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TENSIONS BETWEEN SOCIAL AND ENVIRONMENTAL SUSTAINABILITY: LESSONS FROM VCA4D CASE STUDIES IN AFRICA AND WAYS FORWARD

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Abstract

The aim of this synthesis paper was to describe some of the commonly occurring trade-offs between social and environmental impacts in the VCA4D case studies, and to identify promising situations ("win-win options") where synergies between environmental and social sustainability can be achieved.
The paper has focused on smallholder crop VCs based on extensive rainfed cropping systems in six African situations (maize in Zambia and Nigeria, sorghum and groundnuts in Ghana and cotton in Cameroon and Ethiopia). The extensive nature of the production stage of these VCs raises similar concerns with regard to negative environmental impact, which often conflict with social pressures relating to the security and risks relating to food, income, health and in some cases access to land.
The expansion of cultivation into forest areas, virgin land and natural pastures for both food and cash crops, and a reduction in traditional fallowing periods, results in environmental degradation, while also enabling households to improve their food, income (especially in the short/medium term) and land security. This trade-off between the environmental and social impacts does require to be addressed by appropriate policy measures if these value chains are to be more sustainable in the medium and longer term. In most cases environmental protection policies which require strong enforcement will not work well because of the limited capacity to enforce and in some cases political will to do so. Policies for environmental protection should instead focus on providing incentives backed up with strong educational elements. Policies relating to agricultural services should be well thought out and informed by longer term considerations, both environmental and socio-economic. This implies a commitment by national governments to longer term investments in and support to the relevant institutions and infrastructure required to achieve more sustainable smallholder crop value chains. Behavioural change will be involved at various levels, hence the importance of having clear policies and investment in training and education of the main actors, so they can make informed choices which are informed by a good understanding of both environmental and social impact.

The policies to support these value chains will also need to be well informed by international trends, given that local economies are increasingly integrated into, and subject to international shocks and trends. A case in point is the current increase in energy prices, with major knock-on effects for fertilizer costs, as well as costs relating to transportation and industrial processing of the crops produced in these value chains.

The post-harvest and processing stages of some of the value chains also provide good opportunities for achieving win-win outcomes. For example, reducing post-harvest losses has a positive impact on the environment, particularly for the food grain crops, while also improving incomes and food security for smallholders. Improving the quality control of grain, particularly groundnut aflatoxins, promises to significantly improve prices paid for groundnuts while at the same time improve health outcomes, both for the households consuming these for their food, and for urban consumers. Local processing of the grain crops often requires large quantities of firewood and involves women working in sub-optimal conditions with a risk to their health from fumes. Improved methods and technologies for local processing could not only reduce the environmental impact by reducing the amount of firewood needed, but also reduce the health risks for the women involved.

Introduction

Small-scale farming under rainfed conditions is the main source of livelihood for the majority of rural households in sub-Saharan Africa. The VCA4D studies of smallholder annual rainfed field crop value chains generally report low use of "external inputs", such as chemical fertiliser, certified seed, agro-chemicals and imported agricultural machinery[1]. While use of such inputs does carry benefits, a simplistic “green revolution” approach to smallholder agricultural development has often failed to deliver the desired changes in raising productivity and welfare for poorer rural households (Dawson et al, 2016). Rural households in Africa are generally “cash poor” and face increasing pressures to raise cash to meet household needs through sale of their grain and crop products, including crops grown both for their own food needs and crops grown mainly or exclusively for sale (Jellason, et al, 2021). In some cases, households struggle to achieve food security and a secure livelihood from agriculture, particularly where family land holdings are too small to sustain the household (Giller et al, 2021). Shortage of land to cultivate and increasing integration into the market economy increases pressure on the locally available natural resources, particularly the pressure on land for crop production and also trees for fuelwood and construction.

Where land is available, these pressures often result in an expansion of the cropped area, as an alternative to, (and in some cases in addition to) use of “higher input” production methods. More marginal land previously being used for grazing, foraging (e.g. natural rangelands) or extended fallowing (regenerated woodland or shrubland) is converted to permanent cropped land and/or short duration fallowing. There is also a commonly reported trend of declining land and soil quality related to continuous cultivation of household land. The size of land holdings is gradually decreasing as a result of population increase and land fragmentation (Giller et al, op cit). Increasing encroachment on natural forest areas is resulting in a reduction of tree cover with associated negative environmental impacts.

While at a low level compared with crop production in developed economies, small-scale farmers are increasing their use of fertiliser, pesticides and herbicides. This trend, in addition to crop land expansion, also has potentially negative effects on the environment (soil and ground water quality) and human health (Warra and Prasad, 2020).

As rural households in sub-Saharan Africa strive to remain viable and socially sustainable, trade-offs between social and environmental sustainability are taking place (Martin, et al, 2018; Mainali, et al, 2018). Such trade-offs are typically adaptive livelihood strategies, rather than conscious calculations by smallholders to gain short-term benefit at the expense of environmental impact. Nevertheless, smallholders typically have an understanding of many of the environmental impacts of their farming strategies, particularly those practices impacting soil fertility and pest and disease management. One or more of the following actions by rural households engaged in small-scale farming constitutes a trade-off between environmental impact and livelihood benefit:

- Clearing virgin forest land for cultivation of food and/or cash crops to improve incomes and food security, reduces biodiversity, increases rain-water run-off, reduces water availability in dry seasons (drying of perennial streams and lower groundwater table), and increases Greenhouse gas (GHG) emissions (contributing to global warming and climate change),
- Burning crop residues, weeds and vegetation regrowth (rather than “recycle” via mulching, composting, and feeding residues to animals), reduces pest challenges and labour challenges for small holders and releases some nutrients for crops, at the expense of reducing soil organic carbon and increasing GHG emissions,
- In cropping systems where fallowing is practised, reducing the usual fallow period is a smallholder strategy to achieve household food security. However, this reduces biodiversity and soil quality. The lower potential yields under a reduced fallow period

[1] There are 7 such studies, 6 of which inform the analysis in this paper: Maize in Zambia (Fusillier et al, 2021); Sorghum in Ghana (Onumah et al, 2020); Groundnuts in Ghana (Kleih et al, 2020); Maize in Nigeria (Onumah et al, 2021), Cotton in Ethiopia (Nicolay et al, 2020), Cotton in Cameroon (Fok et al, 2019). The study of rice in Mali is not included in this cross-case comparison because only 18% is produced under rainfed conditions.

also increases reliance on chemical fertiliser and in some cases pesticides and herbicides (shorter fallowing can increase competition from weeds and some pest damage),
- Increased use of agro-chemicals by smallholders to meet household needs, will, in the longer term, negatively impact the quality of water within a watershed. It will also impact the longer term health and productivity of soils, pose added risks to human health and potentially reduce biodiversity,
- Where there is no additional land to cultivate, the quality of soil is depleted through continuous cultivation. Households become food insecure and resort to other strategies to sustain themselves which impact the environment such as migration to other areas where there is land to cultivate, or cutting of trees for charcoal burning or sale as firewood,
- An increasingly important smallholder livelihood strategy is to add value to food crops produced by local processing and sale. The energy required for processing adds pressure on natural resources, particularly trees cut for fuel. This contribute to global warming. Increased time spent on processing activities involving fuelwood or charcoal combustion can also be harmful to human health.

