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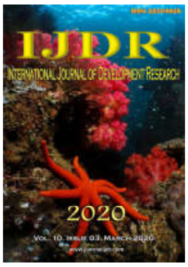

RESEARCH ARTICLE **OPEN ACCESS**

ESTIMATION OF CARBON FOOTPRINT OF TEA PRODUCTS AT NYABIHU TEA FACTORY, WESTERN PROVINCE-RWANDA

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ABSTRACT

The carbon footprint arose out of the debate on climate change, as a tool to measure GHG emissions. This research carried out at Nyabihu tea factory for carbon footprint estimation in tea life cycle was focusing on different key processes and phases or steps through which Nyabihu tea passes until it is delivered to the auction site (Mombasa). Data collection involved: (1) questionnaire survey to assess the life cycle of tea for Nyabihu tea, (2) field observation and measurements (forests and tea plantations), and (3) personnel interview. The study found that carbon footprint from tea production depends on different factors including, transport, burning fuel woods, energy use and fertilizers application which contributed to releasing nitrous oxides (N_2O), carbon dioxide (CO_2) and methane (CH_4) in the atmosphere. The amount of the three greenhouse gases emitted from the life cycle was expressed in terms of the amount of carbon dioxide equivalent (CO_2eq) units as calculated by the Cool Farm Tool 1.1 software. The emission from total area is 150467.3690tCO_2eq. Most of carbon dioxide equivalents were found to be released from off farm activities with a total of 135kg CO_2eq per kilogram. The greatest amount of greenhouse gases emitted is due to transport. The total annual emission from the tea life cycle is -365.31kgCO_2eq per kilogram of finished product. But in terms of compounds the largest emissions in CO_2 equivalents come from N_2O where 0kgs of N_2O equate to 0.696kgCO_2eq per kilogram and the least is from CH_4 (i.e. 0.0kgCO_2eq of CH_4 per one kilogram). Measures to reduce emissions in order to protect the environment were undertaken by Nyabihu tea factory. These include enhanced sequestration through forest and agroforestry trees plantation which accounted for sequestration of 406744.48116tCO_2/hectare sequestered. In order to reduce carbon dioxide and other greenhouse gases emissions, agricultural techniques including appropriate use of fertilizers should be changed to help efficient sequestration of carbon in the soils since soil can act as an effective carbon sink. Furthermore, the management of wastes and tea crop residues through incorporation into the soil will provide more advantageous carbon storage.

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INTRODUCTION

The carbon footprint arose out of the debate on climate change, as a tool to measure GHG emissions. It measures the emission of gases that contribute to heating the planet in carbon dioxide (CO_2)-equivalents per unit of time or product (Ercin and Hoekstra, 2012).

The common baseline is that the carbon footprint stands for a certain amount of gaseous emissions that are relevant to climate change and associated with human production or consumption activities (Wiedmann and Minx, 2007). Deforestation and other land-use changes also release large amounts of carbon dioxide, Nitrous oxides and methane gas. Methane (CH_4) is also produced by domesticated animals, rice paddies and the disposal and treatment of garbage and human wastes. Fertilizer use releases nitrous oxide. Industry has created a number of potent greenhouse gases lasting for a long time (WMO, 2013). In addition, for example, in the wastewater sector, the carbon footprint is attributed to the sum of all emissions associated with the collection, treatment, and ultimate disposal of wastewater. Significant sources of these emissions include the indirect emissions from the purchase of electricity, direct emissions resulting from the treatment process, fugitive emissions from the waste itself, and transportation-related emissions (Ramachandra and Mahapatra, 2016).

Literature applied: A carbon footprint is a measure of the impact our activities have on the environment, and in particular climate change. It relates to the amount of greenhouse gases produced in our day-to-day lives through burning fossil fuels for electricity, heating and transportation etc. It (i.e. the carbon footprint) is therefore a measurement of all greenhouse gases we individually produce and has units of tones (or kg) of carbon dioxide equivalent (IPCC, 2007). Climate refers to the condition of the atmosphere at a particular location (microclimate) or region over a long period of time. It is the long-term summation of atmospheric elements such as solar radiation, temperature, humidity, precipitation type (frequency and amount), atmospheric pressure and wind (speed and direction) and their variations (OECD, 2007). A rise in the concentration of greenhouse gases, carbon dioxide(CO_2), Methane(CH_4), Nitrous oxides(N_2O) and halocarbons in the atmosphere due to anthropogenic activities are connected with global climate change (Dalal *et al.,* 2003). The environmental science has the responsibility of dealing with climate change.

Climate change is a truly global issue caused by greater concentration of greenhouse gases in the atmosphere resulting in environmental hazards; one molecule of greenhouse gas carries with it the same package of impacts irrespective of where or how it is emitted (O'Riordan, 2000). The climate change caused by anthropogenic release of CO_2 is expected to be extremely interesting and attracting global geophysical experiment that human being will ever conduct. Therefore, scientific work should help determine the nature of the upcoming climatic effects as early as possible (Hansen *et al.,* 1981). The United Nations Intergovernmental Panel on Climate Change (IPCC) has concluded that 50% to 80% cuts in global CO_2 emissions by 2050 compared to the 2000 level will be needed to limit the long-term global mean temperature rise to 2.0°C to 2.4°C (IPCC, 2007; OECD/IEA, 2008). Higher emissions will result in higher temperature rises and more significant climate change. The concentration of a greenhouse gas in the atmosphere depends on the competition between the rates of emission of the gas into the atmosphere and the rates of processes that remove it from the atmosphere. For example, carbon dioxide (CO_2) is exchanged between the atmosphere, the ocean and the land through processes such as atmosphere-ocean gas transfer and chemical (e.g. weathering) and biological (e.g. photosynthesis) processes (IPCC, 2007). According to the International Energy Agency report entitled "World Energy Outlook 2007", it is highlighted that in 2030, fossil fuels would remain the dominant source of energy. The bulk of the additional CO_2 emissions and increased demand for energy, 84% of which will come from using fossil fuels, will come from developing countries (IEA, 2007a; OECD/IEA, 2008).

