



**BIOENERGY AND FOOD SECURITY
RAPID APPRAISAL (BEFS RA)**

User Manual

**CROP RESIDUES
AND LIVESTOCK RESIDUES**



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BEFS Rapid Appraisal

Natural Resources Module

Agricultural Residues Component

Crop Residues and Livestock Residues

User Manual

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1 Overview of the Natural Resources Module

Biofuels can be produced from different types and forms of biomass: fuelwood, crops, biodegradable residues and waste of different origins (e.g. municipal, industrial, agriculture and fisheries), etc. Biofuels come in liquid, gaseous and solid forms and can be used for heating and cooking, electricity production and as transport fuels.

The *Natural Resources* module of the BEFS Rapid Appraisal is used to assess the availability of bioenergy feedstock originating from crop production, agricultural residues and forestry. The module is divided into three components, based on the biomass type. The three components are: *Crops*, *Agricultural Residues*, *Woodfuel and Wood Residues*.

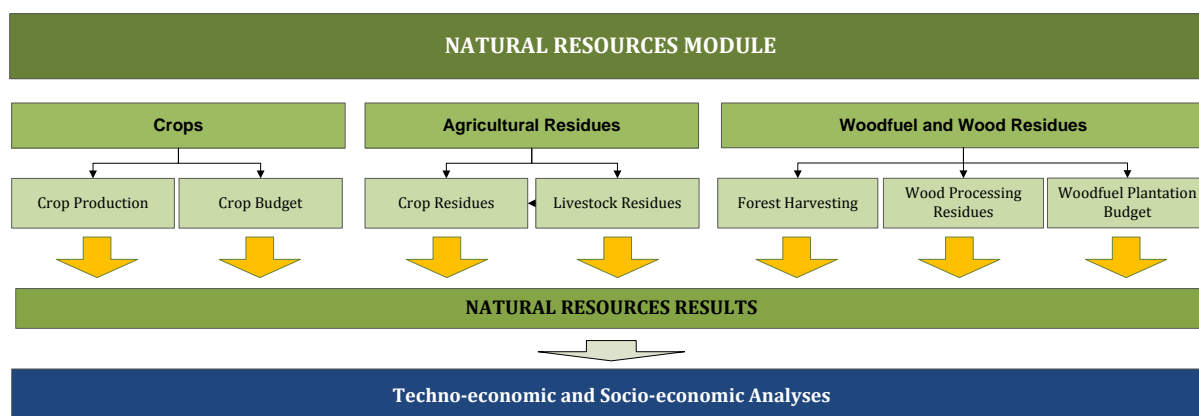


Figure 1: The Structure of the *Natural Resources* Module

Each component is an Excel file and within each file, there are one or more tools. Every Excel file starts with an introductory sheet explaining the structure and purpose of *Natural Resource* module.

The *Crops Component* includes the *Crop Production Tool* and *Crop Budget Tool*. The *Crop Production Tool* is used to assess the potential for additional production of oilseed, sugar and starch crops. The approach used to estimate the amount of these crops that could be available for bioenergy production, takes into account the countries needs for food, feed and other non-bioenergy purposes. Thus, food security measures are integrated into the analysis. These additional crops can then be used as feedstock for straight vegetable oil (SVO), biodiesel and ethanol.

The BEFS Rapid Appraisal land suitability maps are also included in the *Crops Component*. These country level maps were developed for 10 crops⁴ that are suitable for the production of liquid biofuels and were generated using the Global Agro-Ecological Zoning⁵ layers on land suitability and productivity (FAO, IIASA, 2012), the global land cover map GlobCover 2009 (ESA, 2012) and the World Database on Protected Areas (IUCN and UNEP, 2009). They serve to support the *Crops Production* and *Crops Budget* analyses.

The *Crop Budget Tool* provides an overview of input and labour requirements, in addition to crop production costs, profitability and labour demand. The *Crop Budget Tool* mirrors the set-up of the *Crop Production Tool*, allowing for the two tools to be used collectively or individually, depending on the nature of the analysis and the requirements needed. Crop budgeting requirements are differentiated by three input levels (i.e. low, medium, high), as in the *Crop Production Tool*.

⁴ The 10 crops are: cassava, maize, sorghum, sugarbeet, sugarcane, jatropha, oil palm, rapeseed, soybean and sunflower.

⁵ *Agro-ecological suitability and productivity – Total production capacity maps*

The *Agricultural Residues Component* encompasses tools to assess the availability of crop and livestock residues. Crop residues are suitable feedstock for the production of briquettes and pellets (solid biofuels), while manure is suitable for the production of biogas. These biofuels can be used for heating and cooking or for electricity generation through gasification or combustion.

The *Woodfuel and Wood Residues Component* includes three tools: *Forest Harvesting*, *Wood Processing Residues* and *Forest Plantations*. These tools facilitate the assessment of the potential for additional harvesting of fuelwood from production forests and the availability of forest harvesting residues and wood processing residues. The *Forest Plantation Tool* is used to assess the potential harvestable volume of wood from dedicated fuelwood plantations and the costs and benefits of establishing these plantations.

The foreseen flow and options of the analysis within each component are described in the respective manuals. The module can be used for the analysis of all or only selected biomass resources. Which tools will be used will depend on the aim of analysis. For example, if the user is interested to screen which biomass resources are available in the area of analysis (the country), then all of the tools will be used. Whereas, if the user is interested in a specific biofuel chain then only those relevant for the chain will be used. For example, if the user is interested in the production of briquettes from crop residues, then he/she will use the *Crop Residues Tool* of the *Agricultural Residues Component*.

All of the tools in the *Crops Component* have a results sheet that summarizes the outcomes of the analysis. Since one biomass type can be converted into final energy using different technological pathways, the user is asked to allocate the amount of available biomass among the various bioenergy supply chains.

For example, upon assessing the potential for additional production of soybean and sunflower in the results sheet, the user will need to define the percentage of the available crops for the production of straight vegetable oil (SVO) and for biodiesel. These feedstock amounts are then fed into the *SVO and Transport Tools* of the *Energy End Use Options* module. Therefore, the results from the *Natural Resources* module serve as a threshold for defining the appropriate size(s) and number of processing plants in the *SVO and Transport Tools*.

The user manual for the *Natural Resources* module is divided into four sections: *Crop Production*, *Crop Budget*, *Agricultural Residues*, *Woodfuel and Wood Residues*. Each section includes a detailed description of the tool, terms and definitions used, data required to run the analysis and the steps of analysis.

2 Terms and Definitions in the *Agricultural Residues Component*

This section includes definitions of specific terms used in the *Crop Residues* and *Livestock Residues Tools*. They refer to the production of crops and crop-residues and the use of residues, as well as to livestock keeping. Some of the terms are also used in other tools and components of the *Natural Resources* module, especially in the *Crop Production Tool*.

2.1 The *Crop Residues Tool*

- **Crop-Residue type:** refers to the crop-residue that can be used for bioenergy production.
- **Location of residue generation:** the place where the residues occur after harvesting.
- **Crop yield, (t/ha):** yield of the analysed crop obtained in the area of analysis, expressed in tons per hectare.
- **Annual production, (t):** the amount of analysed crop produced in one calendar year in the area of analysis, expressed in tons.
- **Number of harvests/year:** the number of harvests of the analysed crops in one calendar year.
- **Total production area, (ha):** the land area used for the production of the analysed crop, expressed in hectares.
- **Residue-to-crop ratio:** the ratio of the amount of residue generated to the amount of the main product of the crop (e.g. ratio of straw and grain in the case of cereals).
- **Total residue production, (t):** the amount of the analysed crop-residue type produced in one calendar year in the area of analysis, expressed in tons.
- **Residue yield, (t/ha):** the production of the analysed crop-residue type obtained in the area of analysis, based on the crop production, expressed in tons per hectare.
- **Residue left in the field:** refers to the residue left in the field after harvesting or returned to the fields for the maintenance of soil fertility and stability.
- **Production area burnt after harvesting:** the number of hectares burnt after harvesting as a method of land clearing and preparation for the next production cycle.
- **Residues burnt in the field:** the amount of residues burnt in the field after harvesting calculated based on the number of hectares burnt after harvesting the main product.
- **Current use of residues:** refers to the portion of the total amount of residue that is currently used in the country for different purposes; therefore they are not available for bioenergy production.