While the above trade-offs are commonplace in rainfed small-scale farming systems, there is growing awareness of the need for useful and practical frameworks and indicators for the analysis of such trade-offs (Dawson et al, 2018; Ramussen, et al, 2017). Examples from the study of value chains relying on rainfed cropping systems in sub-Saharan Africa provide opportunities for identifying potential synergies between social and environmental sustainability; "win-win options" which mitigate the negative environmental impacts of the above trade-offs (Howe, et al, 2014). For example in some crop production or processing situations it can be possible to identify a change of practice which will not only reduce local environmental impact, but also improve local household livelihoods (e.g. reduce health risks, improve food availability, improve income). Such synergies can result from practices that:

- Use alternative technologies for processes requiring combustion of fuels, or use less impacting fuels for processing, alternative to firewood,
- Adopt cropping practices that enhance non-crop livelihood resources, crop productivity and positively impact on the environment, such as agroforestry systems,
- Reduce postharvest losses, which may have large implications in terms of food or crop for sale availability and at the same time often imply the need to expand cropland to compensate for such losses.

Objectives:
The aim of this synthesis paper is to describe some of the commonly occurring trade-offs between social and environmental impacts, and to identify promising situations where synergies between environmental and social sustainability can be achieved.

Specifically, the paper aims to:

- Describe how main environmental impacts for each VC relate to the main social processes resulting in trade-offs between environmental and social sustainability,
- Identify synergies and win-win options for the VC actors,
- Briefly discuss some aspects of policy to support the win-win options identified.

Methodology and definitions

The VCA4D case studies consulted for this paper were conducted using a standard methodology developed by EC DG INTPA (Fabre et al., 2022). This methodology includes a functional analysis of the overall organisation of the VC, economic analysis of value added, standard questions on inclusion and social impact for assessing social sustainability, and Life Cycle Assessment (LCA) for assessing the environmental sustainability and impact of the VC. The case studies draw mainly on the evidence from the social and environmental sections of the published VCA4D reports and also on the functional analysis which provides important contextual information beyond the scope of the indicators used in the LCA and social sustainability assessments. Additional sources include data gathered during the conduct of the studies not included in the published reports.

With regard to the methodology for interrogation of the case studies, an "atheoretical" (Kaarbo and Beasley, 1999) approach is used. This involves describing the context for each before exploring the main questions.

The selected VCA4D studies were all based on crops predominantly grown by small-scale farmers in rainfed cropping systems with relatively low levels of purchased farm inputs. These value chains provide important sources of livelihood for smallscale farmers, while the production stage of the chain is the main contributor to negative environmental impact. This situation involves an inherent tension between social and environmental sustainability; household needs are met often at the expense of negative environmental impact.

The six value chains chosen were; 1) maize in Zambia (Fusillier, et al, 2021), 2) sorghum in Ghana (Onumah et al, 2020), 3) groundnuts in Ghana (Kleih et al, 2020) and 4) cotton in Ethiopia (Nicolay et al, 2020), 5) maize in Nigeria (Onumah et al, 2021) and 6) cotton in Cameroon (Fok et al, 2019). Maize, sorghum and groundnuts are grown by small-scale farmers as staple food crops which are also sold into the market in these countries. These crops are important for rural cash income and food security and also for national food security. Smallholder cotton is grown alongside staple food crops, usually as part of a rotation with food crops. Cotton is important both for rural incomes and for national textile industries. Cotton is an important export for Cameroon, while Ethiopia imports some cotton.

Defining environmental impact and sustainability

LCA is an internationally standardised methodology (ISO 14040 / ISO 14044) that helps to quantify the environmental impacts of a product taking into account its full life-cycle. In order to perform an LCA, an inventory (Life Cycle Inventory-LCI) must be compiled of resources used and substances emitted along all stages of the life-cycle of a product. This inventory is further processed using factors of impact on different environmental categories in order to estimate how these categories are affected. This is carried out using a proprietary software platform (SimaPro). Within the VCA4D framework, environmental pressures are examined using a specific impact assessment methodology[2] which provides results in terms of three domains, namely resource depletion, ecosystem quality, and human health effects, also known as endpoint impact categories. Through these results, the question posed within the VCA4D framework "*is the VC environmentally sustainable?*" is addressed. This question is further articulated in order to cover the above three domains. The questions are 1) "*what is the potential impact of the VC on resources depletion?*" (Indicators are resource uses such as mineral resources and fuel); 2) "*what is the potential impact of the VC on ecosystem quality?*" (indicators such as land use, global warming and freshwater eutrophication inform on potential deterioration of land quality, of biodiversity, etc.); 3) "*what is the potential impact of the VC on human health*?" (indicators include emissions of harmful substances and global warming affecting human health).

[2] The ReCiPe 2016 Life Cycle Impact Assessment Method. The acronym ReCiPe was adopted as it provides a 'recipe' to calculate life cycle impact category indicators. The acronym also represents the initials of the institutes that were the major collaborators in its design: RIVM and Radboud University, CML, and PRé Consultants.

The benefit of LCA is that it consists in a single tool that is able to provide insights into the environmental pressures along each phase of the VC. However, it does not usually capture some important issues such as the impact of cropping systems on soil fertility, annual increase/decrease of the soil organic carbon pool, etc.[3]. The areas not captured by LCA are often covered through expert knowledge within the VCA4D framework and reported accordingly.

Local and national level environmental impact

In order to appropriately link the main social processes associated with the environmental impacts of the VC, in this paper an attempt is made to identify environmental impacts which are mainly relevant at local scale and affect local populations, as distinct from global environmental impacts such as climate change. Such distinction is not derived from the impact assessment methodology adopted by the VCA4D studies; its purpose is to provide a simplified guidance on the potential strength of the link between "more localised" environmental impacts and the social processes that might be associated with them.

Several types of environmental impacts (called midpoint impact categories) contribute to each of the three endpoint impact categories, as shown in the table below. Some of these midpoint impacts regard the global scale, such as GWP–*Global Warming potential* (causing potential impacts on human health and on ecosystem quality). In this case, the impact is obviously not only at local scale, but its effects on the local population and ecosystem may also be relevant locally, since it causes climate change. Indeed, *Global Warming* and also *consumption of surface* (or land occupation) and *water* are particularly relevant within the context of climate change as sub-Saharan Africa is one of the regions that is identified as being particularly at risk from future climate change impacts.