Carbon dioxide (CO_2) is the main anthropogenic greenhouse gas responsible for warming the atmosphere (UNEP, 2013). Actually, it is known that when carbon dioxide is released into the atmosphere it warms the Earth through heating effect caused by radiations absorbed and reradiated by CO_2 molecules. This means that greenhouse gases affect the ability of the earth's atmosphere to retain heat (Abbott, 2008). A carbon footprint study on tea was presented by Nigel Melican during the 2009 world tea expo in Las Vegas. The amount of carbon footprint in tea depends largely on how tea is produced, processed, prepared and the type of tea consumed (Doublet and Jungbluth, 2010). The kind of fuel a tea consumer uses to heat water for tea also has an impact. Recycling or re-using your tea and its packaging also improves its carbon footprint (Teavant, 2009). Melican discovered that Carbon footprint in the tea (measured by the number of grams of carbon dioxide per cup) can vary greatly from over 200g CO_2 per cup to -6g CO_2 per cup. These changes in grams of carbon dioxide are related to how tea is treated since its plantation until the final product which is ready to be consumed is produced, also the quality of tea produced (Sauer, 2009). For example, the growth of organic tea contributes to an increase of the total carbon footprint than conventional cultivation. The reason is the use of large quantities of compost, which emits fossil methane in the air and results in increasing the total GWP (Global Warming Potential). Another reason of having total GWP increased results from the use of N-fertilizers in the conventional cultivation (Doublet and Jungbluth, 2010). In Rwanda, the agricultural sector, industries and factories contribute to greenhouse gases emissions. Tea cultivation has degraded the environment through different types of Fertilizers used in tea plantations (Mupenzi *et al.,* 2011).

The industrial sector in Rwanda grew with an average of 9.32% growth rate between 2006 and 2009. Manufactured products include cement, agricultural products, small scale with beverages, soap, furniture, shoes, plastic goods, textile, etc (RDB, 2010).Rwanda is currently highly vulnerable to climate change as it is strongly reliant on rain-fed agriculture both for rural livelihoods and exports of tea and coffee. Thus the entire economy is vulnerable to the effects of climate change (RoR, 2011). Calculating a carbon footprint can be a valuable first step towards making quantifiable emissions reductions of GHGs (Abbott, 2008). It is clearly highlighted that although there has been a great deal of environmental deterioration, awareness on quantifying the magnitude of Carbon footprint is scarce. However, the measurement of Carbon footprint requires clarity on (i) inclusion of indirect emissions required for upstream production process, (ii) direct and onsite emission of the production process, (iii) accounting for all stages of the life cycle of a process in terms of services and goods, and (iv) systems boundary and quantification approaches(Ramachandra and Mahapatra, 2016). According to the National Strategy for Climate change and Low Carbon Development in Rwanda report, there are uncertainties in the GHG inventory due to inadequate representation, lack of basic data and application of emissions factors for different conditions. Owing to the rapid development in energy and industry in Rwanda, these figures need to be revisited to account for uncertainties in growth projections, energy intensity and the energy supply mix (RoR, 2011). However, in their research, Ramachandra and Mahapatra argued that the carbon footprint can have a variety of quantifying scales as to determine the impact or the stress/quantity of Carbon emission (tons)/quantity normalized over CO_2 as CO_2 equivalents (tons of CO_2-eq.) as in the case of GHG potential/area for land measurements (Ramachandra and Mahapatra, 2016). The overall objective of this study is to estimate carbon footprint of tea products at Nyabihu Tea factory using the Cool Farm Tool software (CFT 1.1) and provide an understanding of impact of greenhouse gases on environment and climate change. With this respect, the research had the specific objectives of (1) establishing the complete life cycle of tea production at Nyabihu tea factory; (2) collecting all relevant data for calculation of carbon footprint of tea products at Nyabihu tea factory; (3) estimating carbon footprint of 1kg of tea at the factory site (Nyabihu) and auction site (Mombasa) using CFT 1.1. To make it easy for GHGs estimation, this study was limited from cradle to gate of the black where emissions from final disposal are not included. Rwanda has one of the lowest GHG emissions per capita in the world, estimated at 0.6tCO_2eq/person compared to a global average of 6.7tCO_2eq/person, including land use change, in 2005 (RoR, 2011).The ambition to intensify agricultural production could increase GHGs through more intensive use of land for crops. This could be through increase use of nitrogen based fertilizers, which are carbon intensive to produce (Downing *et al.,* 2009). Therefore, the research on Carbon footprint accounting in tea factory is necessary to facilitate the establishment of local climate strategies through relevant planning activities aiming at reducing Carbon Footprint on local and global scale. In this study an estimation of Carbon footprint of tea products at tea factory site and auction site at Mombasa will be made based on a case study of Nyabihu Tea factory, Western province of Rwanda.

MATERIALS AND METHODS

Study area description: Nyabihu district is located in Western Province of Rwanda. It has 12 sectors that are Bigogwe, Jenda, Jomba, Kabatwa, Karago, Kintobo, Mukamira, Muringa, Rambura, Rugera, Rurembo, and Shyira. These areas are themselves divided into 73 cells and 473 villages. The district is characterized by 90% rugged mountains with a slope of more than 55% making the district prone to high risk of erosion and other harms associated with climate change. The characteristic of the soil is sandy and clay, laterite and volcanic. Precipitation is almost uniformly high every month and close to 1400 mm per year. It has a temperate climate with an average temperature of 15^0C favorable for the growth of the agro-pastoral products throughout the year with less risk of development of bacteria and diseases.