2.2 The *Livestock Residues Tool*

- **Dairy Cows/Bufaloes:** refers to cows and buffaloes kept for dairy production.
- **Commercial production:** market-oriented production.
- **Number of heads held by households:** refers to animals kept by households.
- **Cattle feeding system “stable only”:** refers to animals that are held and fed in stables, and the manure produced is easily collected.
- **Cattle feeding system “grazing and stable”:** refers to animals that spend part of the day grazing in pastures and the other part in the stables; only the manure produced when feeding takes place in the stables is collected for biogas production.
- **Cattle feeding system “seasonal grazing”:** refers to animals that spend a certain period of the year in pastures; the manure for biogas production is collected only during the period when feeding takes place in stables and is not collected during the period spent in the pasture.

- **Cattle feeding system “year-round grazing”:** animals spend the whole year grazing in pastures and therefore manure is not collected for biogas production.
- **Manure (kg/head/day):** the quantity of manure (faeces and urine) produced by an animal per day.
- **Volatile solids:** the organic fraction of the total solids in manure that will oxidize and be driven off as gas at a temperature of 600°C.

3 Scope and Objective of the *Agricultural Residues Component*

As described earlier, the *Agricultural Residues Component* includes the *Crop Residues* and *Livestock Residues Tools*. The structure of the component and its tools are presented in the following figure.

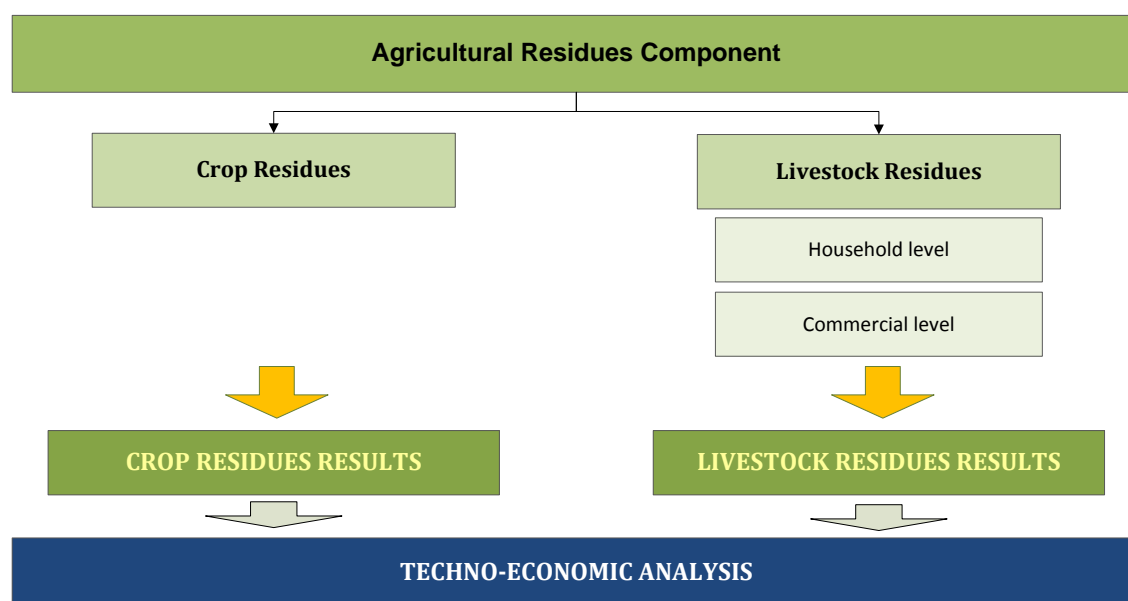


Figure 2: Structure of the *Agricultural Residues Component*

3.1 The *Crop Residues Tool*

Crop residues can be used for the production of solid biofuels, such as briquettes, pellets and charcoal, and can also be burnt directly for heating and cooking. The conversion of residues into solid biofuels entails thermo-mechanical processing, which increases the energy density of the residues and makes them more suitable for final energy consumption. The aim of the *Crop Residues Tool* is to assess the amount of residues available for bioenergy production, based on the production of the respective crops and current use of residues.

Safeguarding the sustainable use of natural resources and soil protection is sought through a defined flow of analysis and underlying methodology. In order to minimize competition with other uses of crop residues, the amount of residues already used for feed and animal bedding, construction, industry or other uses, is identified and not considered as available for bioenergy production. The importance of the fertility and stability of soils for agricultural production and the role of residues in sustaining them, especially when the application of fertilizers and other agro-technical measures are not optimal, is also addressed in the analysis. The user is made aware that certain amounts of residues should be left in the field after harvesting and is asked to provide the percentage of residues that will be left in the field. In case the user does not have

information on the amount of residues left in the field, a default value of 25% can be used. This amount is also excluded from the residues available for bioenergy production. On the other hand, the amount of residues that is currently burnt in the field is considered as potentially available for bioenergy production. Namely, burning of residues has negative impacts on soil and emits greenhouse gases into the atmosphere. Within the analysis, the user is asked to provide information about the production area that is burnt after harvesting. If country-specific data are unavailable, then the default value⁶ which is 10% of the production area can be used to estimate the amount of residues burnt.

In total 30 crop-residue types can be analysed with the tool. It includes default values for residue-to-crop ratio for 30 crop-residue types, and information on 10-year average annual production and crop yields for 17 crops. The crops included in the database are commonly used as staple and cash crops whose residues are suitable for energy production.

The analysis can be conducted for the whole area of the country or a defined sub-national level, in which case the information on the crop yields and the related production has to be provided by the user.

The final results include the information on the amount of residues available for bioenergy production annually, the residue yield per hectare and production area. The results are summarized in the Agricultural Residues Results sheet. Here, the user is asked to define the technology pathways for final energy use of residues, i.e. to allocate the amounts among direct combustion and briquettes for heating and cooking, and gasification and combustion for rural electrification.

The methodology applied and limitations of the tool, as well as the list of required data and suggested data sources are described in detail in the Annex.

3.2 The Livestock Residues Tool

Livestock manure can be used for the production of biogas, which can then be used in the same manner as natural gas, i.e., for heating and cooking or electricity production. Anaerobic digestion of manure represents a good practice for manure management, because the methane which would otherwise be released into the atmosphere is captured and used as energy source (biogas). At the same time the utilization of manure as fertilizer is not diminished, but on the contrary it is improved. Namely, bio-slurry (digestate), which is a by-product of biogas production, is a higher quality fertilizer in comparison to fresh or composted manure, e.g. the concentration of nutrients is higher and the risk of spreading pathogens and xenobiotics is lower, because of thermal treatment of manure during the anaerobic digestion.

The *Livestock Residues Tool* is designed to support the assessment of manure production from cows and buffaloes, swine and chickens on an annual level. In the case of cows and swine, the analysis can be conducted for livestock kept both for commercial and household (subsistence) production, while for chickens it can only be conducted for commercial production.

The analysis is based on the number of heads in commercial and household production, and the estimated manure production per head per day. The tool includes default values on the production of manure per head per day and the content of volatile solids in the manure. The default values integrated in the tool are the IPCC default values, which are used when applying Tier 2 methodology in national greenhouse gas inventories⁷. In line with the IPCC Guidelines, the default values are region specific, whereby the world is divided into nine

⁶ Source: IPCC Guidelines for National Greenhouse Gas Inventories, 2003

⁷ Source: IPCC Guidelines for National Greenhouse Gas Inventories, Vol.4, Annex 10A.2, 2006

regions: North America, Western Europe, Eastern Europe, Oceania, Latin America, Africa, Middle East, Asia and Indian Subcontinent. If country-specific data are available, those can be entered and will automatically be used for the calculations. In the case of cattle, the feeding system and the possibility to collect manure are taken into account as well. Specifically, it is assumed that only the manure collected in stables can potentially be used for biogas production, whereas that generated during grazing is not considered.

The final results include the amount of manure per year produced by the three livestock groups, at both the commercial and household production level. These are also summarized in the Agricultural Residues Results sheet.

The methodology applied and limitations of the tool, as well as the list of required data and suggested data sources are described in detail in the Annex.

4 Running the Tools of the *Agricultural Residues Component*

The *Crop Residues and Livestock Residues Tools* are embedded in the Excel file named *Agricultural Residues*. It contains five Excel sheets, of which the first two give information about the *Natural Resources* module and its *Agricultural Residues Component*, the sheets with *Crop Residues Tool* and *Livestock Residues Tool* follow, and finally, there is the Agricultural Residues Results sheet.