Impact Category (midpoint)	Areas of protection (endpoint)			Description
	Human Health	Ecosystems	Resource scarcity	
Climate change	X	X		Greenhouse gas emissions causing disturbances on the global climate system
Stratospheric ozone depletion	X			Emissions of compounds such as chlorofluorocarbons or halons, which are responsible for the ozone hole phenomenon
Ionising radiation	X			Release of radioactive substances into the environment
Particulate matter formation	X			Emissions of particulate matter or particulate precursors, which contribute to respiratory disorders
Photochemical ozone formation	X	X		Emissions of ozone precursor pollutants such as nitrogen oxides or volatile organic compounds, causing human health problems (irritation, asthma) or damage to plants
Terrestrial acidification		X		Emissions of acidifying pollutants, causing phenomena such as acid rain, and damage to terrestrial ecosystems
Freshwater eutrophication		X		Emissions of nutrients into the natural environment, causing disequilibria in freshwater ecosystems (proliferation of plant or animal species at the expense of other species)
Toxicity and ecotoxicity	X	X		Emissions of pollutants toxic to human health and ecosystems
Water consumption	X	X		Effects for human population and ecosystems of freshwater consumption
Land use		X		Biodiversity changes due to land transformations and occupations
Mineral resource scarcity			X	Depletion of mineral ores
Fossil resource scarcity			X	Cumulated primary energy demand from fossil and nuclear sources

[3] This can be done only if robust scientific evidence on such issues referred to the local conditions can be included in the LCI. In many cases this is very unlikely though, since often the VC has a national scope; any scientific evidence to be included in the analysis should refer to all areas of interest of the study, which very often is not feasible. The strategy adopted within the VCA4D studies to overcome the issue of robustness is to have the LCA undergo a backstopping process, consisting in a critical review of the study by an independent environmental expert. Furthermore, issues such as potential deterioration of workers' health, for instance, due to effects of localised emissions are not completely captured by LCA.

Summary of the midpoint impact categories included in each endpoint impact category of the ReCiPe2016 methodology. Source: adapted by authors from Recipe 2016 v 1.1 Report I.

Other midpoint impact categories can affect more directly the population involved in the VC and the local communities. This is the case, for instance, of *fine particulate matter* generated on the site of emission (for example from fuelwood combustion), causing respiratory disorders as it reaches the upper part of the airways and lungs when inhaled. Particulate matter can be formed by firewood combustion, field burning, fuel use, ammonia from manure application to soil, etc. Although this impact category does have a local effect on population, it may be negligible (as it is often the case) under low concentrations. Nevertheless, for instance, in the presence of extensive field burning for land clearing/crop residue combustion, concentrations might increase, posing relevant potential health issues. Similarly, as shown by the evidence of some studies, firewood combustion for food processing may also generate significant potential health issues, in part due to particulate matter formation.

Finally, impact categories affecting ecosystem quality, such as *land use (land use change and land occupation)* or *freshwater eutrophication*, the latter deriving from processes associated with field crop production (phosphorus emission from soil erosion and fertilisation) are potentially relevant. Nevertheless, the relevance of freshwater eutrophication highly depends on the carrying capacity of the specific environment where the phenomenon occurs; the extent of the local impact of such phenomenon is more difficult to determine. These are examples of environmental impact which are relevant in most of the case studies examined in this paper.

Defining Social impact and sustainability

The VCA4D methodology relating to social sustainability comprises questions which serve as proxy indicators for six social "dimensions" which are: working conditions, land and water rights, gender equality, food and nutrition security, social capital and living conditions (Fabre et al., 2021). The underlying premise is that the social analysis identifies the social benefits, disadvantages and risks which participation in the value chain poses for the different social groups and actors. The VC's social sustainability could be said to be promising if the main disadvantages and risks associated with participation are reducing for the main VC actors, and not promising if these disadvantages and risks are increasing.

The six social domains in the VCA4D methodology imply, but do not make specific reference to, important social processes relating to social sustainability. Of particular importance when considering tensions between social and environmental sustainability in smallholder farming communities is household re-production. Children are reared and supported by their parent/s to form new farming households which, while not completely independent, are expected to operate semi-autonomously. Rural population increase means that households reproduce and increase in number. The resulting fragmentation of land holdings and/or the migration to other areas in search of land to clear and cultivate both typically have a negative environmental impact.

Emphasising the need for complementarity between environmental and social sustainability, Chambers and Conway (1991) note "Social sustainability refers to whether a human unit (individual, household or family) can not only gain but **maintain** an adequate and decent livelihood" (p10 author emphasis). The household is the main unit of production, processing and consumption in rural sub-Saharan Africa. Most rural households are sustained through agriculture plus a variety of other activities. In the context of a VCA4D study, the assessment of social sustainability relates to the contribution of the specific crop VC to a household's sustainability.

If the VC activity is assessed as making a generally positive contribution to social sustainability but having a generally negative environmental impact, a trade-off is involved. The ideal situation is when the VC activity is making a positive contribution to social sustainability and also having a positive environmental impact; then a synergy or "win-win" outcome has been identified. The opposite situation is when the VC activity is having a negative contribution to both environmental and social sustainability; a "lose-lose" or unfavourable situation.

The cases in this paper do not specifically refer to aspects of economic sustainability. An underlying assumption is that if an activity at household level does not make economic sense for the household, even if it may be helpful to the environment, it is unlikely to be socially sustainable. For example, using fertiliser at the officially recommended rate can improve productivity per unit area, reducing the environmental impact of more extensive cultivation, but the yield increase achieved per unit area may be less profitable than spreading using a lower rate of fertiliser over a wider area (Sheahan, et al, 2013).

Small-holder Rainfed Crop Case Studies

This section identifies the main environmental impacts of each VC. These impacts are linked to the main social impacts and social processes which might involve trade-offs, synergies, or mutually unfavourable relationships between environmental and social sustainability. The cases examined focus mainly on low input cropping systems (except for including a comparison with cotton produced by commercial farmers in Ethiopia). This translates into relatively reduced environmental impacts arising from use of purchased inputs. On the other hand, low crop yields are generally associated with low external input cropping systems. High levels of land occupation affect ecosystem quality, especially if land use change is involved from forest or bush cover to annual cropping.

Smallholder Maize in Zambia

Overview:
Maize has been Zambia's dominant smallholder cereal staple food crop for over 50 years, largely replacing sorghum and millet. The majority of maize grown for human food is produced by small-scale farmers[4]. The reasons that small-scale farmers dominate maize production include their lower production costs and their need for household food security, government policy to subsidise maize inputs and marketing services in remoter areas of the country and the ready availability of maize inputs supported by advisory services. Subsidies to smallholder maize growers have taken up increasing amounts of the Zambian government's agricultural budget in recent years, its Farm Input Support Programme (FISP) targeting around one million households each season (just under half rural farming households).

In recent years, much of the smallholder maize crop is produced using hybrid seed, chemical fertiliser and, increasingly, herbicides. Smallholders grow maize as a rainfed crop under permanent and semi-permanent cultivation systems, often clearing regenerated fallow or virgin bushland to expand their production. Maize is an important cash crop for many smallholders when grown as such it is usually monocropped. Maize grown as a household food crop is often intercropped with low densities of cowpeas or climbing beans and cucurbits.

