Highlights:

We present a multidisciplinary analysis for bioenergy production assessment

We include food security and sustainability considerations

The methodology provides a set of Microsoft Excel based tools

We analyze the case of bioenergy production for rural electrification in Malawi.

Combining bioenergy and food security: An approach and rapid appraisal to guide bioenergy policy formulation

Irini Maltsoglou[1a], Ana Kojakovic[1], Luis E. Rincón[1,2], Erika Felix[1], Giacomo Branca[3], Stefano Valle[3], Arturo Gianvenuti[3], Andrea Rossi[1], Andreas Thulstrup[1] and Heiner Thofern[1]

[1] *Food and Agriculture Organization of the United Nations, Rome, Italy*

[2] *Universidad Nacional de Colombia, sede Manizales*

[3] *University of La Tuscia, Viterbo, Italy*

Abstract:

In the bioenergy discourse that ties energy and agricultural markets closely together, evidence based policy formulation is key to ensure integrated food and energy systems are developed when viable. Bioenergy is a particularly complex form of renewable energy as it covers a broad range of disciplines thus requiring a multidisciplinary approach to ensure viability. If built in a specific manner it has the option to target and provide investments in agriculture, a key sector for a number of developing economies.

Due to the complexity of the issue, generating information, especially when resources are limited, can be cumbersome. We present a multidisciplinary approach, the Bioenergy and Food Security (BEFS) Rapid Appraisal, that can provide a first level of information within the decision making process.

The analysis within the BEFS Rapid Appraisal defines the country context, estimates the biomass available for bioenergy production and ties this amount to specific bioenergy supply

[a] Corresponding author: irini.maltsoglou@fao.org, Climate, Energy and Tenure Division, Food and Agriculture Organization of the UN, Viale delle Terme di Caracalla Rome Italy. Tel +39-06-570 53639.

chains. Available biomass originating from agriculture is calculated net of current and foreseen uses and needs, thus accounting for food security. The bioenergy production potential is evaluated by quantifying the feedstock available, identifying income and employment opportunities, and energy access options. We present an application of the BEFS Rapid Appraisal for rural electrification options in Malawi.

Keywords: biomass potential, bioenergy, renewable energy, food security, rural electrification

1. Introduction

Energy plays an essential role in modern life, is central to development and enables food security. In fact, both in the Post2015 debate and under the UN's Sustainable Energy for All Initiative, the central role of energy and the need to ensure universal energy access is recognized and targeted [1, 2].

At present, the energy sector heavily relies on fossil fuel supply and is the source of two-thirds of global greenhouse gas emissions. Consequently, current and future energy pathways will be pivotal in determining whether or not climate change goals will be achieved [3]. This is especially important when considering the differences in current energy access levels across the globe. Energy policy decisions of emerging and developing countries will play an important role. Developing countries still use a lot less energy compared to developed countries, although differences are forecasted to reduce over coming years, but will still remain large. For example, average per capita energy consumption in Africa is estimated to be less than one third of the global average in 2035, while emerging economies and their energy strategies will become the center of gravity for future energy demand [3]. Finding alternative energy strategies is vital to ensure climate change targets are met and that fossil fuels are not seen as the only solution to meet additional demand. As part of an alternative energy mix, bioenergy could play a role in developing countries, this could be especially attractive for those countries that are resource abundant and heavily rely on the agriculture sector [4-6]. The question to be answered is if, and what role bioenergy can play in contributing toward achieving energy security within the overall energy mix [7], while safeguarding food security.

The debate on bioenergy has been controversial. On one hand, bioenergy is seen as a source of additional demand for agricultural feedstock, putting pressure on resources, competing with food production, resulting in increased food insecurity [8, 9]. On the other, some find that bioenergy can be a driver for increased agricultural production and productivity through investment in agriculture, rural development, job creation and income and contributing to climate change mitigation [4, 5, 10]. In addition, growth that targets the agriculture sector can better target poverty reduction [6]. The experience of those countries that have succeeded in reducing hunger and malnutrition shows that economic growth does not automatically ensure success – the source of growth matters too. Growth originating in agriculture, in particular in the smallholder sector, is at least twice as effective in benefiting the poor as growth in non-agricultural sectors [11]. This is not surprising since most of the poor in today's developing countries live in rural areas, where their incomes are directly or indirectly tied to agriculture [12, 13].

It is generally acknowledged that the use of agricultural feedstock for energy production has strengthened the links between energy and agricultural markets [4]. Recent research in this area has also underlined how the idea of non-food competing feedstock is not the solution and that impact of biofuels on food security may not differ markedly from that of other agro-industrial crops [5, 14, 15].

From an energy point of view, bioenergy is a particularly complex form of renewable energy with implications across a number of disciplines. From an agricultural point of view, bioenergy is a market outlet for agricultural production [14].

For a policy to be evidence based, it is necessary to have a clear understanding of the feedstock production potential, how and where the feedstock can be sourced and what conversion technology is the most efficient to fulfill the specific energy demands. This is particularly challenging because bioenergy bridges across natural resource sciences, economics and engineering. Combining these disciplines allows addressing the complexities involved, resulting in a more robust analysis and delivery of information and evidence for the policy formulation process [16, 17].

This paper presents a rapid appraisal multidisciplinary approach of in country bioenergy potential to meet energy needs, while considering the agricultural, economic and social context. Feedstock production is analyzed based on food production requirements and environmental considerations. All biofuel options are considered covering options for heating and cooking, electrification and transport. The paper first discusses the methodology integrated in the Bioenergy and Food Security (BEFS) Rapid Appraisal tools and then presents their application for the assessment of bioenergy options for rural electrification in Malawi.

2. Material and methods

The BEFS Rapid Appraisal consists of a set of excel based tools that are globally applicable and are used for a first level of analysis of bioenergy options. The analysis can be tailored for country or area level assessment depending on country size and data availability. The BEFS

Rapid Appraisal has four areas of analysis [17], namely 1) Country context, 2) Natural Resources: Biomass Potential Assessment, 3) Energy end use options: Techno-economic Analysis and 4) Energy end use options: Socio-economic analysis. Area 3 and 4 of the analysis are presented jointly. Fig. 1 presents the areas of analysis and the interlinkages across sections of analysis.

"Fig. 1 here"

The analysis carried out within the BEFS Rapid Appraisal covers the whole biofuel supply chain from feedstock production to processing plant gate or the final consumer. The analysis starts with the description of the country context, within which key agricultural features and current energy supply and demand are described and bioenergy pathways of interest defined. Based on this biomass types for the analysis are identified, the potential feedstock availability is estimated, and the competitiveness of the bioenergy pathway options and respective socio-economic implications and tradeoffs are assessed.

At the feedstock level, the biomass potential from forestry, crop production and agricultural residues can be assessed. At the energy end user level, heating and cooking options, rural electrification options and transport are covered. Outputs of one area of the analysis are used to define the underlying context, or are used directly as input parameters into the following step, of the analysis. Where possible, the tools provide default values which can support the analysis, when country specific data is not available. Default values are the result of literature research and reviews, relevant sources per set of default values can be found in the BEFS Rapid Appraisal Manuals [18-30]. Based on the BEFS Rapid Appraisal results, it is possible to define the areas for more detailed analysis that should support the policy formulation.

Food security considerations are interwoven throughout the framework. Based on FAO's definition [17], food security is related to production, access, utilization and the stability of the previous three dimensions. However, stability is not explicitly considered in the BEFS Rapid Appraisal.

In line with this definition, the analysis aims to assess potential availability of biomass that is additional and/or complementary to food, feed and other uses, as to competition for resources and negative impacts on food production. Options for employment and income generation along the biofuel supply chain are taken into consideration. Options for heating and cooking are covered relating to food utilization.

Environmental, economic and social sustainability is also built into the framework as the basis for ensuring the system developed is sustainable [31]. The sustainable use of natural resources is sought by prioritizing intensification of agricultural production over expansion of arable land, i.e. avoiding land use change [32], by excluding protected areas [6], and by excluding or enhancing uses of residues, such as for soil management. Economic and social sustainability is considered as well, by investigating economic competitiveness and financial viability of bioenergy investments, employment options and implications for energy access.

The analysis is primarily static and descriptive and is based on current or foreseen production and consumption levels. As in the case for comparable static analysis in economics, the approach compares different scenarios in which key variables can be changed. Scenarios should be constructed around a targeted set of key parameters stemming from policy objectives. For example energy access targets, job creation or smallholder involvement targets, environmental targets, etc. Although not dynamic, the strength of the analysis lies in the integration of results across disciplines relevant to bioenergy development. Results do not include impact on food prices, although in the longer term allowing for technology shifts to keep prices stable. It is important to recall also that food price changes are the result of a number of different drivers, such as weather shocks, and that the most vulnerable to the food price changes would be the urban poor. On the other hand rural households could benefit from the price increases if they were net producers of the crop [33-35]. As the analysis is static and not dynamic, second round effect such as multiplier effects are not captured and impacts on food prices are not part of the analysis.

2.1. Country Context

The country status tool of the BEFS Rapid Appraisal provides an overview of the country context in terms of key socioeconomic and natural resources indicators, agriculture sector and food security indicators and energy supply and demand requirements. Fig. 2 graphically represents the information contained and reported in the country status. This module identifies the role agriculture plays in the economy, the key food staples and their net trade position and the key agricultural export crops. Food staples are ranked on a calorie contribution basis. Agricultural exports are ranked on a value basis. On the energy side, information on the energy balance, electricity access, heating and cooking and transport sector is collated. Against this backdrop, the selected bioenergy options are screened.

"Fig. 2 here"

2.2. Biomass potential assessment

Within the biomass assessment part of the BEFS Rapid Appraisal, the availability of bioenergy feedstock originating from crop production, agricultural residues and forestry is assessed. Fig. 3 presents the structure and sections of the biomass assessment.