Depending on the aim of analysis, the user can decide whether he/she will analyse both crop and livestock residues, or only one of these. The flow of analysis is pre-defined and the user is navigated step by step through the tools and asked to enter necessary data in order to obtain final results. When the required data are limited or unavailable, then the default values provided by the tool can be utilized. The navigation buttons are placed on the top and bottom of each sheet, indicating the next step with the button “NEXT>>” and allowing the user to return to the previous section with the “<<BACK” button.

The following sub-chapters describe each step of the analysis, using Malawi as an example.

4.1 Starting the analysis

The first step after opening the *Agricultural Residues Component* file is to enable the use of **Macros & ActiveX** in the file, in order to use the tool (Figure 3). Next, the user must select the language of preference in order to view the tool in that language (Figure 4, label 1). The language choices are: English (EN), French (FR) and Spanish (ES).

At the beginning of the analysis, the user is informed about the aim and structure of the *Natural Resources* module and the *Agricultural Residues Component*.

In the *Agricultural Residues Component* sheet, the user should:

1. Select the country of analysis,
2. Select the area of analysis (if the analysis is conducted at a subnational level, then enter the name of the analysed area) and
3. Select the *Crops Residues* or *Livestock Residues Tool* button to start the analysis.

Figure 5 shows the layout of the *Crops Component* sheet with arrows signalling the steps previously described.

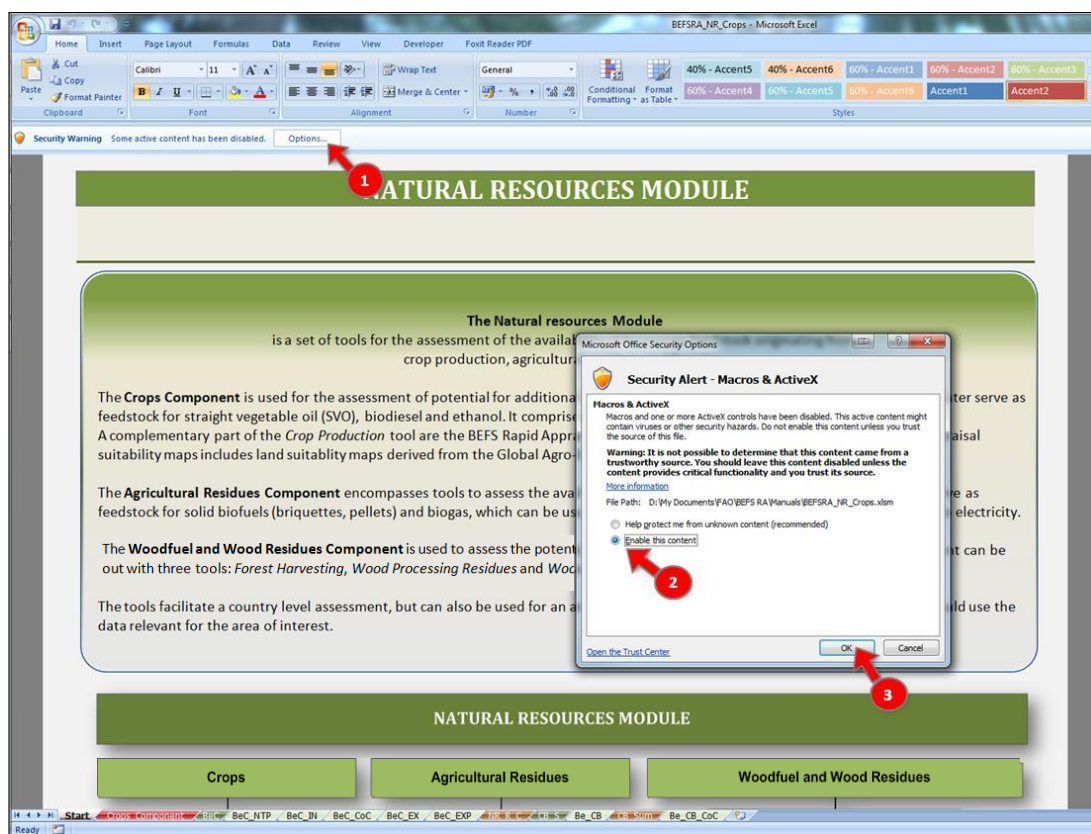
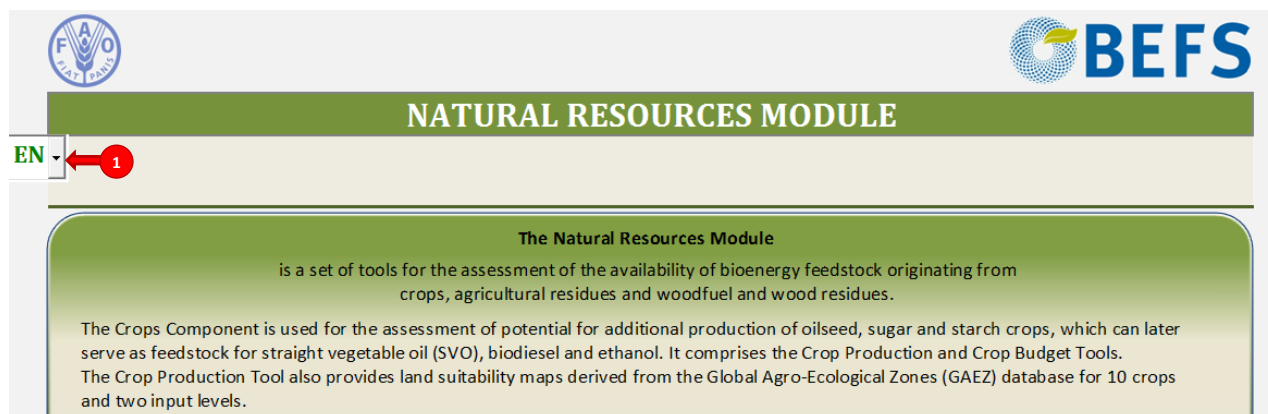
Figure 3: Opening the *Agricultural Residues Component File*

Figure 4: Language Selection

Agriculture Residues Component

Country: *Malawi* ▼ 1

BEFS Rapid Appraisal for *the country* ▼ 2 Clear data 3

The Agricultural Residues Component
includes the Crop Residues and Livestock Residues Tools.

The Crop Residues Tool is used to assess the amount of crop residues available for bioenergy production. The analysis is based on the production of selected crops and the current use of residues for non-energy purposes, such as feed and animal bedding, construction, industrial processing and others. As bioenergy feedstock, crop residues can be used for production of biofuels for heating and cooking (briquettes, pellets and charcoal) and for electricity generation through gasification and direct combustion.

In total 17 crops and 30 crop-residue combinations can be analysed. Residues of the following crops can be analysed with the tool: *barley, cacao, cassava, coconut, coffee, cotton, groundnut, maize, millet, oat, oil palm, rice, rye, sorghum, soybean, sugarcane and wheat.*

The Livestock Residues Tool can be used to assess the amount of manure generated by dairy cattle, pigs and chickens, that can be used for biogas production.

```

graph TD
    ARC[Agricultural Residues Component] --> CR[Crop Residues]
    ARC --> LR[Livestock Residues]
    LR --> HL[Household level]
    LR --> CL[Commercial level]
    CR --> CRR[CROP RESIDUES RESULTS]
    LR --> LRR[LIVESTOCK RESIDUES RESULTS]
    CRR --> TEA[Techno-economic and Socio-economic Analyses]
    LRR --> TEA
  
```

Crop Residues Tool 4 **Livestock Residues Tool**

Figure 5: Layout of the *Agricultural Residues Component* Introductory Sheet

4.2 Agricultural Residues Tool

4.2.1 Step 1: Selecting the crop-residue type

The first step is to select the crop-residue types that will be analysed and to define the location of residue generation. Up to four crop-residue types can be analysed at the same time and those are selected from drop-down lists. The list of crops and respective residues is given in Table 1. For each crop, one or more residues can be assessed.

The crop and crop residue type are selected from dropdown lists (Figure 6, label 1).