In most rural areas maize is also used for brewing beverages (alcoholic and non-alcoholic) widely consumed also in rural sub-centres providing an important source of income for poorer

[4] Commercial farmers mainly grow maize as a hybrid seed crop which is more profitable for them. Some commercial farmers also grow maize as a feed crop as part of vertical integration into their livestock enterprises, particularly poultry.

women. Use of maize flour for confectionary products is becoming increasingly important in urban areas.

While maize is widely grown by many smallholders, both as a food and cash crop, there are significant risks involved. When produced without subsidised inputs, it is more risky as a cash crop for smallholders because of relatively low and unpredictable farm gate prices. It is also a risky cash crop and food crop in areas where rainfall is unreliable. In northern areas of Zambia, where rainfall is generally reliable, risks of declining and low yields are associated with continuous cultivation on more acid soils, unless agricultural lime is used, which is expensive to transport and not readily available to smallholders.

Environmental impact and social process: trade-offs, lose-lose and win-win options.

The VCA4D study of the maize value chain in Zambia identified significant environmental concerns. More recent systematic reviews and consultations with stakeholders in Zambia have confirmed the findings, highlighting the need to explore future trade-offs relating to land cover change (Griffiths et al, 2022), soil degradation (Neina et al, 2022) and their relationship to agricultural expansion (Jellason et al, 2021).

Most of the environmental impact in the maize VC is generated at farm level from land clearing for cultivation and from cultivation activities, including the combustion of field residues. Significant environmental impacts arise from clearing of new land which reduces biodiversity and adds to global warming. Land clearing is driven by an increase in the rural farming population along with increasing commercialisation. Population increase is accompanied by an increase in the number of households seeking to gain a livelihood, in which rainfed farming plays a key role. Newly established households often need to clear new land to meet their needs, as the already cleared family land is not adequate. A benefit of clearing new land, in addition to the use of natural soil fertility which reduces the need for chemical fertiliser, is also less weed competition. Continuous cultivation is associated with increased weed competition, and this means either more labour is required for weed control under conditions of declining soil fertility, or increased dependence on use of herbicides.

A typical “lose-lose” situation arises when resource poorer small-scale farming households have limited land on which they practise maize mono-cropping. As the soil becomes exhausted, more (mainly female) labour is required and yields are declining over time, resulting in household food insecurity as well as soil degradation.

Increasing commercialisation of farming households often goes along with an increase in the cultivated area per household, as more land is needed to grow both food crops and crops for sale to meet the growing household needs. Moreover, in areas where there is no available woodland for households to clear for crop production, continuous cultivation of maize on the same piece of land, along with increased pressure on grazing areas which are converted to cropland, results in land degradation. This is an additional negative environmental impact linked with smallholder maize production.

Additional environmental impact arises when burning crop residues and vegetation regrowth generates particles harmful to human health. This burning also reduces the incorporation of organic matter into the soil, reducing the amount of organic matter and releasing Greenhouse gases into the atmosphere. As with land clearing, trade-offs are involved. For small-scale farmers, burning has some social benefits; reducing the labour burden for land preparation before planting maize, providing patches of more fertile soil where cucurbits grow well when interplanted with maize, and reducing pest damage the following season (mainly maize stem borers). The downside of burning for farming households is that the longer term quality of their soil is reduced, which then increases their need, longer term, to either clear more land to meet their household needs, or to use more chemical fertiliser, which is expensive, to achieve adequate maize yields. Not burning is not a win-win situation because it increases the need to control stem borer, either using expensive chemical means, or labour-intensive low-cost methods, which is a further trade-off involved.

While the use of improved inputs is relatively low in the smallholder maize VC in Zambia compared with commercial maize production, the use of, and dependence on, chemical fertiliser, herbicides and pesticides is increasing, nevertheless. The social and environmental trade-offs and synergies related to the increased use of these inputs by small-scale farming households are somewhat complex.

For example, increased use of chemical fertilisers potentially can impact freshwater quality, while this might have negative implications in terms of ecosystem quality, it is unlikely to impact the health of the farming community involved, as rainfed maize is grown on well drained upland fields from where water drains into streams further down the catchment. Most households in Zambia are also located on the upland areas and draw their drinking water from deep wells or boreholes. Information on the extent of any negative impact of fertiliser and herbicide use on drinking water sources downstream of the cultivation areas is not known. There are also risks to human health from increasing herbicide use, including risks associated with unsafe use and disposal. In most communities, women and children are not involved in operations relating to herbicide mixing and application. What is known is that using both fertiliser and herbicide greatly reduces the labour burden of women in maize production, particularly during weeding; any potential negative environmental impacts are traded off for the massive labour saving benefit in the shorter term.

Chemical fertiliser, while increasing yields, improving food security and saving household labour in the shorter term, poses a risk to soil quality and productivity in the longer term. This is the case particularly in higher rainfall areas and medium rainfall areas on sandier soils. From this point of view some households are prepared to trade the shorter-term benefits of using fertiliser for the longer term risks to their soil quality. In some maize growing areas (e.g. Eastern Province) households with big enough land areas, partition their land so that some areas are kept for growing fertilised hybrid maize mainly as a cash crop, and other areas are kept unfertilised (except through use of animal manure and rotation) for planting local maize as the household food crop.

Fertiliser use also contributes to global climate change via greenhouse gas emissions. This does not present as a “trade-off” for small-scale (or commercial farmers) in Zambia as, unlike the effect of fertiliser on the quality of their soil, a direct visible effect is not apparent to farmers (although global environmental impacts do also affect locally).

In the short term, use of some herbicides on maize does impact the productive use of land for the following crop. Small-scale farmers have experience of this, and for this reason usually avoid planting groundnuts on land where herbicide has been used. There are also suspected links between herbicide use and human health, including links to cancer. This involves a trade-off between the positive impact of reduced female labour burden on the one hand, with the negative short-term impact on soil productivity for food legume crops and potential longer term negative impact on human health on the other.

In summary, rural households are able to reproduce and sustain their livelihoods through both land clearing and continuous cultivation with increased levels of purchased inputs to produce maize. These social needs are met at the cost of the increased negative environmental impacts arising from land clearing, from continuous maize mono-cropping cultivation, and from the environmental impacts of increasing levels of chemical fertiliser and agrochemicals (mainly herbicides).

Initiatives to reduce some of the negative environmental impacts in the small-scale maize growing sector in Zambia have been promoted for over two decades, most notably "conservation agriculture" methods which focus on minimum or zero tillage, incorporation of crop residues and use of herbicides. These are largely presented as "win-win" options, in that they not only improve soil quality longer term (positive environmental impact), but also reduce the female labour when herbicides are used (positive social impact). Given the potentially negative effects of herbicide (for the environment and human health), other options for reducing the female labour burden in maize production, such as improved mechanical weeding tools for small-scale farmers lacking access to draft animals, would be win-wins meriting further investment.