"Fig. 3 here"

The crops component covers both crop production and crop profitability, where a total of 25 crops are covered in this section. For additional feedstock production, three options can be analyzed, namely intensification, extensification and change of crops. The intensification option assesses the additional amount of crops that can be produced through an increase in and how much of this calculated amount could be used as bioenergy feedstock after fulfilling food and other needs. The yield gap is estimated based on the current yield (which can be obtained from FAOSTAT or national statistics) and target potential yields that could be achieved under a defined level of agricultural production. The potential yields can be defined by the user of the tool or based on reference data provided in the tool. Three agricultural production levels are considered, namely low input, medium input and high input. If country or area specific information on the potential yield is not available, the potential yields estimated by Global Agro-Ecological Zoning Layers (GAEZ) [36] can be used. These values are calculated based on the three levels of agricultural production and on the crop specific land suitability of the country. Land suitability maps support the definition of the target potential yield level and are based on the GAEZ layers on land suitability and productivity [36], global land cover map Glob Cover 2009 [37] and the World Database on Protected Areas [38]. The analysis of the extensification option gives an indication of whether there is a possibility for sustainable expansion of arable land, based on trends in land-use change in the analyzed area over the past 10 to 20 years. Changes in forest- and arable land area are used as key indicators [39, 40]. Finally, the change of crops option provides an indication of the amount of bioenergy feedstock that could be produced by substituting the production of a currently produced crop with a bioenergy crop. This level of analysis is purely descriptive as the economic implications of such a change should be further assessed. In addition to the biophysical potential, crop profitability, costs and labour requirements of crop production per hectare are estimated.

Both crop and livestock residues are covered within agricultural residues. The availability of crop residues is estimated based on current crop production yields and the respective residue-to-crop ratios, and takes into account current uses [41-56]. In total, 30 crop-residue types from staple and cash crops suitable for energy production can be analyzed. The default values for residue-to-crop ratios are based on a detailed literature review, whereby the 10-year average annual production data is extracted from FAOSTAT [21, 40]. These default values are integrated into the tool. Residues currently used for feed and animal bedding, construction, industry and other uses and the amount of residues to be left in the field required for soil fertility and stability are excluded, while the amount of residues burnt in the field is considered as potentially available for bioenergy production [32]. The assessment of annual manure availability includes manure from dairy cows and buffalo, swine and chickens. The analysis is based on the number of heads in commercial and household production, and the estimated manure production per head per day [32]. In the case of cattle, it is assumed that only the manure collected in stables can be potentially used for biogas production, thus manure generated during grazing is not accounted for.

Within the woodfuel and wood residues component, the potential for additional forest harvesting, the availability of forest harvesting residues and wood processing residues is assessed. The additional forest harvesting assessment gives only an indication of possible additional harvesting based on trends in forest cover and roundwood removal rates [17, 40]. The available harvesting residues are estimated based on the annual roundwood production, rate of felling removal and the percentage of the residues that are already used. Thereby, it is assumed that tree foliage, small branches and stumps are left in the forest for soil fertilization and protection and biodiversity conservation. The wood processing residues assessment is based on the estimation of available sawdust, slabs and chips generated during sawnwood production. The assessment is based on the annual sawnwood production, average efficiency of sawmills [7, 57, 58] and current use of residues. The analysis can be based on the default values integrated into the tool [22] or sawmill efficiency factors defined by the user. In the case of forest plantations, the potential harvestable volume of wood from dedicated woodfuel plantations and costs and benefits of establishing plantations is assessed on a per hectare basis.

2.3. Energy end use options

In the energy end use option sections, the techno-economic and socio economic viability of different bioenergy production pathways is assessed. The end use options covered include heating and cooking, electricity generation and transport. Fig. 4 graphically represents the energy end use options covered within the BEFS Rapid Appraisal.

"Fig. 4 here"

The assessments for each of the energy pathways were developed through a conceptual design approach based on ‘knowledge’, e.g. mass and energy balances, physical properties of substances and other physico-chemical parameters [59-61]. Techno-economic coefficients were defined and used to carry out the mass and energy balance calculations, equipment size estimation and energy requirements for the equipment for each energy pathway. These coefficients were obtained through a technology specific literature review [62-76]. Representative plant sizes and technologies were selected for the analysis based on the literature review. The standardization of plant sizes and technologies was done to make the assessment globally applicable and their selection was based on a representative range of general plant sizes and technologies used in the global context. In this sense, the selected plant size and technologies may not be representative for a specific country but do allow for comparison across feedstock and type of technologies used within the energy pathway. At the more detailed level of analysis, plant sizes can be case specific and build based on location specific feedstock availability. The heating and cooking options cover biogas, charcoal and briquettes assessments. The rural electrification options include straight vegetable oil (SVO), direct combustion and gasification, while transport covers both biodiesel and ethanol.

The analysis within the energy end use options’ sections generates economic, operating and financial results. The economic set of results includes economic profitability, eg. production costs, production cost breakdown and investment requirements. Particularly, production costs are compared to the market price and/or costs of technologies commonly used in the country for the specific energy option. Operating results include a comparison of the biomass requirement for the different plant scales versus the biomass available as calculated in the biomass availability part of the BEFS Rapid Appraisal, number of plants that can potentially be supplied based on the amount of biomass available, number of jobs created, and potential households supplied. Financial results illustrate the financial viability of the energy end use option based on net present value and internal rate of return indicators. Results are generated both at the single feedstock level and also as a comparison between feedstock. Within the transport tool, the analysis also accounts for commercial large scale versus outgrower production schemes and production for domestic versus international markets.

3. Results and Discussion

In this section the results for the analysis carried out for Malawi and options for rural electricity generation from selected bioenergy feedstock are presented.

The analysis can be extended to include a variety of feedstock options ranging from crops to crop residues, livestock residues, etc. and for a number of energy applications related to heating and cooking, electricity and transport. The part of the analysis presented here is based on the country status, crop and crop residues tools and two of the rural electrification tools, namely straight vegetable oil (SVO) and gasification. The feedstock used are sunflower, soybean, maize cob and sorghum straw and stalk for reasons explained below. This set of analysis should be considered as a first round of analysis that is carried out at the national level. Other feedstock options to be considered could include ground nut, rice husks and pigeon pea. There could also be a focus on specific areas of the country, regions or districts, where particular crops, such as rice husk and pigeon pea, might be available. Agriculture growth projections could also be incorporated in the analysis in the form of projected yields or area coverage.

3.1. Country status results and feedstock selection

Malawi is a Southern African landlocked country and is amongst the world's least developed countries, classified as a Low Income Food Deficit Country. In 2011, GDP per capita was 363

$ capita^{-1} and the country experienced high poverty rates with 1 in 2 people below the poverty line. Moreover, 23% of the population was undernourished [77-79]. The economy of Malawi heavily relies on the agricultural sector for income and employment, with agriculture contributing just over 30% of GDP in 2011 [79]. About 60% of the land area in Malawi is classified as agricultural, of which 63% is arable land. Almost 35% is designated as forest land, but forest cover has been declining continuously over the past 20 years. Malawi is generally considered to be rich in water resources, found around the country in the form of lakes, rivers and aquifers [77, 78]. Access to energy is problematic and biomass is the main source of energy accounting for 89% of the energy consumed, including fuelwood, charcoal and crop residues. Households are the main consumers of energy and account for 83% of total energy use [80]. The key food staples are maize, potato and cassava. Maize is by far the main contributor to calories as it provides 50% of calorie intake, followed by potato (8.4%) and cassava (5.8%). Maize occupies 60% of total arable land [78]. Malawi is mostly self-sufficient in maize production but has fluctuated between being a slight net importer and exporter over the last ten years. Tobacco, tea and coffee are the main agricultural export commodities, with tobacco providing 70% of total export earnings in 2010 [78]. Ground nut production has steadily been increasing over the last ten years reaching a production of 380,300 t in 2013 [78]. Malawi is currently investigating options for crop diversification [81], therefore bioenergy could represent an alternative option.

The selection of feedstock for the analysis in Malawi was the result of a policy discourse with technical experts from a number of ministries including the Ministry of Natural Resources, Energy and Environment, Ministry of Agriculture and Food Security, Ministry of Industry and Trade, etc [82]. Access to energy, more specifically electricity, is a severe problem in Malawi where overall less than 1 in 10 people have access to electricity [81]. Due to the agricultural production context and the country's interest in investigating alternative agricultural export strategies, the feedstock considered are sunflower, soybean, maize cob and sorghum straw/stalk. In 2013, the total production of maize was 1,676,758 t, 111, 977 t of soybean, 86,242 t of sorghum and 12,249 t of sunflower seed. [40].

The rural electrification options considered are SVO using sunflower and soybean, as well as gasification using maize cob and sorghum straw/stalk residues. These two options differ by technology and feedstock type used. SVO technology is based on the direct use of vegetable oils within modified diesel engines connected to electricity generators. Conversely, gasification technology converts biomass into a fuel-gas called syngas. This syngas is then burnt in a gas engine connected to an electricity generator. Both technology options include the electricity distribution cost within their respective analysis. For sake of simplicity hereafter these two options will be called SVO and gasification.

3.2. Calculations of feedstock availability

Within the crop availability assessment, we first assess availability under intensification of production, secondly we assess availability under extensification and thirdly options for crop to crop change.

The results for sunflower intensification are reported in Fig. 5. We first define the current yield level. In order to account for year to year fluctuations, we report average yields over a 5 year period. The average yield for sunflower between 2005 and 2010 was 0.83 t ha^{-1}. By comparing this yield level to the potential yield levels reported in the GAEZ database, we find that the current production level is comparable to a low level input system. We then compare this yield level with the next level up, i.e. the intermediate input level, with a potential yield of

1.73 t ha^{-1}. Under current production conditions the total annual production is 7,902 t and the total production area is 9,520 ha. We assume that the production area is kept constant but we increase the average yield to the intensified yield level of 1.73 t ha^{-1}. In this way we calculate a total potential production of 16,470 t, to be achieved while keeping the production area constant. Assuming that planned production for non-bioenergy purposes remains close to current uses, about 8,470 t of sunflower could potentially be available for bioenergy production through yield intensification. Following the same approach for soybean, results show that the average current yield over the past five years is 0.94 t ha^{-1}. Production area is 78,700 ha with an average total annual production of around 74,000. The potential yield that can be attained at rainfed intermediate levels is 2.12 t ha^{-1}, resulting in a total production of 91,344 t of soybean for bioenergy production. Note that the current area under soybean production is much larger than the one under sunflower, thus the amount attainable under intensification is considerably higher.

"Fig. 5 here"

The results are also supported also by the land suitability maps, Fig 6. These illustrate that suitability for soybean and sunflower are similar, while suitability is slightly higher for soybean.

"Fig. 6 here"

Results for extensification are shown in Fig. 7. We find that there has been a continuous decrease in forest cover over the period 2000-2010 and an increase in arable land. The BEFS Rapid Appraisal does not support spatially explicit analysis and therefore at this level of analysis it is not possible to define the causes of deforestation and whether this was tied to expansion of arable land. Nonetheless, due to the reduction in forest cover, options for extensification were considered unsustainable at this level of analysis.

"Fig. 7 here"

Results for the change of crops option are reported in Fig. 8. In the context of efforts to diversify agriculture exports in Malawi away from tobacco, part of the area under tobacco production could be allocated to either sunflower or soybean.

