggregate sustainable feedstock surplus potentials were estimated to be approximately 7 PJ and 4 PJ respectively. And as result of the intervention, the sensitivity analysis carried out provided the lower limits of 28 and 35 PJ and the higher ones of 55 and 87 PJ of sustainable biomass potential surplus for 2020 and 2030 respectively.

The emerging question is how much of this amount of biomass fulfilled requirements to be exported?

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 three times higher than of Kenya. This means a low biomass potential available for export in Kenya. From 2020 to 2030 about 60-90 per cent of the sustainable feedstock surpluses indicated above can be delivered from 14 €/GJ for the BAU and the Optimistic scenarios respectively. There is not much different between costs to the harbour and cost to the EU of exportable biomass. This can be explained that there are potentials in the countries but feedstocks are located far away from the port, therefore total domestic costs are high whilst intercontinental costs are lower compared to other sourcing countries.

Similarly, the GHGs emitted throughout the biomass supply chain leave a carbon footprint is about 23 kgCO2eq/GJ in 2030 for more than 90 per cent of the total herbaceous and woody biomass delivered from the port of Mombasa to the EU (also depending on what destination in the continent). The emissions of a large part of biomass fulfil the EU sustainability requirement regarding GHG emissions in the entire supply chain so it is likely to be imported to the EU if biomass trade is facilitated.

Dedicated energy crops

At present, the biomass potential originating from energy crops was estimated based on different land use types such as forest areas, 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 medium, high potential areas and semi-arid regions [26], [50]. Any possible marginal or degraded land available in the arid areas was also excluded due to the fact that they are located in the North part of Kenya which is remote and disconnected 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 of 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 neither in a short and a medium term. 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. In details, for the estimation of the technical potential RPR and LHVs were collected from literature and applied to the different crops 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 cases, such as bagasse quantified information was not available and hence through literature review the respective ranges of the shares were derived 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. The decreasing yield is supposed to stop in a three year period as governmental policies and investment into this promising crop might be carried soon out such as fertiliser application, land quality improvement and cultural management, therefore even in BAU scenario, total biomass potential from sugarcane crop will be increased slightly and in the Optimistic scenario, that quantity would be even much higher augmented.

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 specifically in household

use of residues for primary energy and animal feed entailing the need for further research in this aspect.

6. Conclusion and Recommendations

This report has been accomplished in collaboration with Aristeidis Dardamanis, student in Energy Science of Utrecht University for his MSs thesis on the same topic with the aim to ensure data and information could be adequately gathered and the methodological approach developed by BioTrade2020plus partners has been attentively applied. 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, the sustainable surplus of biomass potential to be possibly exported to the EU from Kenya has been assessed.

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. If good governance and investment implemented in agricultural sector, the total biomass potential will be competitive in terms of quantity, cost and sustainability consideration for export.

The most challenges of agricultural residues considered for export were found to be the internal uses (which have been thoroughly analysed in previous chapters) and proximity of production regions to the Mombasa port. In term of logistic conditions, a number of parameters were taken into account in the short and the medium timeline, which significantly affect the total potentials available at present condition. Through the opening of the Kisumu freight station by 2020, the entire sugarcane residues volumes will become accessible and competitive in terms of costs and sustainability constraints. Together with the increased annual yields, expanded production areas and the assumed pre-treatment facilities in a number of agricultural crops 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, additional biomass potentials could be achieved.

Forestry

Timber was recognized as the most promising forestry product among poles, firewood and charcoal. Timber residues, sawdust, off-cuts & chips were investigated and although they 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 including trucks and trains.

Similar to the consideration of various drivers in agricultural sector to augment total biomass potential in forestry sector, net sustainable surplus potential of sawdust was also presumed to be increased. The BAU and the Optimistic scenarios considered annual timber supply expanded 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. Under the BAU scenario it is assumed that there will be moderate changes 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 rises in the different sustainable feedstock surpluses will lead to the reduction in the respective costs and GHGs incurring throughout the biomass supply chain of sawdust. In conclusion, the costs and GHG emissions estimated for the present situation are not considered likely suitable for export due to their high costs (15 €/GJ) with small mobilised quantity. However 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 is indicated by the high woody biomass deficit (10.3 million m^3) and the high demand by livestock and agricultural activities. Furthermore the arid regions, where possible potential areas (marginal and degraded) could be utilized for biofuel production, are not accessible due to the absence of railways connecting these areas with the main port of Mombasa.

Based on a number of determinant parameters on land availability in Kenya, a future perspective for land availability was also assessed. Maize yield rate, food demand, livestock nutritional needs and the woody biomass deficit were estimated for 2020 and 2030. The low yield of maize in conjunction with the increased food demand, the increased livestock nutritional needs and the increased woody biomass deficit for these timelines implied no potential for energy crops cultivation. Regarding the arid regions 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. 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 further 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 investigate in more details any prospective strategies, policies and regulations oriented on the maize sub sector and through them identify the possibilities for exact 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 indicate an important role of sugarcanes sector regarding the total sustainable feedstock surplus. Thus, a further study is also recommended in which the entire sugarcane sub sector in Kenya should 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 has not elaborated domestic demand regarding household consumption, livestock feed, industrial use of residues for 2020 and 2030, more credible insights on a future situation are needed. This study should also focus on identifying the interrelations between the different parameters (primary energy needs, food demand, poverty levels etc.) affecting the different domestic shares as analysed in the previous chapters.

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Appendices

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[24]	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 6-1: 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
Sisal	131	669	800	2	10	12
Wheat	654	0	654	11	0	11

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[24] 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.

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 6-2: 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 6-3: Livestock population distribution per county and livestock unit for the year 2013[25].

Agricultural residues	Metabolizable energy GJ/tn
Maize Cobs	8.8
Maize Stover	7.4
Banana leaves	9.7
Wheat straw	42.0% (TDN)[26]
Soyabean stover	8.5
Cassava straw	50.0% (TDN)
Irish potatoes leaves	14.0% (TDN)
Mangoes leaves	9.7

Table 6-4: 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 6-5: 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 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.

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[25] Source: Mrs. Judy Gachora, production officer of the Ministry of livestock.
[26] The percentages represent the share of the total digestible nutrient content of the respective residue types.

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 6-6: 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 6-7: 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 6-8: 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. Consequently, 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.

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	KwaZulu	Free State	Gauteng	Mpumalanga	Eastern Cape	Limpopo	North west
Kenya							
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 6-9: Matching of Kenyan and South African counties sharing similar annual average rainfalls, temperatures and soil clay contents[27] [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
Western Cape	4.6	3.1	5.4	3.6
Eastern Cape	4.2	3.0	4.8	3.4

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

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 6-10: 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 6-11: 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 6-12: Breakdown at a county level of basic data needed to derive the sustainable feedstock surplus of sisal ball[28].

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

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 6-13: 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 6-14: 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
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 6-15: 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 Companies (Counties)	million*t	thousand*ha	t/ha	t/ha	GJ/ha
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 6-16: 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 Counties	thousand*t	thousand*ha	t/ha	t/ha	GJ/ha
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 6-17: 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 Counties	thousand*t	thousand*ha	t/ha	t/ha	GJ/ha
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 6-18: 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[29]	thousand*t	thousand*ha	thousand*t	PJ
Counties				
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 6-19: Breakdown at a county level of basic data needed to derive the sustainable feedstock surplus of coffee husk[30].

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

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[29] 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.
[30] Source: Data sets of Coffee board.

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 6-20: 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 6-21: 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

County			
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
Kirinyaga	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 6-22: 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 6-23: 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.

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