While the LCA impact assessment did not include aspects of farm level (household level) post-harvest processing of maize grain, the functional analysis identified activities which have significant local social and environmental impacts. An estimated 48% of smallholder maize production is consumed in rural areas and rural service centres. Many households have maize-based porridge for breakfast and maize based nsima for their main meals (up to two times per day). The local mechanical milling of maize for household use has a very low environmental impact, while providing a very large social benefit (saving women a lot of burdensome work manual pounding maize). In addition, some rural women make a living from brewing a non-alcoholic "sweet beer" (munkoyo, or chibwantu) for sale, and others brew a local beer using similar methods, but allowing longer for fermentation. The majority of rural households growing maize as their main staple use locally sourced firewood for cooking their household meals. Households brewing sweet and alcoholic maize-based beer is more energy demanding. The mixture of maize grits is boiled in large containers for about 8 hours prior to fermentation, using firewood. Cooking household meals is a trade-off of the environmental impact of the firewood used for the positive social impact of meals for the household. Brewing beverages for sale is a trade-off for the environmental impact of significant quantities of firewood for livelihood benefits arising from the sale and consumption of sweet beer (income distribution for female headed households and nutrition for the adults and children consuming sweet beer). Sweet beer is also brewed in urban areas, while many urban households cannot afford electricity for cooking, or lack access to this, and depend on charcoal for their household meal preparation. An obvious win-win option to reduce the environmental impacts of extensive firewood use linked with deforestation is the stepping up the promotion and possible subsidy of fuel saving stoves for households who use firewood and charcoal for cooking.

Traditional charcoal stove (left) compared with a fuel saving stove being promoted in Zambia

A further win-win situation observed is the reuse (although the environmental impact -in particular water use- for washing plastic bottles prior to re-use was not assessed).

Selling home brewed “chibwantu” in a local market in Siavonga (Zambia) re-using plastic soft drink bottles (including one used by a commercial maker of chibwantu on the left with a yellow cap).

A conclusion from the environmental analysis is that measures which raise the yield per hectare for smallholder maize would reduce the environmental impact arising from cultivation. More productive use of chemical fertiliser would be a potential win-win outcome, if at the same time this reduced the overall area cultivated to produce the same amount of maize. The current FISP programme, while including advice on seed and fertiliser rates, does not specifically provide an incentive for applying more intensive and sustainable maize cultivation methods. Conservation agriculture has been widely promoted with government and donor support for over 20 years, but smallholder uptake at scale remains fairly low (Zulu-Mbata et. al 2016) overall. Reasons for lower uptake are various, and include the additional labour requirements for land preparation, weed control and making compost, limited funds to purchase herbicides, and limited access to labour saving mechanical ripping and weeding equipment and farm power for ripping and mechanical weeding. It is possible that smallholder fertiliser subsidy is hindering wider uptake of conservation agriculture as it provides an easier way of improving productivity, but one which is not sensible in the longer term because it diverts public resources away from support to research, extension and other agro-support services in support of more environmentally sustainable smallholder production systems.

Smallholder Maize in Nigeria

The environmental impact assessment of smallholder maize production in Nigeria draws similar conclusions to the Zambian case. The main contributors are cultivation, land clearing (deforestation) and post-harvest losses. Fertiliser use is also identified as potentially important because of greenhouse gas and ammonia emissions. Declining levels of soil fertility are also highlighted as a concern. As in Zambia, resource poorer smallholders tend to use lower levels of purchased inputs (including fertiliser) than the resource richer farmers achieving lower yields. In Nigeria resource poorer farmers also receive comparatively lower prices for the grain they sell, possibly because unlike Zambia, the Nigerian government does not provide subsidised maize buying and storage facilities. Notwithstanding this, the main difference from Zambia is the more reliable profitability of maize production in Nigeria for all categories of smallholders. Maize is a profitable crop for all categories of maize producers in Nigeria, while in Zambia profitability is uncertain and for this reason most commercial farmers have ceased to grow maize grain. The reasons for this difference are complex and not the focus of this analysis. However, one factor of importance is much less government involvement in maize input supply, grain trading and maize meal price regulation in Nigeria compared to Zambia. The Zambian government provides many smallholders with heavily subsidised fertiliser and hybrid seed, regulates the floor price for maize grain and also subsidises maize meal production for human food. In Nigeria a generally lower level of fertiliser subsidy applies and there is less regulation of maize trading and price for maize meal. As a result of this, larger maize traders are able to provide inputs on credit to farmer groups and offer higher prices for the maize produced than the smaller traders. This represents a "win-win" option; more intensive production methods result in lower environmental impact, while input credit and favourable prices for maize sold translate into social benefits for households. In Nigeria, as in Zambia, men are the main controllers of profits made from the sale of maize, which means that the win-win options tend to favour men, particularly when most of the production is marketed via larger traders, which is the case for the more profitable win-win situations in Nigeria. Where most of the maize is grown for household consumption (a common case in Zambia but much less so in Nigeria) then women also benefit more from the win-win situations. Where women are involved in the smaller scale maize grain trade as well as in production, as they tend to be in Nigeria but less so in Zambia, women can also benefit.

With regard to the issue of declining soil fertility, looking ahead, maize demands relatively high levels of fertiliser to maintain yields once the natural fertility of the soils has been mined by a decade or so of maize production. Both countries currently subsidise fertiliser, which tends to mask the real cost of production of maize grain. Given the recent worldwide crisis in energy, fertiliser prices are likely to increase significantly. This will certainly impact maize production in both countries, which are currently net exporters. This is likely to lead to further soil degradation and also further clearing of trees for cultivation if current levels of production are to be sustained. The win-win options for maize production in both countries will need to take account of rising fertiliser prices, most likely with greater focus on organic and more environmentally sustainable production options.

Related to this, in both countries, an increasing amount of maize production is being used for the stockfeed industry, which also has significant environmental impacts, alongside social benefits. Notably, use of maize in egg production is a relatively efficient way of converting maize grain into a very nutritious and convenient food for children and busy mothers, as well as for low income families (Onumah, et al, 2018). This option could also be a win-win situation, for environmental and social sustainability, when compared to the alternatives of using maize for the production of milk, beef, pork and broilers.

Sorghum in Ghana

Overview:
Sorghum is an important smallholder crop in Northern Ghana. It is used as a staple food (flour and non-alcoholic Pito, a nutrient-rich unfermented beverage) and for the production of alcoholic beverages (including alcoholic Pito, a type of artisanal beer, and beer produced at industrial level).

Smallholders mostly grow sorghum under low input conditions under a "bush-fallow" rainfed cropping system which includes other crops such as maize, millet, groundnuts and cowpeas.

Low input production accounts for over 80% of sorghum production[5]. Over half of the sorghum produced is marketed, a third is used for household food (including local Pito brewing), while post-harvest losses of about 12% account for the remainder of production. Artisanal Pito brewing, both fermented and unfermented, for local sale as part of the local diet is widespread. Over 80% of the sorghum grain marketed through small and medium scale aggregators is used by Pito brewers; this corresponds to 40% of the overall sorghum grain production. Pito provides an important source of income for women, both in the north of Ghana and in urban areas of central and southern Ghana. Use of sorghum flour for porridge and confectionary products is also becoming increasingly important in urban areas.