"Fig. 8 here"

When looking at the crop budget results for sunflower and soybean at the intermediate input level, see Fig 9, we find that at the farmers' level soybean is preferred to sunflower. Cultivating soybean in fact results in higher gross margins and higher labour demand, when compared to sunflower.

The analysis was undertaken for both soybean and sunflower, but for sake of the argument, we present the results for sunflower. The reasons for this are explained further on. Average tobacco production is 166,730 t between 2006/2007 - 2010/2011 based on an average yield of 1.05 t ha^{-1}. For purely descriptive reasons, we assume a 25% reduction in the production of tobacco and reallocate the equivalent area to sunflower production. The 25% share can be part of the analysis whereby larger or smaller shares can be analyzed. We assume the area is put under the previously defined intensified yield of 1.73 t ha^{-1} and calculate that this would result in a total additional production of 68,676 t of sunflower which could be available for bioenergy production.

By adding up all feedstock calculated in the intensification and change of crop options, we conclude that a total of 77,146 t of sunflower and 91,844 t of soybean could potentially be available for bioenergy production on a per year basis.

Fig. 10 presents the results for the calculation of crop residues available for bioenergy production. We estimate the amount of maize cob available based on current maize production levels and on the default value of 0.33 for the residue-to-crop ratio [21]. Maize cobs are residues generated away from the fields and therefore not left in the field. A total of 90% of residues produced are currently used for cooking and heating based on discussions with the experts in the country [81]. This would leave 10% for bioenergy consumption i.e. 84,500 t of maize cob per year. In the case of sorghum stalk and straw it is estimated that 43,637 t of residues would be available for bioenergy. This value is based on current sorghum production, the default residue to crop ratio of 2.44, the default amount of 25% of residues left in the field and on the expert opinions' assessment that, of the remaining amount, 20% is used as fuel and 30% for construction material.

"Fig. 10 here"

In summary, the crop and crop residues tools allow us to calculate an annual amount of 77,146 t of sunflower and 91,844 t of soybean and 84,500 t of maize cob and 43,637 t of residues of sorghum stalk and straw available for bioenergy production.

The user of the tools can decide how to allocate the total amounts of biomass generated between energy generation options. In the case of this specific example, we allocate all of the biomass to rural electrification. However, and based on the energy policy interests of the country, total sunflower produced could for example be allocated to biodiesel production.

3.3. Rural electrification options

For the two rural electrification options, namely SVO and gasification, results are reported based on three representative plant sizes, namely 10, 40 and 400 kW. In order to assess the economic sustainability of these options in off-grid areas, it is necessary to use a “non-subsidized” comparison price which reflects the current costs of rural electrification. For this, the rural electrification tools offer an in-built calculator that estimates a proxy for the price of electricity. This proxy is calculated based on the steps required to operate a diesel generator such as transport of diesel to the specified area, the cost of the generator, and its operation and maintenance costs. Using this calculator, the comparison price was then estimated to be 96 $ MWh^{-1}, see Fig. 11 for calculation.

"Fig. 11 here"

In Fig. 12, a snapshot of results page obtained using gasification and SVO tools is presented. For the sake of simplicity in upcoming results only selected charts comparing key results will be shown.

"Fig. 12 here"

Results for production costs present a range to give a sentence of the initial level of assessment. As shown in Fig. 13, we find that both gasification options and the SVO-sunflower option are competitive when compared to the 96 $ MWh^{-1} comparison price. The SVO-soybean option is most likely notcompetitive, as generally the range of production costs in around or above the comparison price. This illustrates that the farmer level and the energy production level may be in contradiction with one another. Farmers' will have less incentive to produce sunflower, while at the rural electrification level for electricity generation to be cost competitive the SVO plants will prefer to use sunflower. Increasing soybean production even further by shifting out of tobacco to soybean could increase feedstock production but still the plants might not be economical.

"Fig. 13 here"

When focusing on the three options that are more clearly competitive, the results show that gasification from maize cob is slightly more competitive than the other two. Nevertheless, investment costs for a single gasification plant are approximately 7 times higher compared to the same SVO plant size. The main reasons for this lie in differences in technology maturity, as well as differences in prices of equipment and the number of pieces of equipment required (see Fig. 14).

"Fig. 14 here"

On a plant level basis, by construction, the number of households supplied for both electrification options is approximately the same. However, SVO options have the potential to generate more jobs as the equipment is more labour intensive and the larger availability of biomass would allow constructing a much larger number of sunflower based SVO generating facilities (Fig. 15 and Fig. 16).

"Fig. 15 here"

"Fig. 16 here"

In the case of gasification, as illustrated in Fig. 17, a total of 366 plants of 10 kW could be built based on maize cob availability and 304 based on sorghum residue availability. In the case of SVO, for example a total of 3,470 of 10 kW plants could be built based on potential availability of sunflower and 1,781 plants for the case of soybean.

"Fig. 17 here"

This illustrates that, if considering feedstock availability in combination with the potential number of plants that can be constructed then, a much larger quantity of household could be supplied with electricity from sunflower-SVO and more jobs created. Therefore, from an investment requirement point of view, cost competitiveness, labour and household access characteristics, SVO-based electricity generation from sunflower could be the preferred option. Note also that it is assumed that the feedstock is purchased on the market and paid at the market price. Consequently there would be no difference for the farmer whether selling their product to an SVO production plant or another outlet. Nonetheless, from the farmer's point of view, sunflower awards less returns when compared to soybean.

4. Conclusions

In the bioenergy discourse that ties energy and agricultural markets closely together, evidence based policy formulation is key to ensure integrated food and energy systems are developed when viable. Bioenergy is a particularly complex form of renewable energy as it covers a broad range of disciplines thus requiring a multidisciplinary approach to ensure viability. Nonetheless, it has the option to target and provide investments to a key sector for a number of developing economies, namely the agricultural sector, if built sustainably.

Due to the complexity of the issue, generating information, especially when resources are limited, can be cumbersome. For this, we present a multidisciplinary rapid appraisal level approach, the BEFS Rapid Appraisal, that can provide a first level of information within the decision making process. This appraisal allows for the integration of the agriculture and energy sectors, while prioritizing agricultural sector needs and considering sustainability requirements.

To illustrate the integrated approach, we present results from the analysis of biomass use in electricity generation in Malawi, an agriculture based economy with severe energy access problems. The analysis assesses options for rural electricity generation based on biomass availability. We first calculate the amount of biomass that could be produced without competing with current food and agricultural production needs, considering the yield gap potential and a partial shift out of tobacco production. We then tie this biomass produced to the requirements for energy generation. Of the options analyzed, at the rural electrification level, we find that the most interesting option for Malawi would be sunflower-SVO based electricity generation, followed by maize cob and sorghum stalk and straw gasification. Sunflower-SVO is the most cost competitive, with comparatively lower investment requirements in technology, higher labour impacts, and due to a higher feedstock availability compared to the residues, would allow to build more SVO based facilities. Nevertheless, we find that these results are in juxtaposition with farmer level returns, as at the farmer level, soybean offers higher returns when compared to sunflower. In the case of residues, investment requirements in technology are much higher and the number of plants comparatively lower when compared to the SVO options. From a policy point of view, the analysis provides initial insights into the potential for biomass based rural electrification in Malawi. The next steps would require more location specific analysis, screening of other energy and feedstock options, and also screening of competitiveness of the biomass based electricity options with respect to other renewables. In addition, with reference to soybean and sunflower, one option that could be investigated might be to intercrop soybean and sunflower. This could potentially allow farmers to produce both. The impacts on costs and yields would need investigation. Having said that, if the selling price of soybean and sunflower were to change, the competitiveness at the farmer level might change. Therefore it would also be useful to investigate how prices of soybean and sunflower have changed over time. Yield changes, in combination with feedstock price changes and further work on the definition of the fossil fuel comparison price, might alter the competitiveness position of soybean with respect to sunflower and of sunflower-SVO and soybean-SVO with respect to fossil fuel based electricity production.

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REFERENCES

[1] The World We Want. Global thematic consultation on energy and the post 2015 development agenda: Key messages 2013 [cited 2014 July]. Available from: http://www.se4all.org/wp-content/uploads/2014/02/Global-Thematic-Consultation-on-Energy-and-the-Post-2015-Development-Agenda_November-2013.pdf.

[2] The Secretary General's Advisory Group on energy and climate change (AGECC). Energy for a sustainable future: Summary Report and Recommendations. New York, USA: 2010 April 28. Report No.: 1.

[3] International Energy Agency. World Energy Outlook 2013. Paris, France: International Energy Agency-OECD/OEA; 2013.

[4] Food and Agriculture Organization of the United Nations (FAO). Biofuels: prospects, risks and opportunities. Rome, Italy: FAO-Electronic Publishing Policy and Support Branch; 2008.

[5] Pingali P, Raney T, Wiebe K. Biofuels and Food Security: Missing the Point. Rev Agr Econ. 2008; 30 (3): 506-6.

[6] United Nations Environment Programme (UNEP). Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication. Geneva2011 [cited 2014 June]. Available from: www.unep.org/greeneconomy.

[7] United Nations Economic Commission for Europe (UNECE), Food and Agriculture Organization of the United Nations (FAO), editors. Forest product conversion factors for the UNECE region. Generva, Switzerland United Nations Publication; 2010.

[8] Mitchell D. A note on rising food prices. World Bank Policy Research [Internet]. 2008 [cited 2014 July]; Document Number 4682(July):[20 p.]. Available from: https://openknowledge.worldbank.org/handle/10986/6820.

[9] Bailey R. Another inconvenient truth: How biofuel policies are deepening poverty and accelerating climate change. Oxfam Policy and Practice: Climate Change and Resilience. 2008; 4 (2): -1-58.

[10] Ewing M, Msangi S. Biofuels production in developing countries: assessing tradeoffs in welfare and food security. Environ Sci Pol. 2009; 12 (4): 520-8.

[11] Food and Agriculture Organization of the United Nations (FAO), editor How to feed the world by 2050, Issue Brief. Background document for the High level expert forum; 2009 Oct 13-16 Rome ;2009.

[12] Clancy J. Are biofuels pro-poor? Assessing the evidence. Eur J Dev Res. 2008; 20 (3): 416-31.

[13] Arndt C, Pauw K, Thurlow J. Biofuels and economic development: A computable general equilibrium analysis for Tanzania. Energ Econ. 2012; 34 (6): 1922-30.

[14] Maltsoglou I, Koizumi T, Felix E. The status of bioenergy development in developing countries. Global Food Secur. 2013; 2 (2): 104-109.