Table 1: List of Crop-Residue Types which can be Analysed with the *Crop Residues Tool*

Crop	Residue	Crop	Residue	Crop	Residue
1. Barley	straw	7. Groundnut	husk	12. Rice	straw husk
2. Cacao	Pods	8. Maize	cob husk stover	13. Rye	straw
3. Cassava	stalk			14. Sorghum	straw/stalk
4. Coconut	fronds husk shell	9. Millet	straw	15. Soybean	straw pods
		10. Oat	straw		
5. Coffee	husk	11. Oilpalm	empty bunches fronds shell	16. Sugarcane	tops/leaves bagasse
6. Cotton	hull stalk			17. Wheat	straw

4.2.2 Step 2: Defining the location of crop residues

For each crop-residue, the location of residues generation has to be defined, i.e., where the residues are located. From a drop-down list the user can select among three options: spread in the field, collected in the field and processing plant (Figure 6, label 2).

This information is important in order to evaluate the accessibility of residues and the cost-effectiveness of their use for energy production. Namely, if residues are spread in the field, they have to be collected and transported to a location for further processing into biofuels and energy generation. This requires additional time, labour and financial resources, which will have an impact on the production costs of bioenergy.

4.2.3 Step 3: Defining crop production

The amount of crop residues produced depends on the production of the crop; therefore it is necessary to assess the characteristics of crop production.

The user has to provide the following information for the selected crops (Figure 6, label 3):

- Crop yield (t/ha)
- Number of harvests per year
- Annual production (t/year)

If the required data are available from national statistics or reports, they should be used. In case such data are unavailable, the default values from FAOSTAT can be used (Figure 6, label i). The tool includes a table on the 10-year average yield and total production at country level. These values reveal neither the level of production (e.g., small-holders or large-scale/market-oriented) nor if production comes from rain-fed or irrigated agriculture.

If the aim of the analysis is to assess the crop-residues production in the future, based on the intensified yields of the respective crops, the information about the potential crop yields can be retrieved from the *Crops Component* of the *Natural Resources Module*. For further information, please refer to the chapter in the *Crop Production Tool User Manual* on the section over the intensification option and the *Crops Excel* file.

4.2.4 Step 4: Producing crop residues – Residue-to-Crop Ratio

Residue-to-crop-ratio is the ratio of the residue amount to the amount of main product of the crop (e.g., ratio of the amount of straw to grain, in the case of cereals). In order to calculate the amount of residues generated

on an annual level, it is necessary to enter the “residue-to-crop” ratio for each crop-residue type analysed, (Figure 6, label 4).

If country-specific data on the residue-to-crop ratio is not available, the tool provides default values, (Figure 6, label ii). The values provided by the tool are based on a literature review, which included scientific articles, studies and reports on surveys conducted in different countries as well as compendia from technical consultations.

CROP RESIDUES

COUNTRY: *Malawi*

BEFS Rapid Appraisal for the country

Enter data into white cells | Grey cells are calculated

Select crop-residue type

	Crop 1	Crop 2	Crop 3	Crop 4
Crop	maize	rice	sorghum	sugarcane
Residue	cob	husk	straw/stalk	baggase
Location of residue generation	processing plant	sing plant	field - spread	processing plant

Crop production

	Crop 1	Crop 2	Crop 3	Crop 4
Crop yield (t/ha)	1.64	1.67	0.71	107.72
No. of harvests/year	1.0	1.0	1.0	1.0
Annual production (t)	2,554,766	95,453	51,097	2,415,000
Total production area (ha)	1,557,784.15	57,157.49	71,967.61	22,419.24

Generation of crop residues

	Crop 1	Crop 2	Crop 3	Crop 4
Residue to crop ratio	0.33	0.25	2.44	0.26
Total residue production (t/year)	844,997.42	23,863.25	124,676.68	622,725.00
Residue yield (t/ha)	0.54	0.42	1.73	27.78

10-years average annual production at country level (based on FAOSTAT 2004-2013)

Parameter	Unit	Crop 1	Crop 2	Crop 3	Crop 4
Crop		maize	rice	sorghum	sugarcane
Yield	t/ha	1.85	1.72	0.74	107.76
Production	t/year	2,926,581	101,044	57,911	2,515,000

Residue to crop ratio

Crop - residue type	maize - cob	rice - husk	sorghum - straw/stalk	sugarcane - baggase
average	0.33	0.25	2.44	0.26
min	0.20	0.15	1.00	0.14
max	0.86	0.36	4.60	0.40
stdev	0.16	0.06	0.97	0.07

Figure 6: Layout of the *Crop Residues Tool* – Part 1

When using the default values in the analysis, the user should bear in mind that they represent global averages, which in turn reflect on the level of accuracy in the final results. In practice, the residue-to-crop ratio is species and cultivar-specific and can be affected by agricultural management practice, inputs, climatic conditions during the growing period, and so forth. For example, advanced cultivars usually have a lower residue-to-crop ratio than traditional ones.

After selecting a crop-residue type, the tool shows an average residue-to-crop ratio as well as the respective minimum, maximum and standard deviation values. Thus, after considering the predominant agricultural practices in crop production (e.g., type of cultivars, use of agro-chemicals, pest management, etc.), the user can evaluate which residue-to-crop ratio would be most appropriate to use.

4.2.5 Step 5: Defining the residues left in the field

In this step, the user defines what percentage of the generated residues will be left in the field after harvesting (Figure 7, label 5).

The amount of residues which should be left will depend on the soil type and structure, crop rotation, tillage system and existing conservation practices. The residues can improve soil fertility by providing macro- and micro-nutrients, preventing erosion by stabilizing the top layers of the soil and increasing soil organic matter, which provides carbon and energy for soil microorganisms that are essential for maintaining the nutrient cycles. All these factors, as well as the existing agricultural practices and the use of fertilizers, should be considered when defining the percentage (amount) of residues left in the field.

If country-specific information or recommendations do not exist, then the default values provided by the tool can be used (Figure 7, label 5). The default value of 25% is set for the residues generated in the field. This value represents an estimation based on a literature review, which can be applied globally and ensure sustainability of agricultural production. For residues generated in the processing plant, the default value is set at 0%.

4.2.6 Step 6: Estimation of the residues burnt in the field

In many countries, burning crop residues in the field is still practiced to prepare for the subsequent production cycle. This practice has harmful effects on the soil biota, diminishes soil fertility, and causes additional emission of greenhouse gases while wasting the resource, which could be used for energy production.

In order to identify the amount of residues which is currently burnt (and could actually be used as bioenergy feedstock), the user is asked to provide information about the production area which is subjected to burning after the harvest.

If the country-specific data are not available, then the default value⁸ of 10% of the production area can be used to estimate the amount of residues burnt (Figure 7, label 6).

4.2.7 Step 7: Defining the current use of crop residues

In order to avoid double counting and competition with other uses of the residues available for bioenergy production, it is necessary to identify the amount of residues currently used. Therefore, the user is asked to estimate the percentage of the total residue amount which is currently used as animal feed and bedding, fuel, construction material, in the industry or for other purposes (Figure 7, label 7).

Finally, the annual amount of residues potentially available for bioenergy is calculated (Figure 7, label 8). Residues that are burnt in the field are considered as potentially available for bioenergy, while those left in the field or currently used are not considered.

⁸ Source: IPCC Guidelines for National Greenhouse Gas Inventories, 2003

Residues left in the field (for soil fertility and stability)				
User defined (%)	<input type="text" value="5%"/>	<input type="text" value="0%"/>	<input type="text" value="25%"/>	<input type="text" value="0%"/>
Default value (%)				
Total (t/year)	42,249.87	0.00	31,169.17	0.00

Residues burnt in the field (production area burnt after the harvest)				
Production area burnt after harvesting	User defined (t/ha)	<input type="text" value="0.00"/>	<input type="text" value="7,136.76"/>	<input type="text" value="0.00"/>
	Default value (t/ha)			
Amount of residues burnt (t/year)	0.00	0.00	12,467.67	0.00

Current use of crop residues				
animal feed and bedding	%	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>
	t	0	0	0
fuel (including charcoal)	%	<input type="text" value="90.00%"/>	<input type="text" value="20.00%"/>	<input type="text" value="20.00%"/>
	t	760,498	4,773	24,935
construction	%	<input type="text" value="0"/>	<input type="text" value="30.00%"/>	<input type="text" value="30.00%"/>
	t	0	7,159	37,403
industry	%	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>
	t	0	0	0
other	%	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>
	t	0	0	0
Total currently used	(%)	90%	50%	50%
	(t/year)	760,497.68	11,931.63	62,338.34

Potentially available for bioenergy				
	maize - cob	rice - husk	sorghum - straw/stalk	sugarcane - baggase
Total (t/year)	42,250	11,932	43,637	249,090
Total production area (ha)	1,557,784	57,157	71,968	22,419
Residue yield (t/ha)	0.03	0.21	0.61	11.11
Location of residue generation	processing plant	processing plant	field - spread	processing plant

Figure 7: Layout of the Crop Residues Tool – Part 2

4.3 Livestock Residues Tool

4.3.1 Step 1: Cattle production

At the beginning of the analysis the user has to:

- Select the type of cattle which will be analysed: dairy cows or buffalo (Figure 8 or **Error! Reference source not found.**)
- Enter the total number of heads in the area of analysis
- Enter the percentage of heads in commercial production

The tool provides a table on the 3-year average number of heads in the country as reported in FAOSTAT, which can be used if data from national statistics are not available (Figure 8 or **Error! Reference source not found.**, label i).