Agricultural plots in northern Ghana are usually scattered with trees, since while clearing land for cultivation, farmers leave large trees and trees with an economic value (i.e., shea tree, *dawadawa* or locust bean) on the field, with the crops sown among those trees. This results in a cropping system that is very close to an agroforestry system. The beneficial practice, in Northern Ghana, of managing the crops under a system close to agroforestry, besides carrying benefits for the environment, contributes to the livelihood of rural households in the area. Indeed, harvesting seeds of shea or *dawadawa* tree for commercial use is a common activity, carried out by women in the fields where sorghum is cultivated[6].

The parts of the sorghum VC where environmental impact greatest are smallholder sorghum cultivation at low input levels, post-harvest losses, and Pito brewing which uses large quantities of fuelwood.

Environmental impact and social process: trade-offs, win-win and lose-lose options

With regard to smallholder cultivation and social sustainability, the trade-offs between social and environmental sustainability are mainly linked to the extensive nature of cultivation using low levels of purchased inputs which means that land use is the predominant contributor to environmental impact. Sorghum is a valued source of food with many nutritional benefits, but the majority of the sorghum crop is sold, rather than consumed, with maize and rice which are less nutritious being preferred. From this point of view, the negative environmental impact of cultivation is not offset by potential nutritional benefits of the sorghum produced. However, being able to grow a drought resistant crop for sale with very low levels of purchased inputs is a significant advantage for poorer smallholders which does involve a trade-off of livelihood benefit from the sale of sorghum for the environmental impact of extensive cultivation. From the point of view of gender equity, because sorghum is largely a male managed crop prior to processing, women are not burdened with the more strenuous work associated with sorghum cultivation. If the environmental impact of land use was reduced by improved yields arising from increased use of improved inputs, this would not significantly benefit women with regard to their labour burden in cultivation, but it would reduce the labour burden of men. Women are disadvantaged in that they have limited access to land and to credit for inputs, and also limited decision making power with regard to cultivation and marketing activities. If women's access to land and input credit was improved, then women might become more involved in sorghum cultivation, with a reduced labour burden arising from appropriate fertiliser use, and with a lower climate change impact due to the yield increase. This change would be a win-win outcome in terms of social and environmental impact.

With regard to post-harvest losses, it is known that these significantly increase environmental impact. For example a 12% post-harvest loss of grain would be equivalent to a 12% increase

[5] This figure is based on an estimated 62% of national production by smallholder farmers who use hardly any external inputs on sorghum and a further 35% of national production by farmers who use improved inputs (seed, herbicide and fertiliser) on 20% of their sorghum crop.

[6] This is also true for the groundnuts VC in Ghana, which shares the cultivation areas of sorghum, and may be grown in rotation with sorghum.

in land use environmental impact[7]. It seems that post-harvest grain losses are mostly linked to unfavourable weather conditions, drying and storage methods. If these losses could be reduced the environmental impact of cultivation would be reduced. Grain traders linked to a support programme linked to smallholder sorghum production for the commercial brewing sector have helped to address post-harvest losses and grain quality by providing tarpaulins to groups of farmers. This is an initiative, which with further policy support has win-win benefits both socially (reducing female labour in grain cleaning and improving overall returns to labour) and environmentally.

As the gender division of labour relating to post harvest activities is not described in the report, it is not clear what the social impact of other measures to reduce post-harvest losses might be (e.g. would the measures reduce or increase labour demands or impact on local employment opportunities and how would these relate to social capital).

With regard to Pito brewing, two activities related to the use of firewood have relatively large environmental impacts: 1) *firewood extraction* causing forest degradation and changes in land use alongside greenhouse gas (GHG) emission due to forest carbon loss, and 2) *firewood combustion*, in open fires used for brewing, which causes GHG and air pollutant emissions, such as fine particulate matter formation causing potential damage to human health.

It is argued that although Pito brewing is important in terms of inclusiveness (it is perceived as a woman's business), working conditions for brewers are harsh. Indeed, the brewing process is hazardous and can cause serious health problems because of emissions of fine particulate matter, smoke and heat from the open fire. Among the actors it seems awareness or recognition of the potential harm is rather low.

A win-win option is the promotion of ovens for Pito brewing which would significantly reduce the identified health risks in traditional Pito processing. The adoption of ovens at scale would also result in a significant reduction of energy cost and in improvements in the overall environmental sustainability of the VC. Since the ovens use fuelwood more efficiently (saving up to 50%) their adoption would impact positively on the environment. Indeed, forest degradation and fuelwood combustion would be reduced accordingly. Positive impacts would also include a reduction of direct exposure of brewers to harmful open fire pollutants and to excessive heat because the ovens are equipped with chimneys that drive away the heat and dissipate the smoke.

[7] Product loss (including post-harvest loss), imply a high risk that the need to compensate for such loss would lead to further land occupation, in particular in situations such as that of sorghum in Ghana where, under the current situation, it is unlikely that crop yields could be easily boosted. This might apply to any crop in other countries.

Pito brewing sites in Ghana. Upper left: Pito brewing site (oven type), upper right: pile of firewood for brewing, below: open-fire brewing site.

Groundnuts in Ghana

Overview:
Groundnuts are an important crop in Ghana, ranking 5th in terms of area planted. Groundnuts are particularly important as a smallholder crop in Northern Ghana. The average farm size for smallholders growing groundnuts who are not linked to aggregators is 0.76 ha, who contribute an estimated 88% of production, with average yields of 1.3 t/ha. of unshelled groundnuts. The remaining 12% of production is by smallholders linked to aggregator schemes and a small number of commercial farmers. More than 90% of farm families in northern Ghana grow groundnuts.

Groundnuts are grown under rainfed conditions and usually planted as a pure stand, following the clearing of scrubland and cultivation (usually by hired tractor). Extra labour is usually hired for planting, weeding and harvesting.

Groundnuts are usually grown by women as part of a rotation on family land, which is under the control of men, and regarded as not fertile enough for cereal crops. The following cereal crop, under the control of men, benefits from the nitrogen produced by nodulation remaining in the soil.

Groundnuts are produced mainly as a cash crop, with about 20% of the crop being retained for household use and seed for the next season. After being purchased by traders, the crop is transported and sold to other traders or to processors. According to traders, about 60% of groundnuts produced in the north of Ghana are consumed in the south of the country.

Processors of groundnuts prepare a range of products, including paste, snacks/roasted groundnuts, *kulikuli* (with oil as by-product), and groundnut flour (also with groundnut oil as by-product). Other, less important, groundnut products include *nkatie* cake. The bulk of the production takes place in the informal sector, mostly consisting of micro or small-scale enterprises. The resulting products, which form an important part of the Ghanaian diet, are sold through retailers, street vendors, restaurants, or institutions.