[15] Locke A, Henley g. Biofuels and local food security: what does the evidence say? Agri Dev Pol [Internet]. 2004 [cited 2014 July]:[4 p.]. Available from: http://www.odi.org/publications/7485-biofuels-food-security-food-prices-evidence.

[16] Hubacek K, van den Bergh JC. Changing concepts of 'land'in economic theory: from single to multi-disciplinary approaches. Ecol Econ. 2006; 56 (1): 5-32.

[17] Food and Agriculture Organization of the United Nations (FAO). Bioenergy and food security: The BEFS Analytical Framework. Rome: Climate, Energy and Tenure Division (NRC) publications; 2010.

[18] Food and Agriculture Organization of the United Nations. Bioenergy and Food Security Rapid Appraisal (BEFS RA) User Manuals: Country Status Module. Rome, Italy 2014 [cited 2014 June]. Available from: http://www.fao.org/energy/befs/rapid-appraisal@191900/en/.

[19] Food and Agriculture Organization of the United Nations. Bioenergy and Food Security Rapid Appraisal (BEFS RA) User Manuals: Crop Production Module. Rome, Italy 2014 [cited 2014 June]. Available from: http://www.fao.org/energy/befs/rapid-appraisal@191900@191905/en/.

[20] Food and Agriculture Organization of the United Nations. Bioenergy and Food Security Rapid Appraisal (BEFS RA) User Manuals: Crop Budget Module. Rome, Italy 2014 [cited 2014 June]. Available from: http://www.fao.org/energy/befs/rapid-appraisal@191900@191905/en/.

[21] Food and Agriculture Organization of the United Nations. Bioenergy and Food Security Rapid Appraisal (BEFS RA) User Manuals: Crop Residues and Livestock Residues Module. Rome, Italy 2014 [cited 2014 June]. Available from: http://www.fao.org/energy/befs/rapid-appraisal@191900@191905/en/.

[22] Food and Agriculture Organization of the United Nations. Bioenergy and Food Security Rapid Appraisal (BEFS RA) User Manuals: Forest Harvesting and Wood Processing Residues Module. Rome, Italy 2014 [cited 2014 June]. Available from: http://www.fao.org/energy/befs/rapid-appraisal@191900@191905/en/.

[23] Food and Agriculture Organization of the United Nations. Bioenergy and Food Security Rapid Appraisal (BEFS RA) User Manuals: Woodfuel Plantation Budget Module. Rome, Italy 2014 [cited 2014 June]. Available from: http://www.fao.org/energy/befs/rapid-appraisal@191900@191905/en/.

[24] Food and Agriculture Organization of the United Nations. Bioenergy and Food Security Rapid Appraisal (BEFS RA) User Manuals: Charcoal Module. Rome, Italy 2014 [cited 2014 June]. Available from: http://www.fao.org/energy/befs/rapid-appraisal@191900@191904/en/.

[25] Food and Agriculture Organization of the United Nations. Bioenergy and Food Security Rapid Appraisal (BEFS RA) User Manuals: Briquettes Module. Rome, Italy 2014 [cited 2014 June]. Available from: http://www.fao.org/energy/befs/rapid-appraisal@191900@191904/en/.

[26] Food and Agriculture Organization of the United Nations. Bioenergy and Food Security Rapid Appraisal (BEFS RA) User Manuals: Biogas Module. Rome, Italy 2014 [cited 2014 June]. Available from: http://www.fao.org/energy/befs/rapid-appraisal@191900@191904/en/.

[27] Food and Agriculture Organization of the United Nations. Bioenergy and Food Security Rapid Appraisal (BEFS RA) User Manuals: Gasification Module. Rome, Italy 2014 [cited 2014 June]. Available from: http://www.fao.org/energy/befs/rapid-appraisal@191900@191904/en/.

[28] Food and Agriculture Organization of the United Nations. Bioenergy and Food Security Rapid Appraisal (BEFS RA) User Manuals: Straight Vegetable Oil (SVO) Module. Rome,

Italy 2014 [cited 2014 June]. Available from: http://www.fao.org/energy/befs/rapid-appraisal@191900@191904/en/.

[29] Food and Agriculture Organization of the United Nations. Bioenergy and Food Security Rapid Appraisal (BEFS RA) User Manuals: Combustion Module. Rome, Italy 2014 [cited 2014 June]. Available from: http://www.fao.org/energy/befs/rapid-appraisal@191900@191904/en/.

[30] Food and Agriculture Organization of the United Nations. Bioenergy and Food Security Rapid Appraisal (BEFS RA) User Manuals: Transport Module. Rome, Italy 2014 [cited 2014 June]. Available from: http://www.fao.org/energy/befs/rapid-appraisal@191900@191904/en/.

[31] Pearce D, Markandya A, Barbier E. Blueprint for a green economy. 1st ed: Earthscan Publications Limited; 1989.

[32] Eggleston S, Buendia L, Miwa K, Ngara T, Tanabe K, editors. 2006 IPCC guidelines for national greenhouse gas inventories. Hayama, Japan: Institute for Global Environmental Strategies (IGES); 2006.

[33] Headey D, Fan S. Reflections on the global food crisis : how did it happen? how has it hurt? and how can we prevent the next one? . Washington, USA: International Food Policy Research Institute; 2010.

[34] Headey D, Fan S. Anatomy of a crisis: the causes and consequences of surging food prices. Agr Econ. 2008 December; 39: 375-91.

[35] Dawe D, Maltsoglou I. Marketing margins and the welfare analysis of food price shocks. Food Policy. 2014 June; 46: 50-5.

[36] GAEZ - Global Agro-Ecological Zones [Internet]. 2012 [cited 2012 July]. Available from: http://www.fao.org/nr/gaez/en/.

[37] ESA's global land cover map [Internet]. European Space Agency. 2012 [cited 2012 June]. Available from: http://www.esa.int/Our_Activities/Observing_the_Earth/Space_for_our_climate/ESA_global_land_cover_map_available_online.

[38] World Database on Protected Areas [Internet]. The International Union for Conservation of Nature. 2009 [cited 2014 March]. Available from: https://www.iucn.org/about/work/programmes/gpap_home/gpap_biodiversity/gpap_wdpa/.

[39] Global Forest Resources Assessments (FRA) [Internet]. Food and Agriculture Organization of the United Nations. 2010 [cited 2010 January]. Available from: http://www.fao.org/forestry/fra/en/.

[40] FAOSTAT [Internet]. Food and Agriculture Organization of the United Nations. 2014 [cited 2014 June]. Available from: http://faostat3.fao.org/faostat-gateway/go/to/home/E.

[41] Bhattacharya S, Shrestha R, Ngamkajornvivat S. Potential of biomass residue availability: the case of Thailand. Energ Sourc. 1989; 11 (3): 201-16.

[42] Eisentraut A. Sustainable production of second-generation biofuels: potential and perspectives in major economies and developing countries. International Energy Agency - OECD [Internet]. 2010 [cited 2014 March]; 1:[16 p.]. Available from: http://www.iea.org/publications/freepublications/publication/biofuels_exec_summary.pdf.

[43] Food and Agriculture Organization of the United Nations (FAO). Agricultural residues: bibliography 1975-81 and quantitative survey. 47 ed. Rome, Italy: FAO-Agricultural Services Bulletin; 1982.

[44] Food and Agriculture Organization of the United Nations (FAO), editor Proceedings of the Regional Expert Consultation on Modern Applications of Biomass Energy. FAO Regional Wood Energy Development Programme in Asia; 1998; Bangkok.

[45] Gregg JS, Smith SJ. Global and regional potential for bioenergy from agricultural and forestry residue biomass. Mitigation Adapt Strateg Glob Chang. 2010; 15 (3): 241-62.

[46] Jenkins BM, Ebeling JM. Thermochemical properties of biomass fuels. Calif Agric. 1985; 39 (5/6): 14-16.

[47] Jiang D, Zhuang D, Fu J, Huang Y, Wen K. Bioenergy potential from crop residues in China: Availability and distribution. Renew Sustain Energ Rev. 2012; 16 (3): 1377-82.

[48] Jingura R, Matengaifa R. The potential for energy production from crop residues in Zimbabwe. Biomass Bioenergy. 2008; 32 (12): 1287-92.

[49] Koopmans A, Koppejan J, editors. Agricultural and forest residues-generation, utilization and availability. Proceedings of the Regional Consultation on Modern Applications of Biomass Energy; 1998; Bangkok, Thailand: FAO Regional Wood Energy Development Programme in Asia.

[50] Maithel S. 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), 2009.

[51] Milbrandt A. Assessment of biomass resources in Liberia [Internet]. USA: National Renewable Energy Laboratory (NREL); 2009 [cited 2014 Febraury]. Available from: http://www.nrel.gov/docs/fy09osti/44808.pdf.

[52] Jingjing L, Jinming B, Overend R. Assessment of biomass resource availability in China. Beijing, China: China Environmental Science Press; 1998.

[53] Prasertsan S, Sajjakulnukit B. Biomass and biogas energy in Thailand: Potential, opportunity and barriers. Renew Energ. 2006; 31 (5): 599-610.

[54] Scarlat N, Martinov M, Dallemand J-F. Assessment of the availability of agricultural crop residues in the European Union: Potential and limitations for bioenergy use. Waste Manag. 2010; 30 (10): 1889-98.

[55] Tripathi AK, Iyer P, Kandpal TC, Singh K. Assessment of availability and costs of some agricultural residues used as feedstocks for biomass gasification and briquetting in India. Energ Convers Manag. 1998; 39 (15): 1611-18.

[56] Yevich R, Logan JA. An assessment of biofuel use and burning of agricultural waste in the developing world. Global Biogeochem Cy. 2003; 17 (4): 1095-1137.

[57] Sedivka P. Estimation of Technical Efficiency in Production Technologies of Czech Sawmills. Drvna Ind. 2009; 60 (4): 197-207.

[58] Olufemi B, Akindeni JO, Olaniran SO. Lumber Recovery Efficiency among Selected Sawmills in Akure, Nigeria. Drvna Ind. 2012; 63 (1): 15-18.

[59] Smith R. Chemical Process: Design and Integration. West Sussex, England: John Wiley & Sons Ltd; 2005.

[60] Edgar TF, Himmelblau DM, Lasdon LS. Optimization of chemical processes. 2nd ed. New York, USA: McGraw Hill; 2001.

[61] Douglas JM. Conceptual Design of Chemical Processes. 1st ed. New York, USA: McGraw-Hil; 1988.