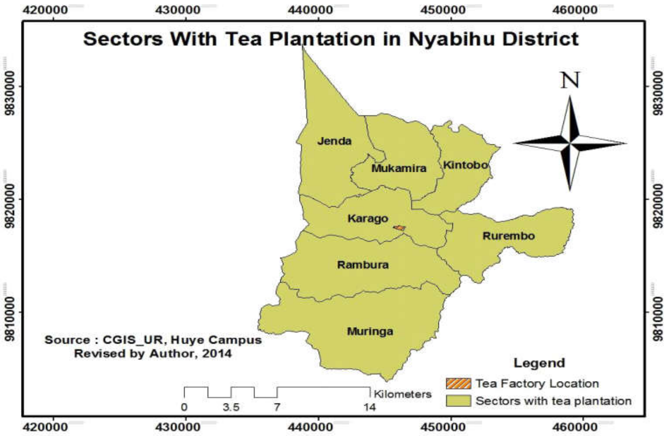


Figure 1. Tea plantations and location of Nyabihu Tea Factor

Nyabihu tea factory: Nyabihu tea factory is among tea factories privatized recently (2006) by government of Rwanda, Nyabihu tea factory is located in the North-West of Rwanda in the Western Province, Nyabihu District, Karago Sector, Kadahenda Cell, to 123 km away from Kigali, the capital city of Rwanda, it is owned by Rubaya–Nyabihu Tea Company, managed by Rwanda Mountain Tea (RMT).The tea factory comprises 658.38 hectares of plantations, subdivided into the industrial plantations and village blocks. The area of the industrial block is 622. 87 hectares comprised of the following 7 divisions: Nyabihu, Mutaho, Mukamira, Cyamabuye, Mugogo, Gitwa, Rutuku I, Rutuku II, Mabenga and Bwiza. Villagers‟ teas occupy an area of 30.50 hectares; the tea factory also counts 80 hectares of forests for the supply of its boiler. The tea plantations of Nyabihu are located mainly on high altitudes, up to 2300 meters above the sea level, 41% of the plantations are located in marshes. The ground is volcanic, which ensures a better quality, and a better taste to the teas of Nyabihu. The tea production is still low and covers only 30% of Nyabihu tea factory. Currently, the annual production of the factory is estimated to 40,000 metric tons by the end of 2012. The district plans to expand the tea plantation which will allow an increment of 27,000 metrics tons as new production that represents the gap of 133,333metric tons of Nyabihu tea factory total capacity installed.

Figure 2. Nyabihu tea factory

Research design and data collection

The research consisted in collecting data that would enable the computation of carbon footprint of tea products at Nyabihu tea factory. The main methods used include:

- Direct observation
- Questionnaire survey
- Field measurements in tea plantations and forests

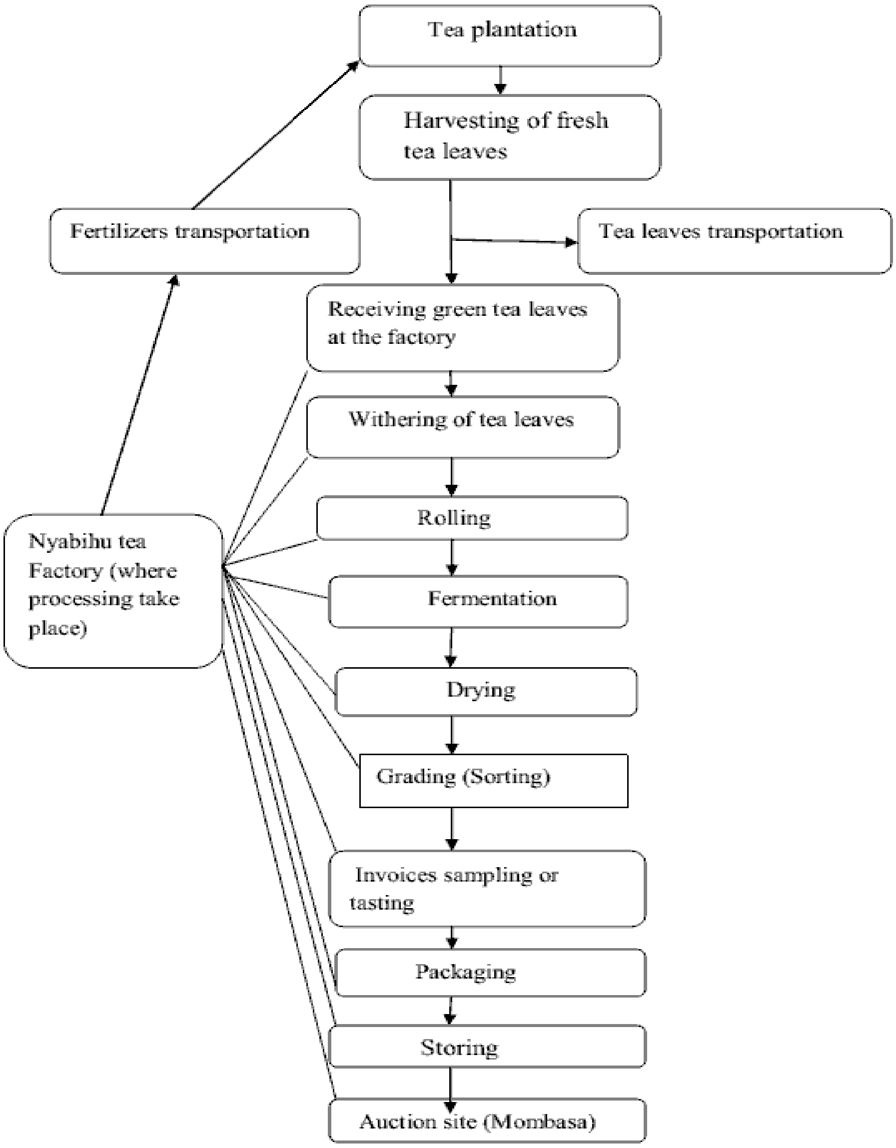
Carbon footprint parameters: Parameters to be estimated were all types of gases known as greenhouse gases associated with production of one kilogram of tea including carbon dioxide as a reference greenhouse gas. Relevant data helping to estimate carbon dioxide equivalent of major greenhouse gases were collected. Taking into account the activity and the processes taking place during tea production, these gases are Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O). All emissions had to be estimated considering the sources for each gas or emission factors. Thus the following factors were considered in order to estimate carbon footprint: (1)Types of cars used in transportation of tea and Distance travelled by cars, (2)Type of fuel consumed by cars and other fuel-consuming machines,(3)Type of fertilizers used in tea plantations,(4)Energy consumers (for electricity users, heating, fuel wood, etc.), (5)Tea consumed or quality of tea produced and mean diameter (DBH) at 15m of tea stump and for trees at 1.3m.