An estimated 500,000 to 800,000 adults (producers, traders and processors) depend to a great extent on groundnuts for their livelihoods, and about 90% of these are women.

Seed production and availability is a major issue and constraint.

The stages of the groundnuts VC where environmental impact greatest are smallholder groundnuts cultivation at low input levels, post-harvest losses, and groundnuts processing (roasting) which uses relatively large quantities of fuelwood. In the case of! processing by formal Small-Medium Enterprises, since the product (groundnut paste) travels over long distances, transport has significant environmental impact.

Environmental impact and social process: trade-offs and win-win options

With regard to smallholder cultivation and social sustainability, the trade-offs between social and environmental sustainability are mainly linked to the extensive methods used for cultivating groundnuts, with low levels of external inputs. In the cropping systems described groundnuts are grown at low plant population densities with very little use of chemical fertilizer. The consequence is that land use is the predominant contributor to environmental impact. This impact is traded off for the several benefits smallholders derive from growing groundnuts. Groundnuts are important in the crop rotation as a nitrogen fixing crop, although this aspect is not captured by the LCA study as an environmental benefit. Groundnuts are a valued source of food with many nutritional benefits and contribute significantly to the diet of smallholder families. Groundnuts also contribute to household income as much of the harvest is sold, rather than self-consumed.

The study indicates potential to reduce environmental impact by increasing plant populations of improved varieties and using some chemical fertilizer, to increase yields per unit area. This is potentially a win-win situation, provided the additional cost of extra seed and fertilizer required can be more than recovered by the added value of the increased production. This change would also require improvements in the supply of seed of improved varieties, the required type of fertilizer, and possibly affordable credit for these inputs.

Furthermore, the aflatoxin contamination of groundnuts is a serious food safety concern which reduces the potential of this product as nutrient-dense food in Ghana. This has a negative impact on human health, both for households in the North of Ghana who produce and consume groundnuts, and for households in other parts Ghana who use groundnuts produced in the north which are traded into the south. There is a strong need for measuring aflatoxin levels across the value chain because the lack of a traceable supply chain makes it difficult to obtain groundnuts with low aflatoxin levels.

From the point of view of gender equity, the groundnut VC is dominated by women. Women are actively involved in the production, processing and marketing of groundnuts. In this context, reducing the environmental impact of land use through yield boosting agricultural practices[8] would significantly benefit women with regard to their labour burden in cultivation and would also produce benefits to the household. This is particularly because in recent years

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[8] Use of improved seed, adequate sowing density, use of crop residues such as groundnuts shells (up to 52% of the mass of the pod), to improve soil quality and nutrient availability.

groundnuts demand and consumption has increased, while production has reduced by 9% (in the period 2008-2017). Overall, any initiative for VC upgradation has significant likelihood of benefitting women and consequently health, education and food and nutrition security[9] of a large number of families in Ghana.

With regard to post-harvest losses, cutting these is fundamental to effectively reducing land occupation. These losses occur along the value chain due to storage conditions, shelling processes, mould and overall quality of the product and range from 9% to 16%. Improving post-harvest operations would also contribute to reducing aflatoxin contamination; rapid drying on platforms, avoiding contact with soil, sorting at various stages (removing damaged and immature pods) and using new and clean storage bags could reduce fungal growth and toxin production.

With regard to processing, two activities associated with the roasting process have relatively large environmental impacts: 1) *firewood extraction* causing forest degradation and changes in land use alongside greenhouse gas (GHG) emission due to carbon loss from degraded forests, and 2) *firewood combustion*, for roasting (and frying, in the case of *kulikuli*) which causes GHG and air pollutant emissions, such as fine particulate matter formation generating potential damage to human health.

In the context of small-scale processing, which involves almost exclusively women, working conditions are especially harsh for small scale processing workers (typical for roasting), with extreme heat and smoke due to the use of fuelwood and to an inadequate work environment (semi-closed, poorly ventilated compounds). Children of workers also live in this working environment and are expected to inhale smoke, potentially posing dire health and safety risks for both mothers and children. This requires attention as roasting technologies can be improved and new types of roasting equipment can be introduced. From the environmental viewpoint, the substitution of open fire roasting drums fed by firewood used for almost all products with improved ovens or more efficient roasting devices (using electricity or natural gas where possible) can have a very positive effect on the ecosystem quality, contributing to the reduction of firewood consumption and deforestation. A shift away from firewood for roasting, or at least an improvement of the roasting technology using fuelwood, could significantly reduce worker's potential health problems linked to the smoke and the extreme heat.

Cotton in Ethiopia

Overview:

Cotton is one of the oldest fibre crops in Ethiopia providing a means of livelihood to many households engaged in its farming, processing, trade and marketing. Although the VC Analysis of Cotton in Ethiopia considers all categories of farmers, this paper focuses on the smallholder part of the cotton VC. About 30% of the cotton is grown by smallholder farmers, and the remainder is produced on commercial farms. There is a very strong traditional textile sector which involves manual ginning, spinning and handloom weaving. About 5% of the cotton is produced for this sector by 7,000 "type 1" smallholder traditional cotton farmers growing rainfed cotton on areas averaging 0.5 ha under low input conditions. Type 1 farmers achieve relatively high yields (1.3 mt/ha). About 25% of the national production is grown by "type 2" small/medium scale farmers on areas averaging 0.75 ha under mainly rainfed conditions using more purchased inputs and purchased by traders for sale into the more commercial textile sector. Type 2 small holders yields average 1.6 mt/ha. Type 3 are

[9] Especially if such upgrades include improvements in terms of reduction of aflatoxin contamination.

commercial farms averaging 400 ha, achieving somewhat higher yields (1.9 mt/ha) mostly using irrigation and using higher levels of purchased inputs. They produce about 70% of Ethiopia's cotton supplying the commercial textile sector. Ethiopia is currently the second largest consumer of cotton in Africa, after Egypt, importing cotton to supply its burgeoning textile industry.

Environmental impact and social process: trade-offs and win-win options.

Cotton is produced in the drier areas of Ethiopia. Large commercial farms have been established in areas traditionally used mainly for grazing livestock, generating tension with the pastoralists losing part of their traditional grazing grounds. Most of the commercial farms use irrigation powered by hydro-generated electricity, and some are facing problems with soil salinity.

Small-scale farmers grow cotton in rotation with other crops, including sesame and food crops such sorghum, chickpeas and cowpeas. As a rotation crop, cotton is perceived to enhance soil fertility which helps with the production of food crops and household food security. With the fibre and oilseed as cotton's main commercial products, it provides rural incomes and a valuable input into the textile and animal feed industries which provide employment. However, less than 50% of the cotton grown falls under this category of diversified and relatively sustainable production. The prospects are that the less diversified and less sustainable commercial farms will increase production in a few years, reaching over 90% of the total national output, from the 70% at the time of the VC analysis.