[62] Rincón LE, Hernández V, Cardona CA. Analysis of technological schemes for the efficient production of added-value products from Colombian oleochemical feedstocks. Process Biochemistry. 2014; 49 (3): 474-89.

[63] Rincón LE, Moncada J, Cardona CA. Analysis of potential technological schemes for the development of oil palm industry in Colombia: A biorefinery point of view. Industrial Crops and Products. 2014 January; 52: 457-65.

[64] Posada JA, Rincón LE, Cardona CA. Design and analysis of biorefineries based on raw glycerol: Addressing the glycerol problem. Bioresource Technology. 2012 May; 111: 282-93.

[65] Luoga E, Witkowski E, Balkwill K. Economics of charcoal production in miombo woodlands of eastern Tanzania: some hidden costs associated with commercialization of the resources. Ecol Econ. 2000; 35 (2): 243-54.

[66] Grover P, Mishra S. Biomass briquetting: technology and practices. Bangkok, Thailand: Food and Agriculture Organization of the United Nations (FAO), 1996 April. Report No.: 46 Contract No.: GCP/RAS/154/NET.

[67] Tumuluru JS, Wright CT, Kenney KL, Hess JR, editors. A technical review on biomass processing: densification, preprocessing, modeling, and optimization. ASABE Annual International Meeting; 2010.

[68] Bhattacharya S, Kumar S, editors. Technology Packages: Screw-press Briquetting Machines and Briquette-fired Stoves. Bangkok, Thailand: Regional Energy Resources Information Center (RERIC), Asian Institute of Technology; 2005.

[69] Ratamu I. Low Cost Biodigesters for Zero Grazing Smallholder Dairy Farmers in Tanzania. Livest Res Rural Dev [Internet]. 1999 [cited 2014 July]; 11(2). Available from: http://www.lrrd.org/lrrd11/2/inno112.htm.

[70] Schmitz TD. Feasibility Study for a National Domestic Biogas Programme in Tanzania. Eschborn, Germany: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), 2007.

[71] Arena U, Di Gregorio F, Santonastasi M. A techno-economic comparison between two design configurations for a small scale, biomass-to-energy gasification based system. Chem Eng J. 2010; 162 (2): 580-90.

[72] Nouni M, Mullick S, Kandpal T. Biomass gasifier projects for decentralized power supply in India: A financial evaluation. Energ Pol. 2007; 35 (2): 1373-85.

[73] Bouffaron P, Castagno F, Herold S. Straight vegetable oil from Jatropha curcas L. for rural electrification in Mali – A techno-economic assessment. Biomass Bioenergy. 2012 February; 37: 298-308.

[74] Rordorf J. Opportunities for a sustainable rural energy supply through renewable energies in developing countries. [dissertation]. Berlin, Germany: Berlin School of Economics and Law - Institute of Management; 2011.

[75] Pinheiro G, Rendeiro G, Pinho J, Macedo E. Rural electrification for isolated consumers: Sustainable management model based on residue biomass. Energ Pol. 2011; 39 (10): 6211-19.

[76] Cardona CA, Sanchez OJ. Fuel ethanol production: process design trends and integration opportunities. Bioresour Technol. 2007; 98 (12): 2415-57.

[77] FAO Aquastat country profile for Malawi [Internet]. Food and Agriculture Organization of the United Nations. 2014 [cited 2014 June]. Available from: http://www.fao.org/nr/water/aquastat/countries_regions/mwi/index.stm.

[78] FAOSTAT Country Profile for Malawi [Internet]. Food and Agriculture Organization of the United Nations. 2014 [cited 2014 June]. Available from: http://faostat.fao.org/CountryProfiles/Country_Profile/Direct.aspx?lang=en&area=130.

[79] World Development Indicators [Internet]. The World Bank. 2011 [cited 2013 July]. Available from: http://data.worldbank.org/data-catalog/world-development-indicators.

[80] Biomass Energy Strategy (BEST). Biomass Energy Strategy for Malawi, EU Energy Initiative Partnership Dialogue Facility [Internet]. 2009 [cited 2012 March]. Available from: http://www.euei-pdf.org/country-studies/biomass-energy-strategy-best-malawi.

[81] Food and Agriculture Organization of the United Nations. Roadmap for Action towards Sustainable Bioenergy Development and Food Security. 2013. (Unpublished Report).

[82] Food and Agriculture Organization of the United Nations. Bioenergy and Food Security (BEFS) Country Support - Malawi Rome, Italy 2014 [cited 2014 June]. Available from: http://www.fao.org/energy/befs/82377/en/.