Survey instruments: Interview was conducted. The Director General (D.G.) of Nyabihu tea factory, Technical staff, Agronomists and personnel in charge of tea production and supply chain processes (i.e. tea maker) were all the targeted key informants. Information was given by one or a group of persons at a time. Field observation was made while taking measurements of diameter at breast height (DBH) for teas and for trees in the forest plantations. During survey and field measurement, any kind of information was recorded on worksheets and questionnaires. These questionnaires contained a number of questions whose objectives were to help respondents to give accurate information and necessary data to estimate carbon footprint. Pens, pencils and Computer (to help in data entry for analysis with Cool Farm tool 1.1software) were used. The mean diameter of tea stumps and other tree species were measured using meter tape.

Data analysis: Data collected were entered into computer to make calculations and analysis with the Cool Farm Tool 1.1 software. Emissions were calculated taking into account appropriate emission factors. The results were recorded for each parameter including allocation of emissions taking into account emission sources. In reporting, the amount of greenhouse gases emitted was expressed in terms of the amount of carbon dioxide or its equivalent expressed as carbon dioxide equivalent (CO_2eq) units. All calculations were done with the help of the above mentioned software and released results already expressed in CO_2eq. According to Kyoto Protocol Greenhouse gases**,** six types of greenhouse gases are distinguished Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and finally Sulphur hexafluoride (SF_6)(WRI and WBCSD,2004). Among those gases, we have been able to estimate the carbon dioxide equivalent of the first three greenhouse gases, mainly CO_2, CH_4, and nitrogen oxide (N_2O).

RESULTS PRESENTATION AND DISCUSSION

Life cycle of black tea production of Nyabihu tea factory



Source: (Author, 2014)

Figure 3. The life cycle of black tea (from cradle to gate)

The results from Nyabihu tea life cycle, as emissions are allocated with respect to different processes taking place during black tea production which are the main sources of those emissions, are presented and discussed accordingly. Emission sources include field or crop management, transport and processing (energy consumption). Sequestration was taken into account as the process that helped to know the carbon storage changes occurred over the year 2013 in Nyabihu tea life cycle. Therefore, according to WRI and WBCSD (2011), allocation is the partitioning of emissions and removals from a common process between the life cycle of the studied product and the life cycle of the co-product(s). Accurately allocating emissions or removals to the studied product is completely necessary to maintaining the quality or standard of a GHG inventory.

Relevant data for computing carbon footprint

Table 1. Data for carbon footprint estimation

General information	Production area	623.74 ha	Soil characteristics	Soil texture	Medium
	Fresh products	4,507,950 kg		Soil organic matter	15%(approximately)
	Finished products	111,5347kg		Soil drainage	Good
	Climate	Tropical		Soil moisture	moist
	Average temperature	15.5^0C		Soil pH	pH=5
Crop management	Fertilizer	Nutrients	Application rate	Application method	Emission inhibitors
	NPK 25-5-5 +3S	product	2	broadcast	none
	Crop residues (kg/ha)	-	5,555.2 kg/ha	Left, mulched on the field	-
Annual biomass	Species	Trees density	DBH this year (cm)	DBH last year (cm)	Change in number of trees this year
	Tea	13,888	2.5	1.8	2,864
	Tropical moist hardwood	1,111	21.46	20.5	769
Processing	Electricity from local grid (kWh/year)	Diesel (liters/year)	Fuel wood (tones/year)	Oil (liters/year)	Waste water (liters/year)
	1,256,172.6	34,840	1,310	2,190	1,460,000
Transport	Item	Quantity	distance	mode	Return empty or no
	Fertilizers and other inputs	403,150 kg	15,435 km	Light good vehicles (diesel)	Empty
	Fresh products	4,507,950 kg	69495 km	Light good vehicles(diesel)	No
	Finished products	1,115,347 kg	130,702.144km	Heavy good vehicles	Empty
	Fuel wood	1,310 tons	25496 km	Light good vehicles(diesel)	No

Source: (Author, 2014)

Table 2. Emissions from farming activities

Process	CO_2	N_2O	CH_4	Emissions for total area, kg CO_2eq	Per hectare	Per kilogram	Percentage of (%) emissions
Fertiliser production	1,197.6	0.0	0.0	1,197.6	1.9	0.0	0.2
Fertiliser application	0.0	1,797.9	0.0	532189.0	853.2	0.5	68.4
Crop residue management	0.0	825.8	0.0	244,444.2	391.9	0.2	31.4
Total	1,197.6	2,623.7	0.0	777,830.8	1,247	0.7	100

Source: (Author, 2014).