4.3.2 Step 2: Defining the cattle feeding system

In order to assess the amount of collectable manure, it is necessary to characterize the cattle feeding systems. It is assumed that only manure from stables can be easily collected and used for biogas production. Therefore the user has to enter the percentage of cattle in the four types of feeding systems (Figure 8 or **Error! Reference source not found.**, label 2):

- Daily feeding: Stable only
- Daily feeding: Grazing and stable
- Seasonal grazing and number of months in pasture
- Year round grazing

This information has to be entered for both cattle kept by households and those in commercial production.

4.3.3 Step 3: Production of manure per head per day

Daily production of manure per animal depends on the size and age, as well as the amount and composition of feed intake. These parameters and the herd composition are taken into account when estimating average manure production per head per day for a herd or herds in a specific area.

If country-specific data are available, those should be entered in the “User Defined” column (Figure 8 or **Error! Reference source not found.**, label 3). The user defined data will automatically be used for the assessment of annual manure production.

The tool provides default values on manure production, expressed in kg per head per day, and the content of volatile solids in manure. The default values are those suggested by the IPCC Guidelines⁹ for Tier 2 methodology for the development of National Greenhouse Gas Inventories. The default values are region-specific, whereby the world is divided into nine regions: North America, Western Europe, Eastern Europe, Oceania, Latin America, Africa, Middle East, Asia and Indian Subcontinent.

When only one of the required parameters is defined by the user, the calculation will be based on that number and the default value will be considered for the other parameter. For example, if the user enters the value for manure production per head per day (kg/head/day), but not the content of volatile solids in the manure, then the estimated manure production will be based on the “user defined” value while the default value will be used for the estimation of biogas production in the techno-economic analysis section.

⁹ Source: IPCC Guidelines for National Greenhouse Gas Inventories, Vol.4, Annex 10A.2, 2006

Cattle: Dairy cow

Cattle production	
Species	Dairy cow
Total number of heads	84,667
Commercial production (%)	60.00%

i

3-years average annual production data (FAOSTAT 2011-13)	
Species	Dairy cow
heads	110,333

Household level production

Number of heads held by households	33,867
------------------------------------	--------

Cattle feeding systems

1. Daily feeding: stable only	%		30%
2. Daily feeding: grazing and stable	%		50%
3. Seasonal grazing	%		20%
- Number of months in pasture			4.0
4. Year-round grazing	%		

Commercial level production

Number of heads in commercial production	50,800
--	--------

Cattle feeding systems

1. Daily feeding: stable only	%		10%
2. Daily feeding: grazing and stable	%		50%
3. Seasonal grazing	%		30%
- Number of months in pasture			1.0
4. Year-round grazing	%		

Production of manure per head/day

DEFAULT VALUE		USER DEFINED
14.34	Manure (kg/head/day)	
13.25%	% of volatile solids in manure	
1.90	Volatile solids (kg/head/day)	0.00

Figure 8: Layout of the *Livestock Residues Tool* – Dairy cow

Cattle: Buffalo

Cattle production	
Species	Buffalo
Total number of heads	84,667
Commercial production (%)	60.00%

i

3-years average annual production data (FAOSTAT 2011-13)	
Species	Buffalo
heads	

Household level production

Number of heads held by households	33,867
------------------------------------	--------

Cattle feeding systems

1. Daily feeding: stable only	%		30%
2. Daily feeding: grazing and stable	%		50%
3. Seasonal grazing	%		20%
- Number of months in pasture			4.0
4. Year-round grazing	%		

Commercial level production

Number of heads in commercial production	50,800
--	--------

Cattle feeding systems

1. Daily feeding: stable only	%		10%
2. Daily feeding: grazing and stable	%		50%
3. Seasonal grazing	%		30%
- Number of months in pasture			1.0
4. Year-round grazing	%		

Production of manure per head/day

DEFAULT VALUE		USER DEFINED
0.00	Manure (kg/head/day)	
-	% of volatile solids in manure	
0.00	Volatile solids (kg/head/day)	0.00

Figure 9: Layout of the *Livestock Residues Tool* – Buffalo

4.3.4 Step 4: Swine production

The user has to enter (Figure 10, label 4):

- Total number of heads in the area of analysis
- Percentage of heads in commercial production

The tool provides a table on the 3-year average number of heads in the country as reported in FAOSTAT, which can be used if data from national statistics are not available (Figure 10, label i).

4.3.5 Step 5: Production of manure per head per day

If country-specific data are available, those should be entered in the “User Defined” column (Figure 10, label 5). The user defined data will automatically be used for the assessment of annual manure production.

The tool provides default values on manure production, expressed in kg per head per day, and the content of volatile solids in the manure. The default values are those suggested by the IPCC Guidelines¹⁰ for Tier 2 methodology for the development of National Greenhouse Gas Inventories. The default values are region specific, whereby the world is divided into nine regions: North America, Western Europe, Eastern Europe, Oceania, Latin America, Africa, Middle East, Asia and Indian Subcontinent.

When only one of the required parameters is defined by the user, the calculation will be based on that number and the default value will be considered for the other parameter. For example, if the user enters the value for manure production per head per day (kg/head/day), but not the content of volatile solids in the manure, then the estimated manure production will be based on the “user defined” value while the default value will be used for the estimation of biogas production in the techno-economic analysis section.

4.3.6 Step 6: Chicken production

The user has to enter (Figure 10, label 6):

- Total number of heads in the area of analysis, expressed in thousands
- Percentage of heads in commercial production

The tool provides a table on the 3-year average number of heads in the country as reported in FAOSTAT, which can be used if data from national statistics are not available (Figure 10, label ii).

The analysis refers only to chickens in commercial production.

4.3.7 Step 7: Production of manure per head per day

If country-specific data are available, those should be entered in the “User Defined” column (Figure 10, label 7). The user defined data will automatically be used for the assessment of annual manure production.

The tool provides default values on manure production, expressed in kg per head per day, and the content of volatile solids in the manure. The default values are those suggested by the IPCC Guidelines¹¹ for Tier 2 methodology for the development of National Greenhouse Gas Inventories. The default values are region specific, whereby the world is divided into nine regions: North America, Western Europe, Eastern Europe, Oceania, Latin America, Africa, Middle East, Asia and Indian Subcontinent.

¹⁰ Source: IPCC Guidelines for National Greenhouse Gas Inventories, Vol.4, Annex 10A.2, 2006

¹¹ Source: IPCC Guidelines for National Greenhouse Gas Inventories, Vol.4, Annex 10A.2, 2006

When only one of the required parameters is defined by the user, the calculation will be based on that number and the default value will be considered for the other parameter. For example, if the user enters the value for manure production per head per day (kg/head/day), but not the content of volatile solids in the manure, then the estimated manure production will be based on the “user defined” value while the default value will be used for the estimation of biogas production in the techno-economic analysis section.

Swine

Swine production	
Total number of heads	792,364
Commercial production (%)	91.00%

i 3-years average annual production data (FAOSTAT 2011-13)

heads	2,469,417
-------	-----------

Household level production

Number of heads held by households	71,313
------------------------------------	--------

Commercial level production

Number of heads in commercial production	721,051
--	---------

Production of manure per head/day

DEFAULT VALUE			USER DEFINED
1.27	Manure (kg/head/day)		
23.60%	% of volatile solids in manure		
0.30	Volatile solids (kg/head/day)		0.00

Manure available for biogas production

Household level biogas production

Production of manure	t/year	33,085.77
----------------------	--------	-----------

Commercial level production

Production of manure	t/year	334,532.69
----------------------	--------	------------

Clear data

Chicken

Chicken production	
Total (1,000 heads)	7,557
Commercial production (%)	51.00%

ii 3-years average annual production data (FAOSTAT 2011-13)

1,000 heads	16,900
-------------	--------

Commercial level production

Number of heads in commercial production	3,854,070
--	-----------

Production of manure per head/day

DEFAULT VALUE			USER DEFINED
0.04	Manure (kg/head/day)		
49.33%	% of volatile solids in manure		
0.02	Volatile solids (kg/head/day)		0.00

Figure 10: Layout of the *Livestock Residues Tool* – Swine and Chicken

5 The Results of the *Agricultural Residues Component*

Upon finalizing the analysis for crop residues and livestock residues, the results are summarized in the Agricultural Residues Results sheet.