Figure

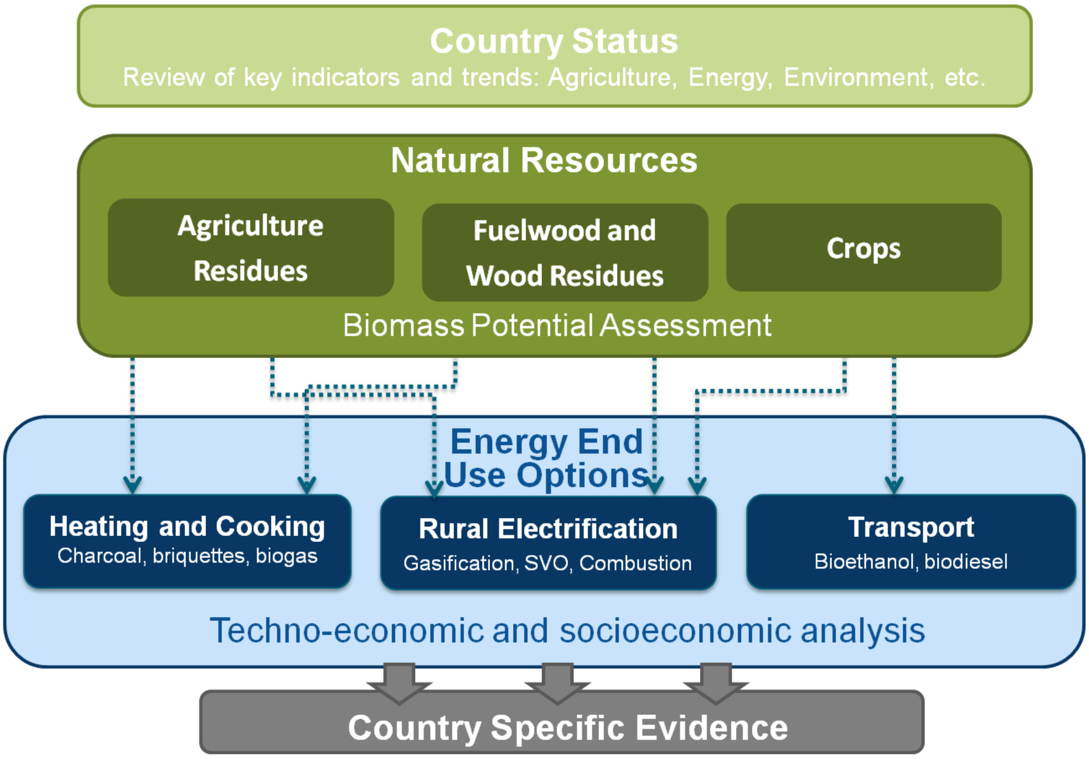


Fig. 1: Diagramme of the BEFS Rapid Appraisal

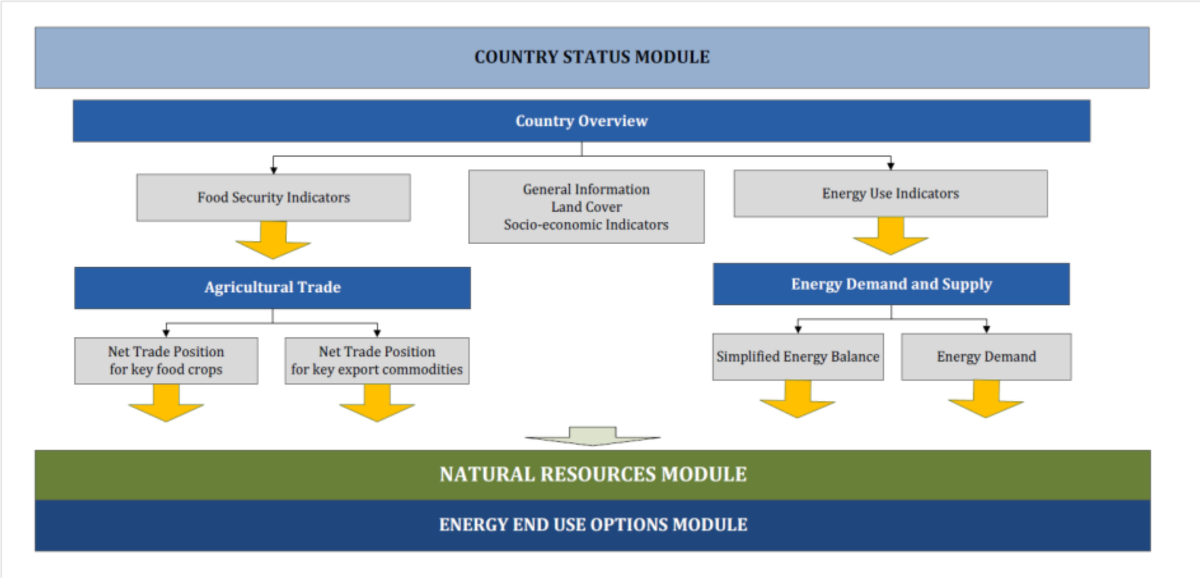


Fig. 2: Components of the country status module

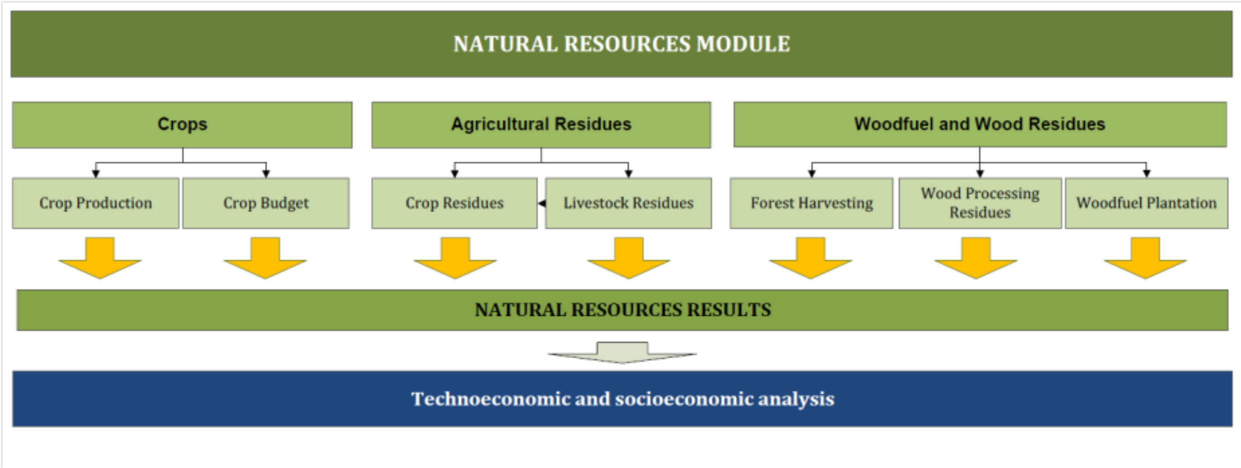


Fig. 3: Natural resources module and components

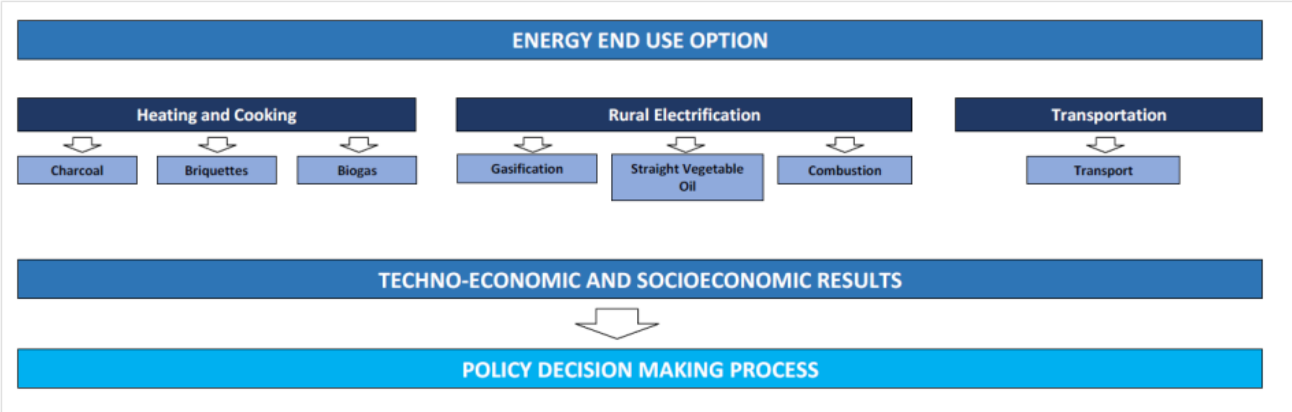


Fig. 4: Energy end use options module and components.

Parameter	Unit	Sunflower	Soybean
		Current production	
Current yield	t/ha	0.83	0.94
No. of harvests/year		1.0	1.0
Annual production	t/year	**7,902**	**73,978**
Total production area	ha	**9,520**	**78,700**
Intensified production (Potential production on the same area with increased yields)			
Input level	Select	Intermediate	Intermediate
Intensified yield	t/ha	1.73	2.12
No. of harvests/year		1	1
Potential production	t/year	**16,470**	**166,844**
Total production area	ha	**9,520**	**78,700**
Planned production for non-bioenergy purposes (food, feed, export, etc			
Planned production	t/year	**8,000**	**75,000**
Area of production	ha	**4,624**	**35,377**

Potential production for bioenergy

		Sunflower	Soybean
Potential production	**t/year**	**8,470**	**91,844**
Area of production	**ha**	**4,896**	**43,323**

Fig. 5: Results for crop intensification section for Malawi.

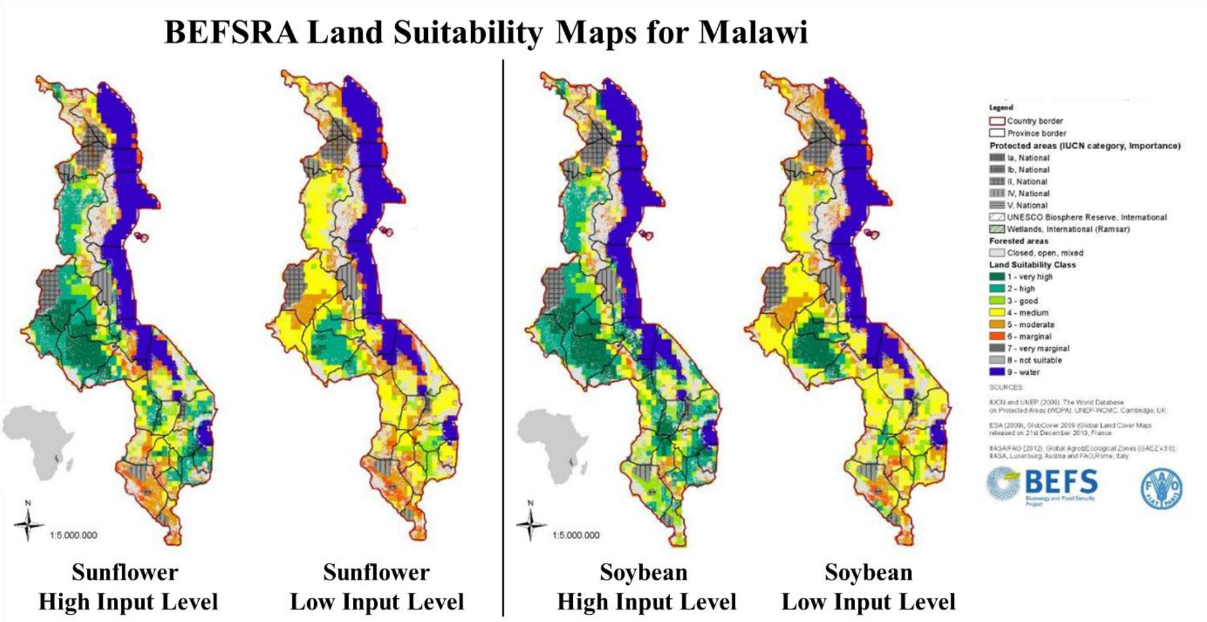


Fig. 6: Land suitability maps for Sunflower and Soybean in Malawi

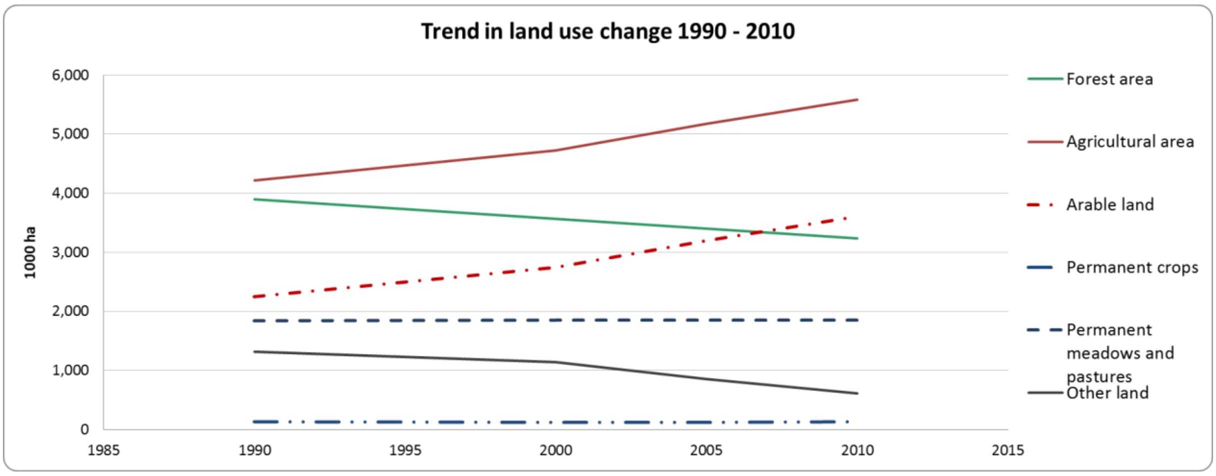


Fig. 7: Results for extensification section for Malawi

Current crop

Current production		
Parameter	**Unit**	**Tobacco**
Yield	t/ha	1.05
No. of crop cycles		1.0
Annual production	t/year	166,730
Production area	ha	**158,790.48**
Planned production		
Annual production	t/year	125,048
Area required	ha	**119,093.33**

Bioenegy crop

Planned production		
Parameter	**Unit**	**Soybean**
Yield	t/ha	1.73
No. of harvests/year		1.0

Potential production for bioenergy

Annual production	t/year	**68,676.06**
Area required	ha	**39,697.14**

10-years average annual yield at country level (based on FAOSTAT 2002-2011)				
Tobacco	**Unit**	**Parameter**	**Unit**	**Soybean**
0.90	t/ha	Yield (t/ha)	t/ha	0.83
133,934	t/year	Annual production (t/year)	t/year	61,656

Potential yields for bioenergy crops for rainfed agricultural production (based on GAEZ)						
Low	**Medium**	**High**	Input level	**Low**	**Medium**	**High**
t/ha			***Soil suitability class***	t/ha		
1.34	**2.52**	**4.77**	Country average	**0.82**	**2.12**	**5.53**
1.84	3.19	5.54	Suitable/very suitable	1.15	2.77	6.67
1.30	2.33	4.17	Moderately suitable	0.69	1.76	4.49

Fig. 8: Results for change of crop section for Malawi

Crop Budget Results

	Unit	Sunflower		Soybean	
		Current	Intermediate input	Current	Intermediate input
Yield	t/ha	**0.85**	**1.73**	**0.98**	**2.12**
Farm-gate price	USD/t	300.00	300.00	380.00	380.00
RESULTS OF THE BUDGET					
Revenue (A) = *(Yield*Farm gate price)*	USD/ha	255.00	518.67	372.40	807.29
Total input costs	USD/ha	113.36	230.10	115.54	221.21
Total labour costs	USD/ha	85.50	179.75	176.56	213.27
Total variable costs (B)=(Input+labour costs)	USD/ha	198.86	409.84	292.10	434.48
Gross margin (GM) = (A - B)	USD/ha	**56.14**	**108.82**	**80.30**	**372.81**
Total fixed costs (C)	USD/ha	40.00	40.00	40.00	40.00
Interest on working capital (D)	USD/ha	5.73	11.80	8.41	12.51
Total costs (E) = (B + C + D)	USD/ha	244.58	461.65	340.51	486.99
Net margin before tax (GM - C - D)	USD/ha	10.42	57.02	31.89	320.30
Cost of production (E / Yield)	USD/t	**287.75**	**267.02**	**347.46**	**229.23**
Returns to capital (A / input and labour costs)		1.28	1.27	1.27	1.86
LABOUR REQUIREMENTS					
Total Manual (F)	days/ha	**57**	**40**	**113**	**56**
Total Machinery (G)	hours/ha	**0.0**	**4.0**	**0.0**	**4.0**