Wastewater produced is treated chemically. The amount of oxygen needed for wastewater degradation accounts for 0.126mgO_2/liter. Meaning that chemical oxygen demand (COD) of the product used to treat this water is 0.126mgO_2/liter. After being treated, wastewater is channeled into anaerobic lagoon of a depth greater than 2m in order to avoid its free movement in the environment around the tea factory. Tea residues or unused tea leaves, when pruned is equal to 5555.2kg per hectare. Pruning is done every four years, so the amount of residues calculated was referred as the average annual residues. This amount of residues is found by weighing average weight of prunings from two trees to help estimate prunings on hectare that would be accumulated over four years. Since the number of tea trees per hectare is known, the initial value found was divided by four to get the estimated amount (5555.2kg/ha) for one year because pruning is done after every four years. The mean diameter of trees including DBH of tea found on study area was measured at 1.3m for trees and at 15cm for tea. Diameter of trees helped to estimate biomass carbon dioxide of tree species found on study area (tea plantation). Not only this but also these DBH measurements for trees contribute to providing information about carbon sequestration. The land use changes in Nyabihu tea plantations occurred in the past 35 years, these changes are not considered because they occurred for more than 20 years ago. The 100% of the land underwent conventional to reduced tillage. Residues incorporation started when first pruning was done after 5 years of tea plantations establishment. This practice of incorporating residues into soils covers 80% of the land in tea plantation.

Carbon footprint estimation results: The life cycle of Nyabihu tea was divided into two main processes: Life cycle accounting for all GHGs emissions sources from the field to the factory includes field or crop management; transport (acquisition and distribution of inputs; and collection of tea leaves) and processing (energy consumption) at tea factory. The second process of the life cycle includes emissions occurred during transportation of tea products from the factory to the auction site.

Emissions from field or crop management: The results from fields as these GHGs are associated with crop management (i.e. Nyabihu Tea factory's tea plantations) and agriculture practices are illustrated in table 2 above. Emissions are allocated from different field management practices, crop and crop residues management. The table mentioned above provides the amount of kgCO_2eq emitted for each greenhouse gas released. The emissions occurred in the farm resulted in the type of fertilizers used and how residues were treated. In addition, soil characteristics are the good indicators which determine the crop management response. This enabled to analyze measures taken so that crop management contributes less carbon footprint to the atmosphere. On the side of field management, higher amount of emissions come from fertilizer application making 68.4% of the total emissions. This is due to Nitrogen-rich fertilizer application which results into emissions of nitrogen oxide (N_2O). It is now found that the type of this fertilizer used had great implication on the GHGs emission during the production of one kilogram of tea. According to Doublet and Jungbluth, (2010) study report, it is now argued that agricultural system (methods) also influence the amount of carbon footprint in tea, the comparison is between organic and conventional cultivation. It was highlighted that the increased global warming potential (GWP) results from the use of N-fertilizers in the conventional cultivation.

Emissions from transportation

Table 3. $KgCO_2eq$ from transportation

Means of transport	$KgCO_2eq$
Road	150,467,369.9

Source: (Author, 2014)

The results in table 3 above show the total emissions from transportation occurring during the acquisition and distribution of inputs; and collection of tea leaves. These analyses as indicated in table 3 show that emissions from transportation are increasing. The distance travelled by vehicles; the types of vehicles including the type of fuels are the main factors which caused an increase in carbon dioxide equivalents. This total amount (i.e. 150, 467,369.9$kgCO_2eq$) of emissions of greenhouse gases (GHGs) came from transportation by vehicles on the road as a sole means of transport. The greatest increase in emissions was caused by transportation of tea from the farm to tea factory and from tea factory to the auction site as the result of vehicles travelling a long distance before they arrive at Mombasa. This is referred to as the off-farm transport.

Emissions from processing (energy consumption): Direct energy use results excluding transport are summarized in the following three tables below. According to the results displayed below in table 4, Nyabihu tea factory uses both renewable and non-renewable energies during production process of black tea and it is seen that the main contributor to the amount of total energy used is non-renewable source of energy.

Table 4. Categories of energy used depending on renewability

Energy category	MJ	kg CO_2eq
Renewable electricity	772,654.2	0.0
Non-renewable electricity	3,749,567.2	805,457.4

Source: (Author, 2014)

Table 5. Types of energy used

Energy	MJ	kg CO_2eq
Grid electricity	4,522,221.4	805,457.4
Local wind, solar, hydro-electric	0.0	0.0
Biomass & Bioenergy	17,021.4	0.0
Fossil Fuels	1,391,100.0	98,911.3

Source: (Author, 2014)

Table 6. Energy use by site and process

Site/process	MJ	kg CO_2eq
On farm use	1,102,132.0	77,934.4
Primary processing	4,828,210.7	826,435.1

Source: (Author, 2014)

Because energy consumption is the step which embodies the use of fuel woods, diesel and electricity, energy consumers at Nyabihu tea factory includes heating machine (boiler), generator. Electricity is used during tea processing and other works which are, energy demanding. The results in table 6 above show that most of emissions come from primary processing where they account for 826,435.1$kgCO_2eq$ of the energy used and 805,457.4$kgCO_2eq$ of emissions came from grid electricity. The net CO_2eq from using biomass energy fall to 0.0$kgCO_2eq$ as the result of intense carbon sequestration due to increased forest plantations and biomass energy use efficiency at the tea factory. The results in table 7 below provide detailed information on GHGs emissions sequestration which show the total annual carbon offsets. The 98,911.3$kgCO_2eq$ emissions from the use of fossil fuels are associated with the use of generator and other energy producers consuming liquid fuels mainly in the time of electricity shortage. According to Downing *et al.,* (2009) study report, Rwanda already has a low carbon electricity sector and this will continue. The carbon intensity per unit of generation (grams of CO_2 per kWh supplied) is falling, thus the Rwandan electricity generation is broadly on a low carbon trajectory.

