2.3 Hydrothermal carbonization
Hydrothermal carbonization occurs biomass is liquid in water and methanol to produce bio coal at temperatures between 300-400 °C and pressure between 120-200 atmospheres. Hydrothermal carbonization can utilize wet biomass reducing on the pre-treatment costs (Lehmann et al., 2004).

2.4 Torrefaction
The torrefaction process is also a thermal process that occurs at temperatures of 200-300 °C (Edelstein et al., 2008). The biomass is converted to a coal like product that can be used in place of coal. Torrefied biomass has high calorific value and cannot absorb moisture easily. Bio coal from the torrefaction process can also be pelletized or used as a raw material in bio refineries.

2.5 Combustion
Combustion refers to the burning of biomass such as wood, dung and agro waste and is the highest utilised process for biomass conversion to energy especially in Africa (IEA, 2008b). In African more than 3 billion people use in efficiency cook stoves resulting in energy loses as well as health problems (Edelstein et al., 2008; IBI 2013). Figure 3 shows a woman from Kenya making an improved cook stove.

Figure 3. Making a bio char stove in Kenya (International Bio char Initiative, 2013).

2.6 Gasification
The process of biomass gasification involves the bio conversion of the solid biomass to gaseous gases such as carbon dioxide, carbon monoxide, methane and hydrogen. This gas is also called syngas and has a low calorific value. Biomass gasification takes place at temperatures above 700 °C.

3. Factors Affecting Biomass Energy Efficiency and Supply
For biomass energy to be completely effective as a renewable energy source public policy must play an important role. In addition issues like process efficiency, scale, environmental impacts, sustainability; funding and scale of production must be considered. The various factors affecting biomass energy are described below:

3.1 Efficiency and scale of production
Biomass energy efficiency is around 80% irrespective of the energy source used. Processes and technologies that enhance the energy density in biomass must be adopted so that the efficiency value can be increased. For biomass energy efficiency to be also greatly increased, the scale of production must be as high as possible for the production process to be economic.

3.2 Sustainability
Sustainability plays a critical role in biomass energy efficiency. The sustainability of bio energy is depended on raw material supplies, harvesting technologies employed and available infrastructure for processing the biomass. Furthermore issues of environmental impacts and air emissions control must be known and taken care of. The economy, social perspective and environment play a critical role in biomass energy usage (Figure 4).

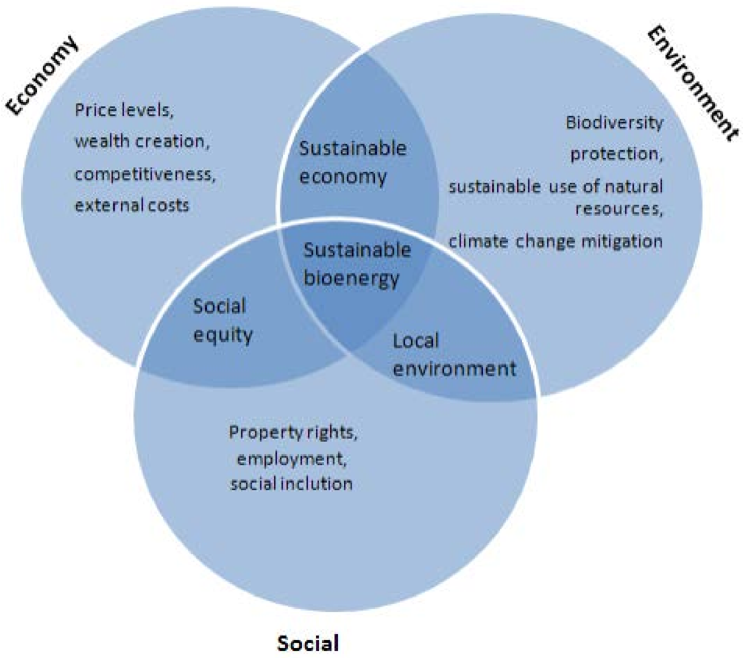

Figure 4. Dimensions of biomass sustainability (World Commission on Environment and Development, 1987)

3.3 Biomass supply and harvesting

The continuous supply of biomass is critical in ensuring biomass energy efficiency. The energy content of the biomass, land availability for its cultivation and its impact on the environment must always be quantified. Sustainable harvesting methods must also be investigated for continuous productivity.

3.4 Climate change effects

Adoption of efficient bio mass energy products has potential to lower carbon dioxide (CO_2) emissions in overall mitigating climate change effects (Guant and Lehmann, 2008). The level to which the biomass energy system reduces the CO_2 levels is dependent on the biomass type, harvesting technology employed as we'll as the energy production method.

4. Use of Biomass Based Biochar in Sustainable Cropping

4.1 Bio char history

The bio char story goes back as early as to the first human settlement and in these studies soil was enriched by burned biomass and the deposits of enriched soil were called *Terra preta* (Lehmann et al., 2004). Recent research indicated the increased demand of biomass energy due to its potential to reduce green house gases in addition to the potential of the bio char to enhance soil quality and soil carbon sequestration. Various biomass sources can be used as raw material for bio char production and some examples are shown in Figure 5.