Fig. 9: Results for crop budget section for Malawi

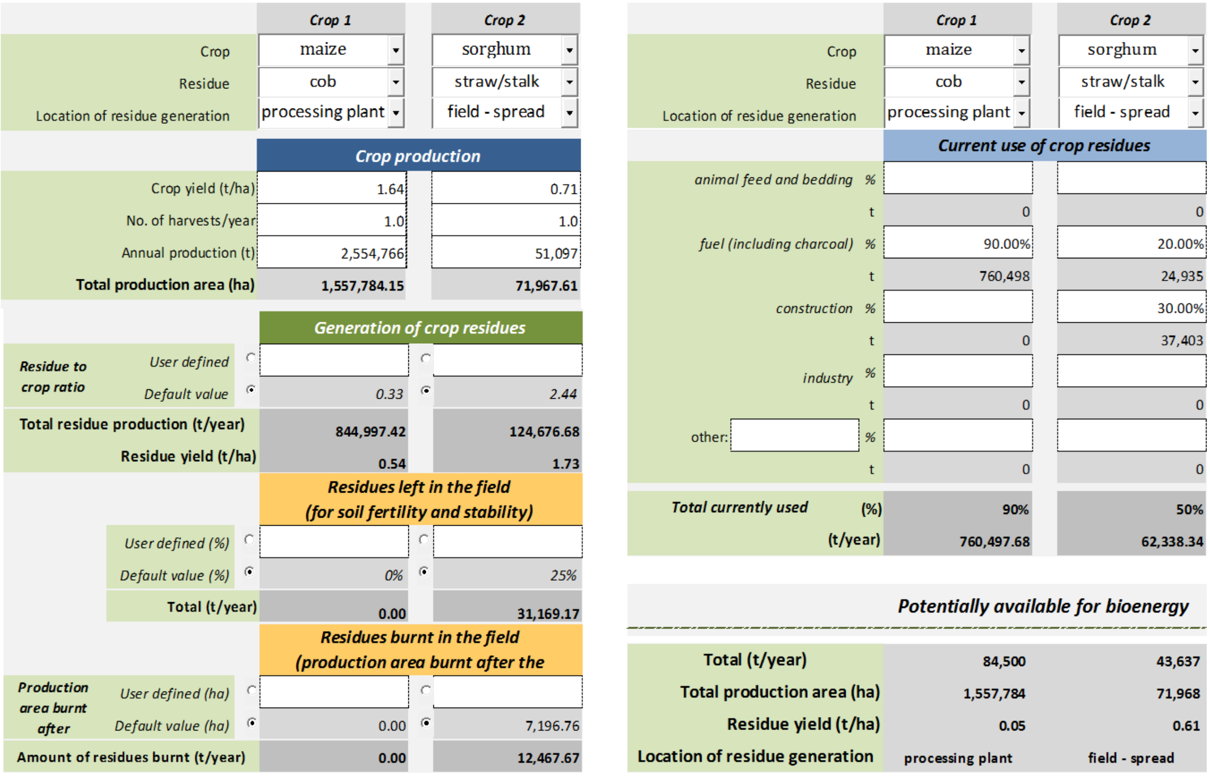


Fig. 10: Results for crop residues section for Malawi

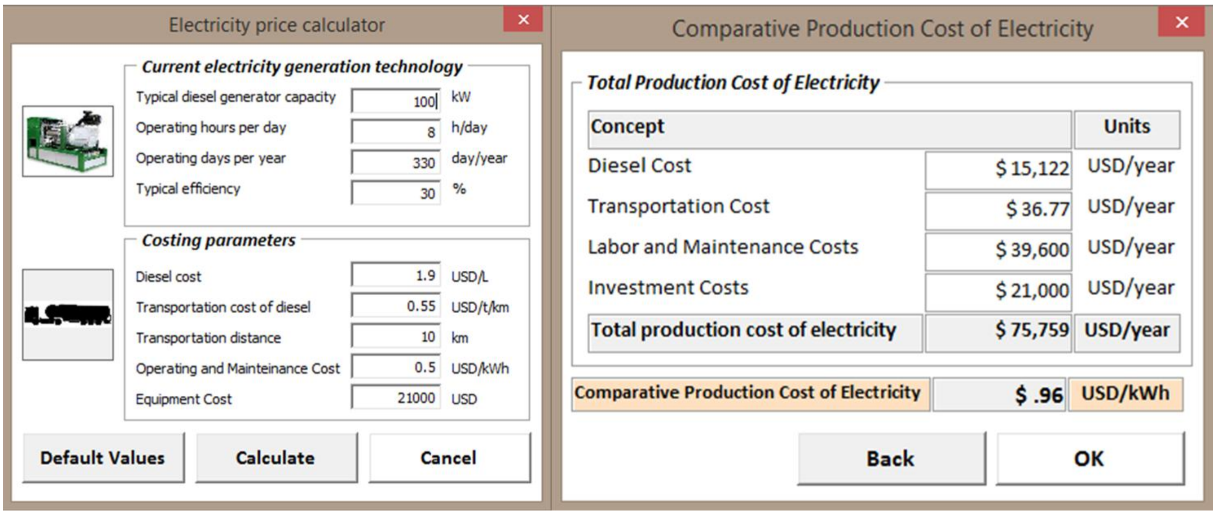


Fig. 11: Snapshot of electricity price calculator in BEFSRA tools

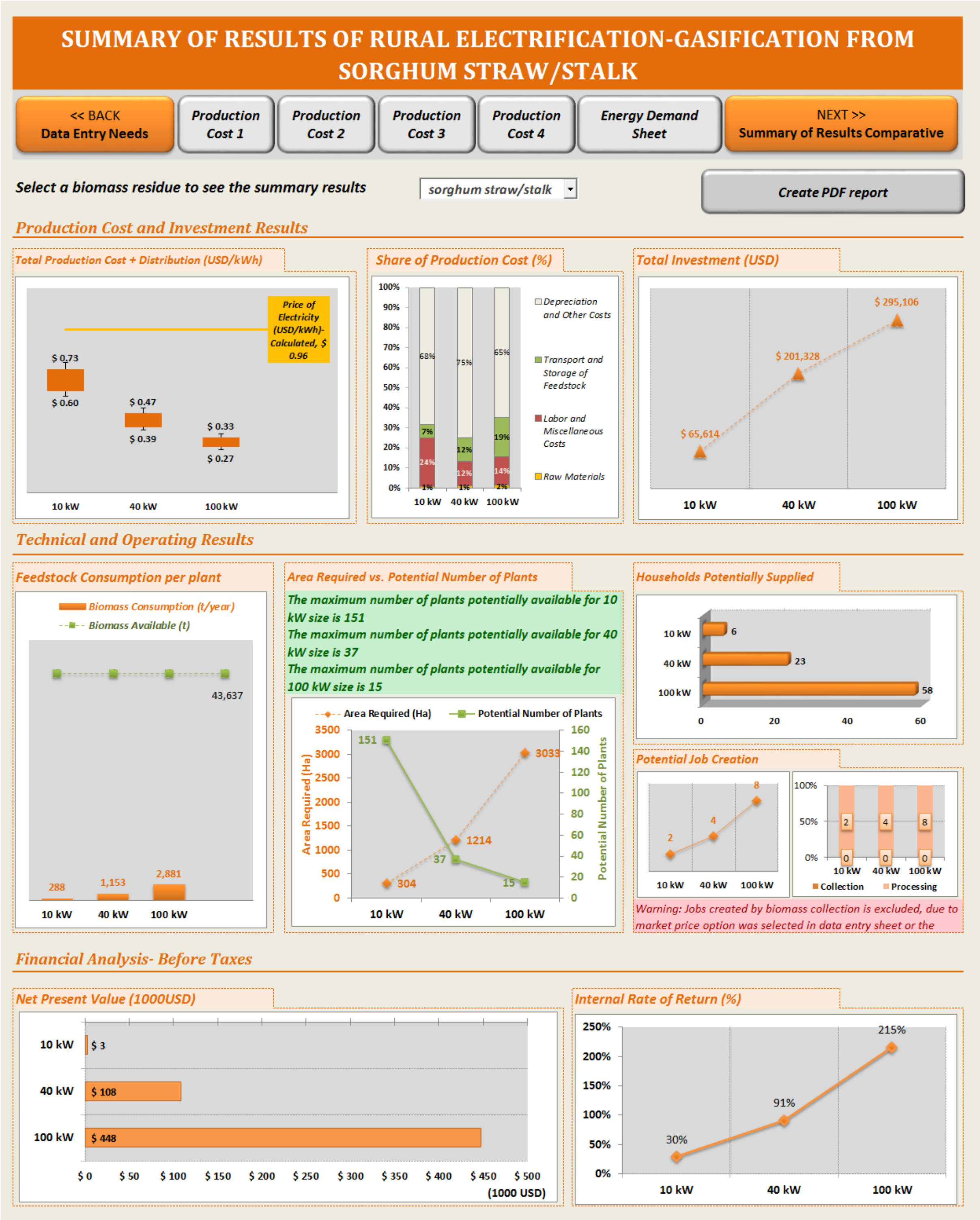


Fig. 12: Snapshot of a typical results page obtained using SVO and Gasification tools