5.1 The crop residues results

The final results of the analysis are the potentially available amount of crop residues that can be used for the production of solid biofuels or burnt directly for heating and cooking. For each crop-residue type, the following information is presented (Figure 11, label 1):

- Amount of residues available for bioenergy, expressed in tons per year
- Total production area, expressed in hectares
- Residue yield, expressed in tons per hectare
- Location of residue generation
- Number of stable reared heads

The annual amount of residues is also presented graphically.

In this sheet, the user can allocate the amount of potentially available crop residues which could be used for heating and cooking and rural electrification.

The user is asked to enter (Figure 11, label 2):

1. Heating and cooking
 - a. the percentage of available residues that will be used directly (combusted)
 - b. the percentage of available residues that will be used for the production of briquettes
 - c. the percentage of available residues that will be used for the production of pellets
2. Electricity and/or Heat
 - a. the percentage of available residues that will be converted to electricity through combustion
 - b. the percentage of available residues that will be converted to electricity through gasification
 - c. the percentage of available residues that will be converted to electricity and heat through combined heat and power generation technology
 - d. the percentage of available residues that will be used for the production of biogas and then converted to electricity and/or heat through combined heat and power generation technology
3. Transport
 - a. the percentage of available residues that will be used for the production of ethanol (second generation) for transport

The amount (t) allocated to each end use is then calculated and the results are presented numerically and graphically.

5.2 The livestock results

The final result of the analysis is the amount of manure potentially available for biogas production. The results are presented for both commercial and household production levels for manure generated by cattle and pigs, while at only the commercial production level for manure generated by chickens (

Figure 12).

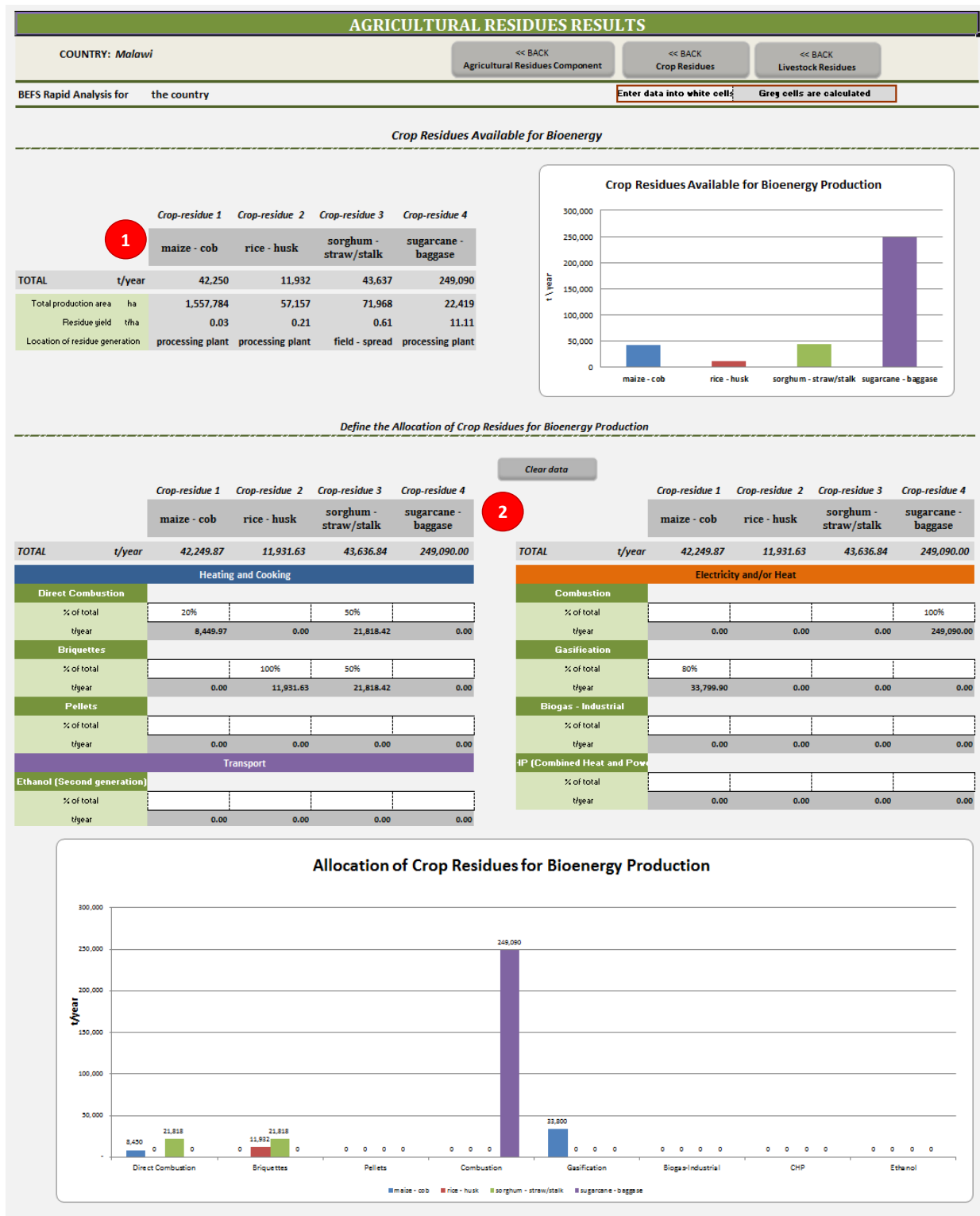


Figure 11: Layout of Agricultural Residues Results Sheet – Crop Residues

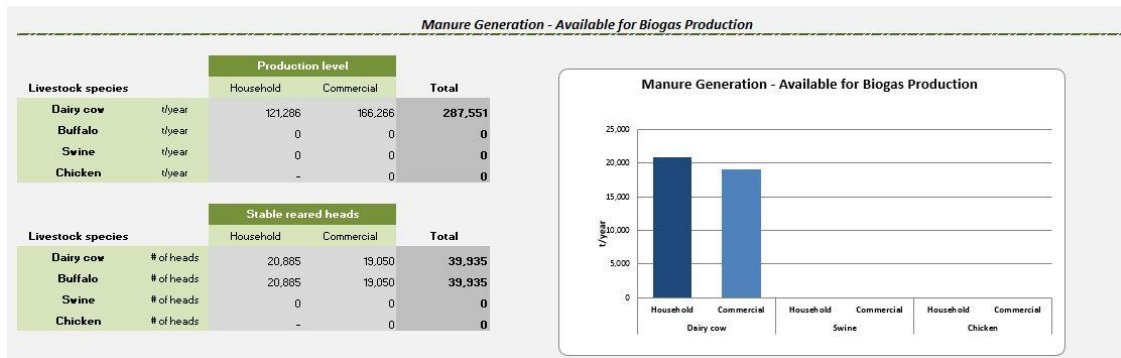


Figure 12: Layout of Agricultural Residues Results Sheet – Livestock Residues

6 Assumptions and Limitations

Before starting an analysis, the user should become familiar with the assumptions and limitations of the tools and take them into consideration during the analysis and most especially when interpreting the results. Apart from the limitations and assumptions, it is of utmost importance to be aware of the aim of the tool. This holds true for all the tools.

The aim of the BEFS Rapid Appraisal is to provide easily applicable and user-friendly tools that can support an analysis even when the user has limited access/availability to the data needed. Furthermore, the aim of the Natural Resources module is to provide an indication of the potential for the production of bioenergy feedstock in a food-secure and sustainable way.