Sequestration

Table 7. Annual carbon sequestration results

Sequestration area	Annual totals, kg CO_2eq
Above ground biomass	-458,638,009.46
Below ground biomass	-1,009,597,354.69
Soil C	0.00
Total	-559,597,354.2

Source: (Author, 2014)

As the results in table 7 above indicate, there is a huge amount of carbon sequestrated or $kgCO_2eq$ sequestered or stored into the above ground and below ground biomasses amounting to -458638009.46$kgCO_2$/hectare and -100959344.69 kg CO_2/hectare respectively. This is due to the fact that there are forest plantations around the tea factory and tea plantations which enhanced sequestration of these GHGs emitted. This made the total annual $kgCO_2$equivalents to be equal to -559597354.2kg CO_2/hectare. The minus (-) sign, means that there was sequestration (i.e. a net sink of GHGs) in either environment. According to Sedjo and Sohngen (2012) forests are able to sequester more carbon. Thus, the fact that the below ground sequestration is higher than above ground is, apart from below ground biomass which is also part of CO_2equivalents sequestered in the soils by trees, related to less soil disturbance which increases the capacity of the soil to act as a net carbon sink and reduces GHGs emissions into the atmosphere. The total annual emissions from the tea life cycle is -391.53$kgCO_2eq$ per kilogram of finished product. In terms of CO_2 equivalents the greatest emissions in this case come from off-farm transport with a total of 109$kgCO_2eq$ per kilogram. But in terms of compounds the largest emissions in CO_2 equivalents come from N_2O. The 0kgs of N_2O equate to 0.696$kgCO_2eq$/kg. The total annual emissions from the tea life cycle are -365.31$kgCO_2eq$/kg of finished product. In terms of CO_2 equivalents the greatest emissions in this case come from off-farm transport, with a total of 135$kgCO_2eq$/kg. But in terms of compounds the largest emissions in CO_2 equivalents come from N_2O. The 0kgs of N_2O equate to 0.696$kgCO_2eq$/kg. Emissions from off farm transport were increased because emissions from tea factory to the auction site were included.

Table 8. Summary of results of life cycle from farm to tea factory

Black tea	CO_2	N_2O	CH_4	Emissions for total area, $kgCO_2eq$	Per hectare	Per kilogram	Per tree if relevant
1. Fertilizer production	1197.6	-	-	1197.6	1.9	0.0	0.0
2. Direct and indirect field N_2O	-	1797.9	-	532189.0	853.2	0.5	0.1
3. Crop residue management	-	825.8	-	244444.2	391.9	0.2	0.0
4. Carbon stock changes	(559597354.2)	-	-	(559597354.2)	(897164.5)	(501.7)	(59.8)
5. Field energy use	77934.4	-	-	77934.4	124.9	0.1	0.0
6. Primary processing	826434.2	-	-	826434.2	1325.0	0.7	0.1
7. Waste water	-	-	0.9	23.0	0.0	0.0	0.0
8. Off-farm transport	-	-	-	121,218,809.9	194,341.9	108.7	13.0
Totals	(558,691,787.9)	2623.8	0.9	(436,696,321.8)	(700,125.6)	(391.5)	(46.7)

Source: (Author, 2014)

Table 9. Total emissions' results of life cycle from farm to the auction site

Black tea	CO_2	N_2O	CH_4	Emissions for total area, $kgCO_2eq$	Per hectare	Per kilogram	Per tree if relevant
1. Fertilizer production	1197.6	-	-	1197.6	1.9	0.0	0.0
2. Direct and indirect field N_2O	-	1797.9	-	532189.0	853.2	0.5	0.1
3. Crop residue management	-	825.8	-	244444.2	391.9	0.2	0.0
4. Carbon stock changes	(559597354.2)	-	-	(559597354.2)	(897164.5)	(501.7)	(59.8)
5. Field energy use	77934.4	-	-	77934.4	124.9	0.1	0.0
6. Primary processing	826434.2	-	-	826434.2	1325.0	0.7	0.1
7. Waste water	-	-	0.9	23.0	0.0	0.0	0.0
8. Off-farm transport	-	-	-	150,467,369.9	241,234.1	134.9	16.1
Totals	(558,691,787.9)	2623.8	0.9	(407,447,761.8)	(653,233.3)	(365.3)	(43.6)

Source: (Author, 2014)

In both cases, the emissions from farm; field energy use; primary processing and sequestration are the same. As the results are provided in table 8 and table 9, these emissions were found to be 0.7$kgCO_2eq$, 0.1$kgCO_2eq$, 0.7$kgCO_2eq$ and 108.7$kgCO_2eq$ respectively. But again, comparing transportation for both life cycles, it is noticed that the amount of carbon dioxide equivalents emissions were increased when emissions due to transportation of finished tea product to the auction site (i.e. Mombasa) were included in the life cycle. This made the annual total emissions to be 135$kgCO_2eq$. If those emissions were not accounted for, the annual total emissions would be 108.7$kgCO_2eq$. The results from the first life cycle provided in table 8 indicate these emissions per one kilogram (1kg) of final product.

Conclusion and recommendations

Conclusions

Estimation of Carbon footprint in the tea life cycle studied showed that different tea production processes have contributed differently in greenhouse gases (GHGs) emissions. This is, in fact due to the nature of the processes themselves, the types of materials and inputs used in tea production. This research gave accurate results showing the extent to which Nyabihu tea factory is contributing to greenhouse gases emissions and how much amount of emission/GHGs offset. Most of GHGs emissions are attributed to transportation sector with a total of 135$kgCO_2eq$ per kilogram. This is due to higher amount of fuels (diesel) consumed by cars transporting inputs to the field, those transporting fresh tea leaves from fields to the factory and finally the emissions due to transportation of finished tea product to its sell point(i.e. auction site, Mombasa). The total annual emissions of GHGs from the life cycle studied are -365.3$kgCO_2eq$ per kilogram. Generally, the emissions from transportation could be reduced if those resulting from transportation of finished tea products are not accounted for in tea life cycle studied for Nyabihu tea factory. The research showed that without transportation of finished tea product to its sell point, the emissions from transportation could fall to 109$kgCO_2eq$ per kilogram of finished product while the total annual emissions could be -391.53$kgCO_2eq$ per kilogram of finished product. The initiative of tree planting in the neighborhoods of the tea factory and agroforestry trees around tea plantations contributed much to carbon sequestration. This practice has contributed much to GHGs emissions reduction. In addition to emissions reduction, these trees also protect the soil against erosion and increase soil organic matter. The whole tea life cycle studied showed that greenhouse gases are emitted. In all steps, except for annual tree biomass that helped to know the amount of CO_2 sequestered, the releases of GHGs was a prevalence and variation depends on the step itself in tea life cycle.