Figure 5. Bio chars from various crop biomass (Zheng et al., 2010)

4.2 Bio char production

Bio char is produced through the thermal conversion of the biomass mainly using the pyrolysis technology. The biomass is carbonized in the absence of oxygen and it is during this process that bio char, a potential soil amender is produced. Figure 6 shows the detailed bio char production processes which include size reduction, drying and pyrolysis.

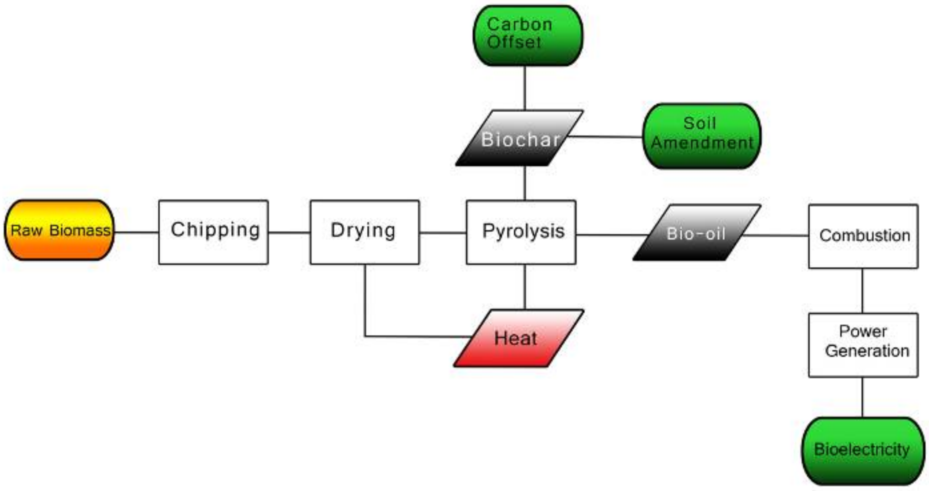

Figure 6: Bio char and its related products production process from biomass

The effectiveness and efficiency of the bio char production process and use varies on the biomass source and classification (McLaughlin et al., 2009). Parameters such as moisture content, ash content, type of feedstock used in bio char, greenhouse gas emissions and the bio char effect on soil quality are important (IBI, 2009).

4.3 Opportunities in using bio char

4.3.1 Increased soil fertility

Bio char can be used in soil amendment hence decrease the need for chemical fertilizers (Collins, 2008). There is still need to fully explore the quantity of bio char to be applied, production cost as well as the bio char availability to the soils. Bio char has little plant nutrients but acts more as a soil conditioner thereby improving the soil structure. Since bio char also has high surface area which provides a habitat it makes it easy for microorganisms to thrive in the soil increasing nutrients availability to plants. Bio char may also provide indirect nutrient cycling through reduction of leaching nutrients.

4.3.2 Soil moisture retention

Bio char application can enhance soil moisture retention lessening potential drought effects. The ability to retain moisture is related to the bio char porosity and surface area (Lehmann and Joseph, 2009). The bio char moisture content is dependent on the biomass source as well as its production process (Lehmann and Joseph, 2009).

4.3.3 Soil pH balancing

Bio char has potential to enhance the soil ph although high bio char quantities may be required for use in pH balancing (Collins, 2008). The application of bio char in soil liming has potential to augment the net carbon benefit.

4.3.4 Potential income from bio char

The monetary benefit from bio char can be realized from its use in soil amendment as a source of bio energy as well as from the net carbon benefit. Depending on the size of production bio char total costs of production ranges between $194 -424 per ton of feedstock (Granatstein et al., 2009).

4.3.5 Bio char environmental control

Bio char exists in particulate matter and has potential to cause air pollution and air bone diseases. These emissions must be managed properly during the production and application processes. There is also potential for heavy metal content in the bio char and its impact on plants and soil must be known.

4.3.6 Bio char's potential for carbon sequestration

The potential for bio char to influence the carbon-negative effects is determined by the energy efficiency and the bio char production process (IBI, 2009; UNEP, 2009). Bio char usage results in a net reduction of green house gases by more than 2.5 times (Guant and Lehmann, 2008; Lehmann and Joseph, 2009; Roberts et al., 2010). However, there is still need to clearly demonstrate that bio char nitrous oxide (N_2O) from soils, N_2O presents a huge amount of green house gases from agriculture production (Tilman et al., 2009; Roberts et al., 2010).

5. Use of Biochar in Nutrient Cycling

5.1 Crop productivity and bio char application rates

Bio char promotes higher microbial activity and accelerates soil stabilization during crop productivity, higher mineralization of soil organic matter as well provision of the required nutrients for plant growth (Covell et al., 2011; Uzoma et al., 2011; Ippolito et al., 2012). Figure 7 shows a pictorial representation of the *Terra preta* effect and the basic function of bio char.