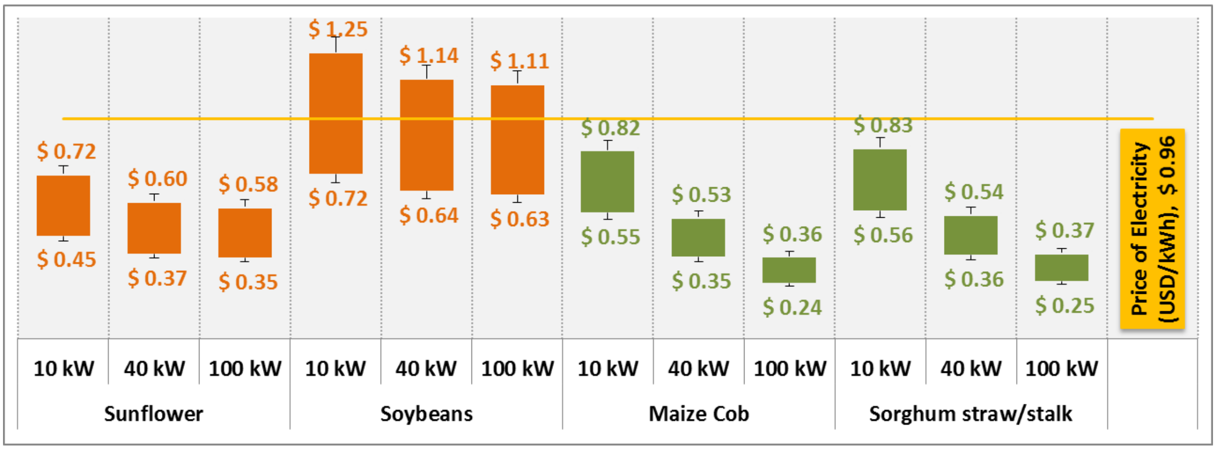
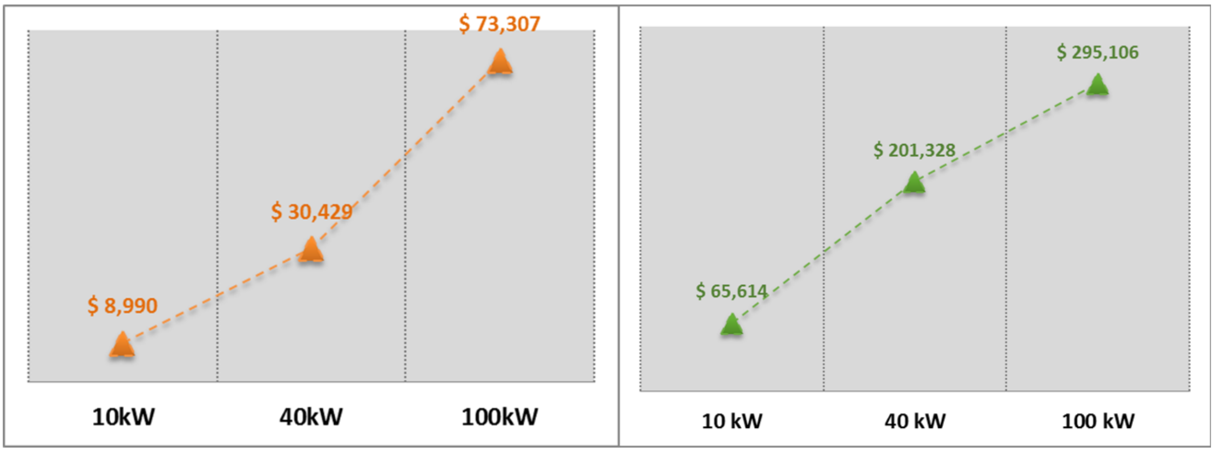


Fig. 13: Comparison of production cost results ($ kWh^{-1}) obtained for SVO (Sunflower and Soybean) and Gasification (Maize Cob and Sorghum Straw/Stalk)



SVO Technology **Gasification Technology**

Fig. 14: Comparison of Capital Investment ($) for SVO and Gasification

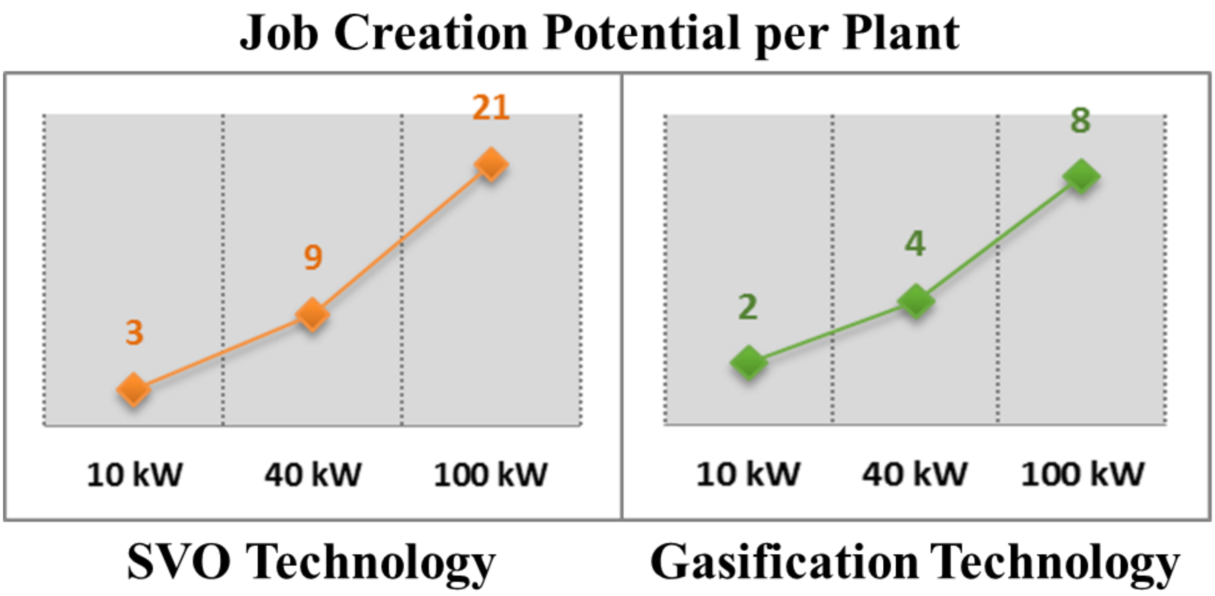


Fig. 15: Comparison of Job Creation Potential for SVO and Gasification

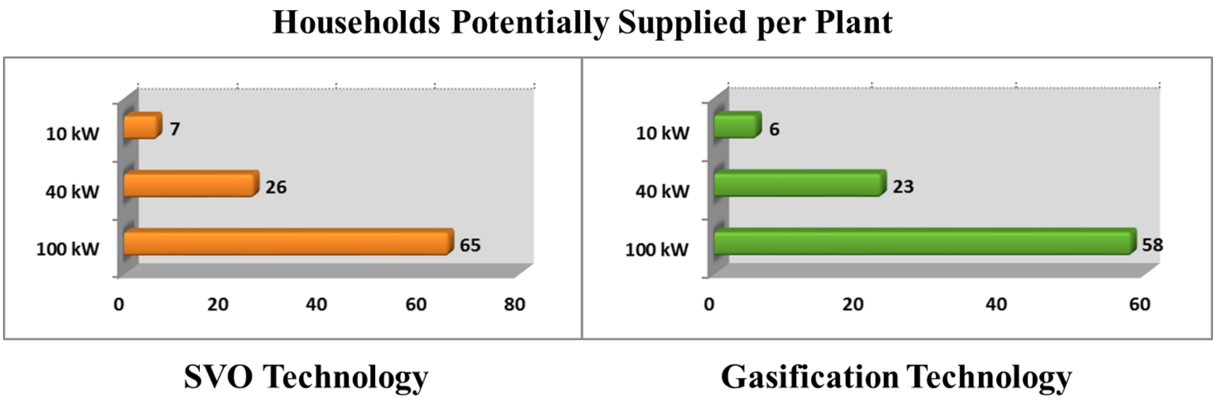


Fig. 16: Comparison of Households Potentially Supplied for SVO and Gasification

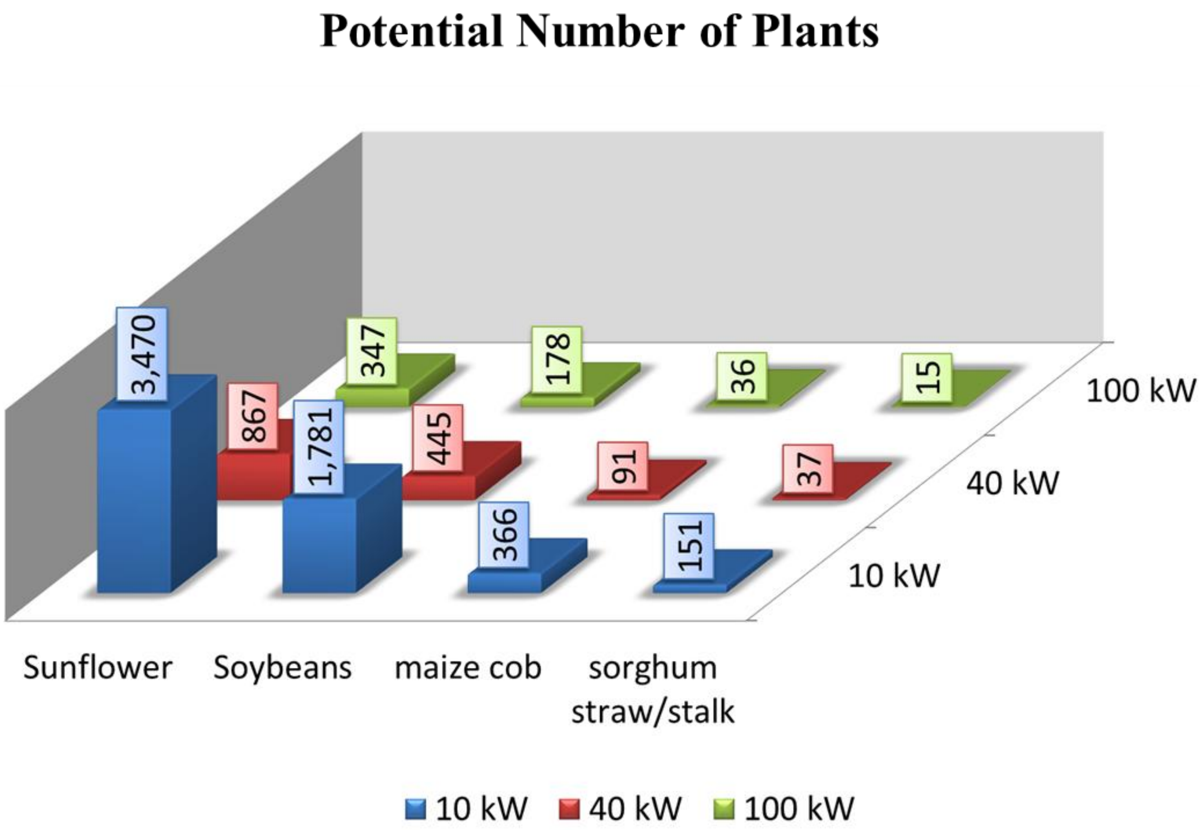


Fig. 7: Comparison of potential number of plants supplied for SVO (Sunflower and Soybean) and Gasification (Maize Cob and Sorghum Straw/Stalk)