6.1 Assumptions and limitations of the *Crop Residues Tool*

The limitations of the *Crop Residues Tool* primarily refer to the default values incorporated in the tool:

1. The FAOSTAT data on the crop production and yield
 - FAOSTAT is a global database on the world agricultural statistics, managed by UN FAO. The statistical data stored in FAOSTAT originate from the respective countries, which send their data to the FAO Statistics Division. The FAOSTAT data integrated into the Agricultural Residues Component refer to the whole country, i.e., the yields are averaged at the country level. This means that differences among agricultural practices and technologies, (e.g., subsistence-market oriented, small holder-commercial, rainfed-irrigated) are not revealed.
2. The residue-to-crop ratio default values
 - Residue-to-crop-ratio is the ratio of the amount of residue and the amount of main product of the crop (e.g., the ratio of the amount of straw to grain, in the case of cereals). It is species and cultivar-specific and can, for example, be affected by agricultural management practice, inputs, and climatic conditions during the growing period. In general, advanced cultivars usually have a lower residue-to-crop ratio than the traditional ones.
 - The tool includes only generic crop species as provided in FAOSTAT, i.e., it does not differentiate among subspecies or cultivars, and aims to be globally applicable (while there is no global database on residue-to-crop ratio, for each crop-residue type an average default value is given). The values are derived from extensive literature research, which encompassed scientific articles, studies and reports for a number of countries around the world. In order to facilitate the decision of which value to use for the analysis, for each average value the minimum, maximum and standard deviation are shown.
3. The default values for the residues left in the field
 - The amount of residues which should be left will depend on the soil type and structure, crop rotation, tillage system and existing conservation practices.
 - Considering the aim and structure of the tool, which does not reveal characteristics of the predominant soil structure and agricultural practices in the analysed area, a single default value had to be determined. The value of 25% is based on expert opinion, which was founded on thorough literature research. This value may be seen as conservative in some cases, but it should be seen as a “safeguard” value that ensures soil conservation and sustainability of agricultural production.
 - For the residues generated at a processing plant, such as rice husk for example, the default value is set at 0%. Namely, it is assumed that it would not be cost-effective to return the residues back to the fields.

4. The default values for the residues burnt in the field

- In many countries, burning crop residues in the field is still practiced to prepare for the subsequent production cycle. This practice is not recommended, due to the harmful effects on the soil biota and the resulting greenhouse gas emissions. The practice of burning is neither crop-specific nor country-specific, but rather depends on the prevailing circumstances and traditions in agricultural practices and the implementation of laws and regulations (which in a number of countries ban field burning). The IPCC Guidelines for National Greenhouse Gas Inventories (2003) estimate that in developing countries, 10% of the fields are burnt post-harvest. This value is utilized as the default value in the *Crop Residues Tool*.

An overview of the assumptions and limitations of the tool is given in the table below. They are also included as part of the methodology description.

Table 2: Overview of the Assumptions and Limitations for each Crop Production Option

Assumptions	Limitations
<ul style="list-style-type: none"> - Crop-residue production is positively correlated with crop production, based on the residue-to-crop ratio. - In order to sustain soil fertility and stability, it is necessary to leave a certain amount of residues on the soil after harvesting. - Burning of residues in the field is not recommended and the residues burnt can be used for bioenergy production. - The residues used for other purposes should not be accounted as a potential resource for energy production, e.g., energy production should not compete with other residues uses. 	<ul style="list-style-type: none"> - The tool provides information about the existing production of the selected crops at the country level. These include a 10-year average annual yields and country level production based on statistical data, (FAOSTAT, 2013). - The tool provides default values for the residue-to-crop ratio, which are not country-specific but based on literature research. - The tool provides default values for the amount of residues to be left in the field. The value is based on expert opinion that is founded on literature research. - The tool provides a default value for the estimated area burnt after harvesting. It is not crop or country-specific, but based on IPCC Good Practice Guidelines (2003).

6.2 Assumptions and limitations of the *Livestock Residues Tool*

The limitations of the *Crop Residues Tool* primarily refer to the default values incorporated in the tool:

1. The FAOSTAT data on the number of animals
 - FAOSTAT is a global database on the world agricultural statistics, managed by UN FAO. The statistical data stored in FAOSTAT originate from the respective countries, which send their data to the FAO Statistics Division. The FAOSTAT data integrated into the *Agricultural Residues Component* refer to the whole country, not differentiating among household and commercial production, variety, age and size of animals.
2. The default values on manure production per head per day
 - Since there is no global database which provides country-specific data on manure production, the tool uses the default values suggested by the IPCC Guidelines for National Greenhouse Gas Inventories, (Vol.4, Annex 10A.2, 2006), for manure management Tier 2 methodology. In line with the IPCC Guidelines, the default values are region specific, whereby the world is divided into nine regions:

North America, Western Europe, Eastern Europe, Oceania, Latin America, Africa, Middle East, Asia and Indian Subcontinent.

3. The tool supports the assessment of manure production per species, but does not support the assessment of other biodegradable residues and waste, which might be also used for biogas production in co-digestion with manure.

An overview of the assumptions and limitations for each production option is given in the table below. They are included as part of the methodology description.

Table 3: Overview of the Assumptions and Limitations for each Livestock Option

Assumptions	Limitations
<ul style="list-style-type: none"> - All of the manure of cattle fed in stables can be collected. - In the daily feeding system of stable-grazing, 50% of manure produced can be collected. - During the grazing period, manure is not collected. - The amount of manure produced per head per day is the same for animals kept by households and those in the commercial production, i.e., only one value is considered in the calculations. 	<ul style="list-style-type: none"> - The tool provides information about the existing production of animals at the country level. These include a 3-year average annual number of heads in the country, based on statistical data (FAOSTAT, 2013). - The tool provides default values for manure production per head per day and the content of volatile solids in the manure, which are the bases for estimating biogas production potential. The default values are region specific, based on the IPCC Good Practice Guidelines (2006).

7 Annex

7.1 Methodology and outputs

This section describes the methodologies used in the *Crop Residues* and *Livestock Residues Tools*. It also includes a description of the databases integrated in the tool. The databases are not visible to the user, but their structure and content are important for interpretation of the results and for those who will update them and/or work on the improvement of the tool.

7.1.1 Crop Residues Tool

The assessment is based on the assumptions that:

- the crop-residue production is positively correlated with crop production, based on the residue-to-crop ratio,
- in order to sustain soil fertility and stability, post-harvest it is necessary to leave a certain amount of residues on the soil,
- the residues currently burnt in the field after harvesting can be used for bioenergy production,
- the residues used for other purposes should not be accounted as potential resource for energy production, e.g., energy production should not compete with other uses.

Considering these assumptions, the residues potentially available for bioenergy production is calculated as the difference between total amount of residues produced and the sum of residues left in the field and those used for other purposes:

$$CR_{be} = CR_{tot} - (CR_{fl} + \sum CR_u) \quad (1)$$

Where:

- CR_{be} , [t/year] = crop residues available for bioenergy
- CR_{tot} , [t/year] = total amount of residues produced per year
- CR_{fl} , [t/year] = residues left in the field
- CR_u , [t/year] = residues used for other purposes

The total amount of residues produced per year is calculated as a product of crop produced and residue-to-crop ratio.

$$CR_{tot} = P * RTC \quad (2)$$

Where:

- P , [t/year] = crop production (t)
- RTC = residue-to-crop ratio

The amount of residues left in the field, (CR_{fl}), is calculated as a product of the total amount of residues produced per year and the user defined percentage of residues left in the field or the default value provided by the tool. If the location of residue generation is *spread in the field* or *collected in the field*, the default value is 25%, and if it is *processing plant* the default value is 0%.

Residues used for other purposes, (CR_u), is calculated based on the defined percentage of total residues produced, which is used for animal feed and bedding, fuel, construction and other purposes.

7.1.2 Livestock Residues Tool

The assessment is based on the following assumptions:

- The manure of the cattle fed in stables can be collected and used for biogas production. In the daily feeding system of stable-grazing, 50% of manure produced can be collected. During the grazing period, manure is not collected.
- All manure produced by pigs and chickens can be collected and used for biogas production.
- The values used for the production of manure per head per day represent an average for all animals in the assessment area.
- The amount of manure produced per head per day is the same for animals kept by households and those in the commercial production, i.e., only one value is considered in the calculations.
- The results represent theoretical potential for biogas production.