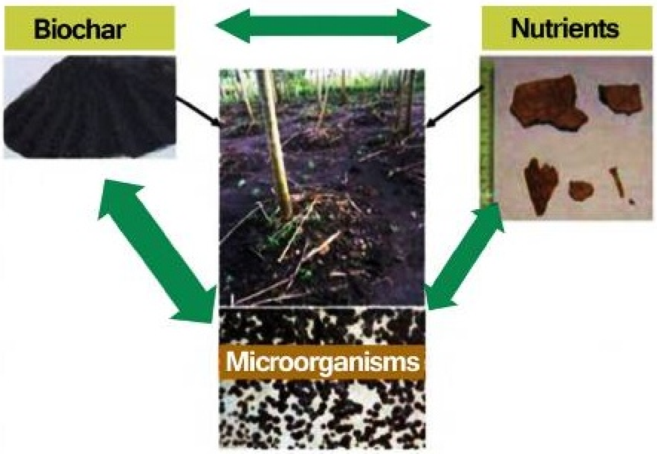

Figure 7. *Terra preta* effects and bio char interactions (Fischer and Glaser, 2012)

Bio char has been widely reported to cause an increase in the crop yield by several authors (Smith et al., 1992; Steiner et al, 2007; Major et al, 2010; Biederman and Harpole, 2013). Jeffrey et al. (2011) reported 10% increase in yield upon applying 10-100 tons/ha of bio char at varying application rates. This was also confirmed by Liu et al. (2013) who obtained an 11% higher yield upon testing 59 pot plants. The increased yields upon bio char application was attributed to the increased nutrient availability in terms of phosphorous and nitrogen as well as improved soil physicochemical properties (Lehmann et al. 2006; Rondon et al., 2007; Asai et al. (2009); Kammann et al. (2011); Harpole, 2013). Table 1 gives a summary of increased yield reported in literature for various crops.

Table 1. Effect of bio char on crop yields

Crop applied on	% Increase	Reference
Corn	140	Major et al. (2010)
Cherry tomatoes	64	Hossain et al. (2010)
Cow pea	100	Glaser et al. (2012)
Radishes	96	Chan et al. (2008)
Legumes	30	Liu et al. (2013)
Vegetables	29	
Grasses	14	
Cereals	8	
Wheat	11	
Rice	7	

5.2 Replacement of conventional fertilizer by bio char

Bio char has proven potential to increase crop yields possibly due to nitrogen utilization making it a potential replacement of conventional fertilizers (Day et al. 2005; Steiner et al., 2007; Chan et al., 2008; Sohi et al., 2009; Masulili et al., 2010; Widowati et al., 2011). An assessment by Gaunt and Cowie (2009) indicated that utilisation of bio char results in 10-30% reduction in nitrogen fertilizer utilization. This helps to curb the 13.3 tons of CO_2 that are emitted every time a ton of nitrogen is produced (Kuzyakov et al. 2009; Zhang et al. 2013).

5.3 Bio char production cost estimates

The bio char cost is determined by the type of feedstock, collection, production method, transportation cost as well as the application method. Williams and Arnot (2010) indicated that that bio char applications of 25 tons/ha using the disk and broadcast method were approximately $63-70/ha.. The estimated bio char production costs reported in literature is shown in Table 2.

Table 2. Cost of production estimates for bio char

Bio char cost (USD/ton)	Source of biomass	Reference
150-260	Green waste and wood waste	Shackley et al. (2011)
50-200	Baggase	Van Zwieten (2008)
500	-	US Bio char Initiative (2013)

6. Biochar's Effect on Soil Nitrogen Dynamics

Bio char enhances the soil's nitrogen content by changing the soil's nitrogen cycle (Rondon et al., 2007). The adsorption and cation exchange ability of NH_4^+ and NO_{3-} of bio char can effectively inhibit the leaching of nitrates and retain nitrogen (Cui, 2015). Bio char provides a habitat for nitrifying bacteria to convert NH_{4+} into NO_{3-} and aerates the soil (Keeney and Nelson, 1982). Further studies are required on the function of bio char in soil so to understand how to best apply bio char in crops to maximize yields and minimize environmental damage. During the bio char dynamics with the soil, the cycle starts with crop waste to make bio char, which is returned to the soil as bio fertilizer to produce more crops (Figure 8). Since the properties of bio char is changeable, bio chars must be accustomed to match the characteristics of a given field, crop, soil and climate.

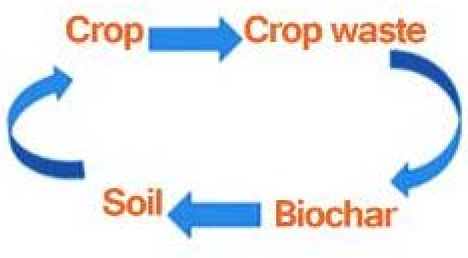

Figure 8. The cycle of nitrogen with bio char amendment (Cui, 2015)

7. Conclusion

There is great potential that can be realized from bio energy and bio char especially in cases where sustainability of the whole process is concerned. Bio char can be used in soil amendment and nutrient cycling to continually complete this cycle for continual biomass production. Bio char can absorb N through ion exchange, take out NH_3 through adsorption, can stimulate mineralization, and reduces N_2O and CO_2 emissions significantly. There is therefore great potential for integrating biomass management for optimum energy efficiency and nutrient cycling.

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