Reducing carbon dioxide (CO_2) emissions into the atmosphere may results in reducing microclimate change at Nyabihu tea factory and around. This is evidenced by the results where it is clearly seen that annual sequestration is greater than emission, for example -365.31$kgCO_2eq$ per kilogram of finished tea product indicated that 365.31$kgCO_2eq$ were sequestered. Nitrous oxide (N_2O) is found to be the compound with the largest emissions in CO_2 equivalents from all compounds where 0Kgs of N_2O equate to 0.696$kgCO_2eq$ per kilogram. Nitrous oxide (N_2O) and Methane (CH_4) are greenhouse gases which last longer in the atmosphere and remain there for many years. Therefore, the emissions of these gases are reduced through sequestration in order to reduce their strong influence on microclimatic change in the region which could affect the global climate across the country. Depending on the inputs used and treatments applied to tea, there was a small amount of methane gas released from the entire process, this amount accounts for 23.0$kgCO_2eq$ per total area. This was mainly due to wastewater treatment which contributed to the release of CH_4. Carbon dioxide (CO_2) equivalents estimated from the whole cycle is 905.5662tCO_2eq and N_2O accounts for 776.6332 tCO_2eq on the total area.

Recommendations

With reference made to the research findings and challenges met during this study, the following recommendations should be addressed in order to make it easy for carbon footprint estimation in the future.

- More efforts are needed by the factory to provide basic information from the farm, and forest inventory to provide quality data are highly advised, especially DBH of trees, amount of annual biomass pruned from production area. This should also be addressed to different tea factories interested in carbon footprint estimation.
- Planting trees in the vicinity of the tea factory and agroforestry tree species will help to sequester carbon from atmospheric CO_2 through incorporation into biomass. To this end, the trees must grow and last longer in the plantation stands for efficient sequestration of greenhouse gases.
- Changing agricultural techniques including reduction of fertilizer application rates will help to effectively sequester carbon in the soils because soil can act as an effective carbon sink. Less soil disturbance techniques and appropriate use of fertilizers will help to effectively control emissions through the adoption of environmental friendly techniques which favor carbon storage.
- Crop residues and wastes should be incorporated into the soils in order to provide more advantageous carbon storage. This agricultural carbon storage practices will have positive ecological effects and increase tea production. Reducing inorganic fertilizers by applying fertilizer enriched composts will help to reduce GHGs emissions and increase factory income due to reduced costs of inputs.
- Better measurements of DBH for tea should be made at 12 cm instead of 15 cm because at this height tea has already begun to develop branches (twigs).
- Calculation database (software used) should be user friendly and provides options to enter the amount of inputs and information different from the ones defined as default data to help users effectively handle all data collected for carbon footprint estimation.

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REFERENCES

Abbott, J., 2008. Project: What is a Carbon Footprint? Report presented to: The Swedish Forestry Industries Federation and Timcon by The Edinburgh Centre for Carbon Management. Reference: ECCM-EM-483-2007.

Dalal, R. C., Wang, W., Robertson, G.P., Parton, W.J., 2003. Australian journal of soil research Nitrous oxide emission from Australian agricultural lands and mitigation options: a review, 41, 165-195, CSIRO Publishing.

Doublet, G. and Jungbluth, N., 2010. Life cycle assessment of drinking Darjeeling tea Conventional and organic Darjeeling tea. ESU-services Ltd.

Downing, T., Watkiss, P., Dyszynski, J. et al., 2009. Report: Economics of climate change in Rwanda. SEI, Oxford, UK.

Ercin, A. E. and Hoekstra, A.Y., 2012. Carbon and Water footprints: Concepts, Methodologies and Policy Responses. Place de Fontenoy, Paris, France: UNESCO.

Hansen, G., Johnson D., Lacis, A., Lebedeff, S., Lee, P., Rind, D., Russell, G., 1981. Science: Climate impact of increasing atmospheric carbon dioxide.Vol 213, Number 4511.

IPCC, 2007. Fourth assessment report: Couplings Between Changes in the Climate System and Biogeochemistry. FAQ 7.1, Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. Report page 512.

Moran, M.J., Morgan, M.D., Wiersma, J.H., eds., 1986. Introduction to environmental science, 2nd edition. University of Wisconsin, Green Bay, New York.

MUPENZI, J.P., Jiwen, G., Habiyaremye, G., Nadege, T. L., Nzayisenga, T., 2011. Tea land degradation in Rwanda. IPCBEE vol.1. Singapore: IACSIT Press.

O'Riordan, T. ed., 2000. Environmental science for environmental management. 2nd ed. United Kingdom: Pearson Education Limited.

OECD/IEA, 2008. CO2 Capture and storage: A key carbon abatement option75739 Paris Cedex 15, France.

Organisation for Economic Co-operation and Development (OECD), 2007. Glossary of statistical terms. Unclassified.

Ramachandra, T.V. and Mahapatra, D.M., 2016.The Science of Carbon Footprint Assessment. In Muthu, S., S., ed. The Carbon Footprint Handbook. Published by Taylor & Francis Group, LLC, ISBN-13:978-1-4822-6223-0 (eBook - PDF)

RDB, 2010. Rwanda Export Catalogue, First Edition, [Online]. Available at: www.rdb.rw.[Accessed 31st December 2013].

Republic of Rwanda (RoR), 2011. National Stratey for Climate Change and Low Carbon Development: Green Growth and Climate Resilience. Kigali, Rwanda.