Cattle

The amount of manure that can be used for biogas production is calculated as a sum of collectable manure produced by cattle in the daily feeding systems *stable only* and *stable and grazing*, and the *seasonal grazing* feeding system:

$$MC_{be} = MC_{st} + MC_{stg} + MC_{sg} \quad (3)$$

Where:

- MC_{be} , [t/year] = total amount of cattle manure available for biogas production per year
 MC_{st} , [t/year] = amount of manure from cattle with daily feeding systems *stable only*
 MC_{stg} , [t/year] = amount of manure from cattle with daily feeding systems *stable and grazing*
 MC_{sg} , [t/year] = amount of manure from cattle with feeding systems *seasonal grazing*

The amount of manure produced by cattle with daily feeding system *stable only* is calculated as:

$$MC_{st} = C_{st} * k_c * 365 * 1000 \quad (4)$$

Where:

- C_{st} = number of heads with daily feeding systems *stable only*
 k_c , [kg/head/day] = kg of manure produced per head per day (dairy cow/buffalo)

The amount of manure produced by cattle with daily feeding system *stable and grazing* is calculated as:

$$MC_{stg} = C_{stg} * k * 365 * 500 \quad (5)$$

Where:

- C_{stg} = number of heads with daily feeding systems *stable and grazing*

The amount of manure produced by cattle with feeding system *seasonal grazing* is calculated as:

$$MC_{sg} = C_{sg} * k * (365 - g * 30) * 1000 \quad (6)$$

Where:

- C_{sg} = number of heads with feeding systems *seasonal grazing*
 g = number of months spent in pasture

Swine and chicken

The amount of manure produced by pigs and chickens is calculated as a product of number of heads and annual manure production per head:

$$MCh_{be} = Ch * k_{ch} * 365 * 1000 \quad (7)$$

$$MS_{be} = S * k_s * 365 * 1000 \quad (8)$$

Where:

MCh_{be} , [t/year] = total amount of chicken manure available for biogas production per year

Ch = number of heads in the analysed area

k_{ch} , [kg/head/day] = kg of manure produced per head per day for chicken

MS_{be} , [t/year] = total amount of swine manure available for biogas production per year

k_s , [kg/head/day] = kg of manure produced per head per day for swine

7.1.3 Databases

The databases incorporated into the tool support the analyses in the *Agricultural Residues Component*. In cases when country-specific data are not available, the data provided by the tool can be used for the analysis. The databases include:

1. FAOSTAT production and yields

- **FAOSTAT_production:** includes data on the country level annual production of 25 key food and cash crops for the years 2002-2011. Source: FAOSTAT.
- **Production:** includes data on the country level 10-years average (2002-2011) annual production of the 26 crops. Source: FAOSTAT_production database.
- **FAOSTAT_yield:** includes data on the country level yields of 26 key food and cash crops for the years 2001-2010. Source: FAOSTAT.
- **Yield:** includes data on the country level 10-years average (2002-2011) yields of 25 the crops. Source: FAOSTAT_yield database.

2. Crops:

includes residue-to-crop ratio: average, minimum, maximum and standard deviation, for 17 crops and 30 crop-residue types.

3. FAOSTAT livestock

- **LVS_FAOSTAT:** includes data on the number of heads of cattle, buffalo (FAOSTAT Item *Milk, whole fresh buffalo*) and cows (FAOSTAT Item *Milk, whole fresh cow*), chicken and pigs for the years 2009-2011 and the 3-year average.
- **LVS:** includes region-specific default values on manure production and the content on volatile solids in manure (Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol.4, Annex 10A.2).

7.2 Data requirements for running the tool

The tables below include data requirements for running the *Agricultural Residues Component*. A suggested data source is provided.

Table 4: Data Requirements for Running the *Crop Residues Tool*

Data	Data Source
<i>Crop Production</i>	
- Current yield (t/ha)	Agricultural statistics (national, sub-national), FAOSTAT. Information provided by the tool.
- Number of harvests/year	Agricultural statistics (national, sub-national), FAOSTAT. NR module <i>crop catalogue</i> .
- Annual production (t)	Agricultural statistics (national, sub-national), FAOSTAT. Information provided by the tool.
<i>Crop Residues</i>	
- Residue-to-crop ratio	Agricultural statistics (national, sub-national), studies and reports. Recommendations for agricultural production. Information provided by the tool.
- Residues burnt in the field	Agricultural statistics (national, sub-national), studies and reports. National GHG inventories.
- Residues currently used	Market survey, agricultural statistics on livestock breeding, studies and reports.

Table 5: Data Requirements for Running the *Livestock Residues Tool*

Data	Data Source
<i>Livestock Production</i>	
- Number of heads in commercial and household level production	Agricultural statistics, market reports.
- Species-specific production of manure and manure composition	Livestock production statistics, research reports.

8 References

- Bhattacharya, S. C., et al. 1989. Potential of Biomass Residue Availability: The Case of Thailand. *Energy Sources* vol. 11 no.3 p. 201-216.
- Eisentraut, A., 2010. Sustainable production of second-generation biofuels. International Energy Agency (IEA) Information paper.
- FAO, 1982. Agricultural residues: bibliography 1975-81 and quantitative survey. FAO Agricultural Services Bulletin.
- FAO (1998), Proceedings of the Regional Expert Consultation on Modern Applications of Biomass Energy, FAO Regional Wood Energy Development Programme in Asia, Report No. 36, Bangkok.
- FAO (2012). Global Forest Resources Assessment 2010 (FRA2010)
- FAO (2013a). FAOSTAT – Data portal. FAO, Rome, Italy. Available at <http://faostat.fao.org/>.
- (FAO, 2013b). Roadmap for Action towards Sustainable Bioenergy Development for Food Security – Malawi. (Working draft).
- Gregg, J.S., Smith S.J., 2010. Global and regional potential for bioenergy from agricultural and forestry residue biomass. *Mitigation and Adaptation Strategies for Global Change* vol 15 is.4 p.241-262.
- IPCC Guidelines for National Greenhouse Gas Inventories, 2003
- IPCC Guidelines for National Greenhouse Gas Inventories, 2006
- Jenkins, B.M., Ebeling, J.M. 1985. Thermochemical properties of biomass fuels. *California Agriculture* 39(5,6):14-16.
- Jiang, D. et al. 2012. Bioenergy potential from crop residues in China: Availability and distribution. *Renewable and Sustainable Energy Reviews* 16 p.1337-1382.
- Jingura, R.M., Matengaifa, R. 2008. The potential for energy production from crop residues in Zimbabwe. *Biomass and Bioenergy* vol. 32 is.12 p.1287-1297.
- Koopmans, A., Koppejan, J., 1997. Agricultural and forest residues: Generation, Utilization and Availability, in FAO (1998), Proceedings of the Regional Expert Consultation on Modern Applications of Biomass Energy, FAO Regional Wood Energy Development Programme in Asia, Report No. 36, Bangkok. Available from: http://wgbis.ces.iisc.ernet.in/energy/HC270799/RWEDP/acrobat/p_residues.pdf. Last accessed: April 2014.
- Maithel, S. 2009. Biomass Energy: Resource Assessment Handbook. Prepared for Asian and Pacific Centre for Transfer of Technology Of the United Nations – Economic and Social Commission for Asia and the Pacific (ESCAP). Available from <http://recap.apctt.org/Docs/Biomass.pdf>. Last accessed: April 2014.
- Milbrandt, A., 2009. Assessment of Biomass Resources in Liberia. Technical Report. National Renewable Energy Laboratory. Available from: <http://www.nrel.gov/docs/fy09osti/44808.pdf>. Last accessed: April 2014.
- Milbrandt, A., Overend, R., 2011. Assessment of Biomass Resources in Afganistan. Technical Report. National Renewable Energy Laboratory. Available from: <http://www.nrel.gov/docs/fy11osti/49358.pdf>. Last accessed: April 2014.
- Li, J., et al. 1999. Assessment of Biomass Resource Availability in China. Report. Available from http://frankhaugwitz.com/doks/bio/1999_12_China_RE_Biomass_Assessment_of_biomass_resource_availability_in_China.pdf. Last accessed: April 2014.

Prasertsan, S., Sajjakulnukit, B. 2006. Biomass and biogas energy in Thailand: Potential, opportunity and barriers. *Renewable Energy* vol.31 p.599-610

Scarlat, N., et al. 2010. Assessment of the Availability of Agricultural Crop Residues in the European Union - Potential and Limitations for Bioenergy Use. *Waste Management* vol. 30 no. 10 p. 1889-1897.

Tripathi, A.K. et al., 1998. Assessment of availability and costs of some agricultural residues used as feedstocks for biomass gasification and briquetting in India. *Energy conversion and management* vol.39 no. 15 p. 1611-1618.

Yevich, R., Logan, A., 2003. An assessment of biofuel use and burning of agricultural waste in the developing world. *Global Biochemical Cycles* vol.17 no.4 p.1095.