Sauer, J. L., 2009. Tea's Carbon Footprint. Available at: http://www.samovarlife.com/teas-carbon-footprint/. [Accessed 20th, November 2013].

Sedjo, R. and Sohngen, B., 2012. Annual Review of Resource Economics: Carbon Sequestration in Forest and soils. Vol. 4:127-144.doi:10.1146/annurev-resource 083110-115941.

Teavant, B., 2009. Tea's carbon footprint discussed at the world tea expo. Las Vegas, USA. Available at: http://bonteavant.com/2009/05/teascarbon -footprint-discussed-at-the-world-tea expo.html. [Accessed on 18th November 2013].

UNEP,2013. Emerging issues in our global environment, page 21, Nairobi, Kenya

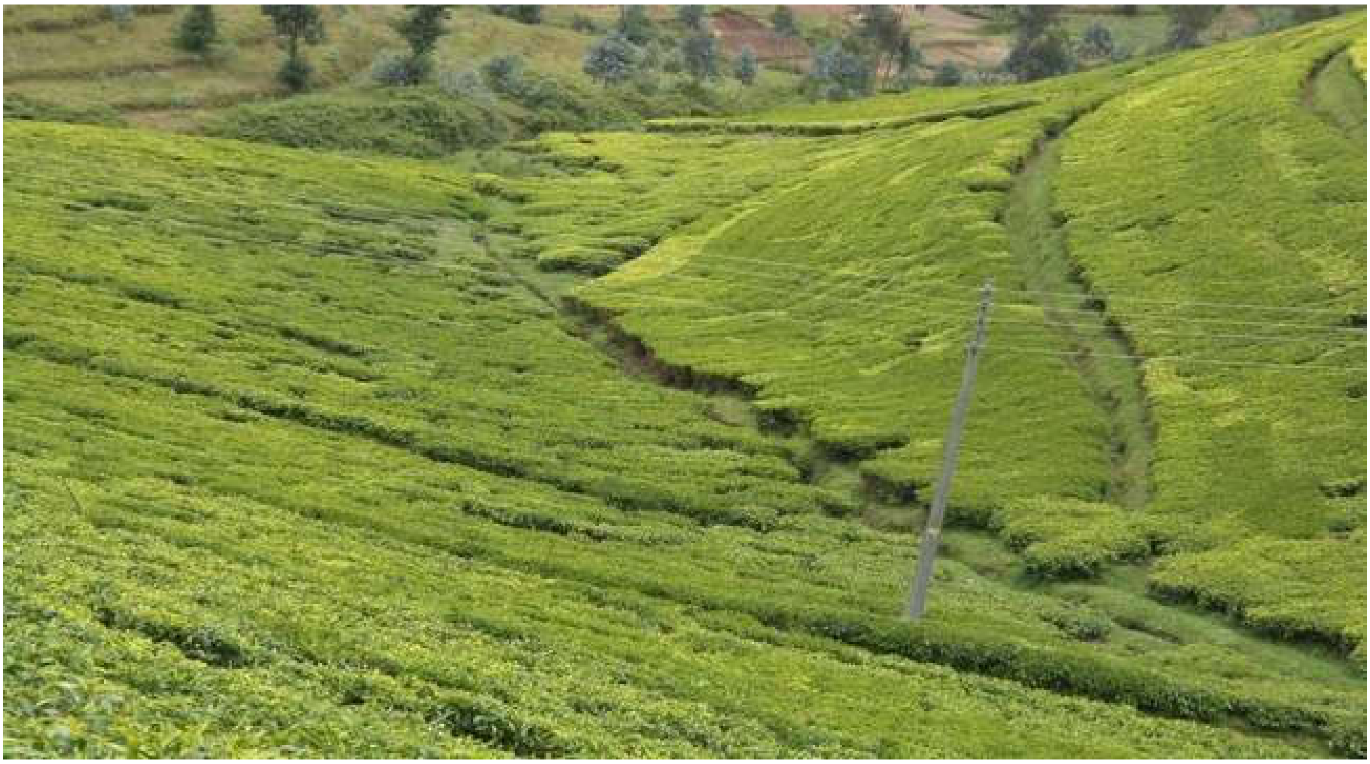
Wiedmann, T. and Minx, J., 2007. ISAUK Research report 07-01: A Definition of 'Carbon Footprint'. Durham, United Kingdom: ISAUK Research and Consulting.

WMO, 2013. A WMO Information note: A summary of current climate change findings and figures. 7 bis, Avenue de la Paix, CH 1211Geneva2-Switzerland. Available at: http://www.unep.org/climatechange/ Publications/Publication/tabid/429/language/enUS/Default .aspx?ID=6306.[Accessed 22nd November 2013]. WRI and WBCSD, 2004. GHG Protocol: A Corporate

Accounting and Reporting Standard. Washington, DC: Hopkins Fulfillment Service and Earth print Limited. Printed in USA.

WRI and WBCSD, 2011. Product Life Cycle Accounting and Reporting Standard. Printed in USA.

Appendix 1: Mountain tea



Appendix 2: Global warming potential and atmospheric lifetime of greenhouse gases

Global warming potential (GWP) of selected greenhouse gases. The global warming potential is a measure of radiative forcing power set against a CO_2 baseline. Though somewhat controversial in subsequent meaning, these calculations are generally well regarded. The figures formed the basis of the agreement made over the six pack of greenhouse gases at Kyoto.

	Chemical formula	Gas lifetime (years)	Global warming potential		
			20 years	100years	500years
Carbon dioxide	CO_2	70-200	1	1	1
Methane	CH_4	12 ± 3	56	21	6.5
Nitrous oxide	N_2O	120	280	310	170
HFC group	C-H-F	1.5-50	5000	3000	500
Sulfur hexafluoride	SF_6	3200	16300	23900	34900
Perfluorocarbon	C-F	3-10000	6000	8000	14000

Source: IPCC, (1997) and O'Riordan, T., (2000)

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