An established policy in Ethiopia of forced resettlements, enforcing sedentary lifestyles on pastoral peoples, poses problems for both socio-cultural arenas and the natural environment. Resettlement of people from highland areas and the immigration of workers and farmers into newly developed areas is resented by the indigenous communities in the lowland areas with potential for cotton production. This leads to a lose-lose situation in which both social and environmental aspects are negatively impacted.

Forced labour is prohibited but it does occur, mainly in areas of immigration of highlanders and affecting indigenous lowlanders. Child labour is a cross-cutting problem, and child labour in this VC is not an exception. Most of these children live in rural areas but are also employed in the traditional weaving sector, and the problem is due to poverty. Child labour in the weaving sector in Addis Ababa is well known.

With regard to social impact, most workers employed in the VC earn insufficient salaries. Growth in this VC is not equitable in two distinct segments; the large commercial farms producing cotton, and the modern textile factories, both use cheap labour (mainly young women) with poor employment conditions.

Concerning work safety, the exposure to pesticides (particularly DDT and Endosulfan), poses the main threat to human health. This threat is lower for the small-scale farmers who use minimal levels of pesticides.

Most environmental impacts are concentrated at the farm level. Yarn produced from traditional systems (types 1 and 2) with the lower yields is less eco-efficient due to land occupation, affecting ecosystem quality. Furthermore, these systems have a higher human health impact score if large quantities of manure are applied as fertiliser (due to ammonia and particulate emissions associated with manure application). Nevertheless, it is argued that the traditional systems have the potential to be sustainable. It is further argued that this might sound counterintuitive as these types of farms showed greater environmental impacts. The reason for the high overall impact is the occupation of land and the large quantity of dedicated organic fertiliser that is supplied to compensate for a lack of chemical inputs.

Under a scenario of good organic cultivation practice (including effective weeding and appropriate bio-control mechanisms), the possibility of increased yields and reduced land occupation which would constitute a win-win situation. The cultivation of cotton and the production of yarn provides a large quantity of residues and by-products; by developing mechanisms for an efficient use of available organic matter in the by-products and by transferring good practices such as muching, crop yield and soil fertility might improve substantially. There are examples of good practices in this regard although they may have associated challenges in terms of labour demand, especially if the price of cotton is not seen as attractive. Such practices might have large positive impacts by improving the efficiency of land and by reducing the need of farmers to migrate to other areas. In addition, despite the greater LCA scores in terms of overall impact of farm types 1 and 2, the commercial farming systems might pose higher risks for the environment. Most commercial farms are based on irrigated production, have a reduced rotation regime (with negative impacts on soil fertility) as compared to those in place among smallholders. Regarding irrigation, the water price for agricultural use is very low. This is particularly peculiar in a context of water shortage and climate change and considering that most new cotton areas should emerge in rather arid regions. In addition, for climate change and resource use, larger, more intensive farms have significantly higher impacts than smallholders.

There are issues of social exclusion and negative social impact regarding land rights. Commercial farms are mostly set up in areas populated by pastoralists or traditional farmers, through leases negotiated without the involvement of the indigenous or newly settled people (coming from the densely populated highlands). The indigenous people are often excluded from the economic opportunities and decision making about land and water rights. With respect to land and water rights, a major problem is represented by the “closed contracts” between the government and investors under a 99-year lease contract. The local communities suffer from the consequences of unfulfilled non-compliance of the commercial farms towards them. Land lease contracts are supposed to be linked with provisions of health services by the health officials. It is not clear how these commitments are met. The non-delivery of promised health infrastructure and services could lead to negative attitudes of communities towards investors and the state authorities.

In summary, rather than concentrating on any adverse environmental impact linked to commercial farming (which are substantial issues deriving from irrigated production in dry areas the reduced rotation regime this type of farming system adopts), the attention should primarily be focused on investments causing resettlement and immigration of workers and farmers into newly developed regions and areas. These processes always pose severe problems with indigenous communities and may lead to social conflicts and human suffering. Therefore, current and future investors should ensure they can comply with best practices of corporate social responsibility and refrain from any investment activities in areas where land title is contested, and involuntary resettlement is occurring.

The VCA4D report concludes that the smallholder-based VC is socially sustainable, while the commercial or industrial cotton production-based VC is not, suggesting a potential win-win situation for smallholders, considering also that their environmental impact is reduced compared to that of the commercial farmers.

Cotton in Cameroon

Overview

Most of the smallholder cotton is produced in the north of Cameroon, where it is grown in rotation with food crops, including maize (also grown as a cash crop for sale into Nigeria when prices are higher), groundnuts, and cowpeas, sorghum and millet in the drier northernmost areas.

The context of this VC is that of limited government services in the northern part of Cameroon, neighbouring Nigeria, where cotton is important for the livelihoods of many small-scale farmers. For this reason, cotton companies play a key role in providing services and stability beyond cotton production (including road maintenance and local grain storage), and which support income earning opportunities and food security. Regarding environmental impact, encroachment of cultivation on reserve hunting and wildlife areas is a serious issue in the northern part of the country. According to an opinion survey, an increase of 20 to 30% of cotton producing areas was registered recently.

Cotton expansion has been stimulated because the prices of other agricultural products are negatively influenced by Nigeria's policy of promoting its national production, whereas cotton always assures a guaranteed price and a relatively high income paid in a single instalment.

Environmental impact and social process.

Most of the issues regarding land occupation and cropland expansion that characterise the VC examined are also common to the cotton VC in Cameroon, which has several specific features.

On the level of small-holder farmers (70% of cotton farmers are small-scale producers), the predictable increase in production will be based on the continued expansion of farms in the context of the decreasing fertility of soils. This raises problems related to land, which threaten stability and social order. In the context of a high demographic growth rate, there is increasing difficulty of access to land for the smallholders across all cotton-growing regions; this risk is particularly high in the Far North Region, while in the Northern Region, the conversion of non-agricultural land into arable land for cotton cultivation can be done only at the expense of protected areas which would decrease their biodiversity in the process. Furthermore, the reluctance to provide adequate answers to the problems linked to land availability has the effect of exacerbating conflicts between sedentary crop farmers and transhumant livestock farmers.

The results of the environmental analysis show the possible effects of an increase in cotton production in Cameroon, which could be achieved either by increasing the area under cultivation or by intensifying production on existing cropland. The extension of cotton cultivated areas can be done either inwards – on existing agricultural land – or outwards – by converting non-agricultural land into agricultural land –. Inward expansion of land would be detrimental to food security because fewer crops could be grown for human consumption. From the point of view of social sustainability this option is not viable. Also, adverse environmental effects may be expected from reducing the number of crops in rotation, which may negatively influence soil fertility.

The environmental analysis showed that land use contributes most to impacts on ecosystem quality. An increase in land under cotton production would aggravate the impact on the quality of ecosystems in absolute terms in the North and Far North Regions. Therefore, as seen in other VCs, also for the case of Cameroon, it is suggested that efforts should concentrate on increasing cotton yields by intensifying cultivation on the existing cotton cultivation areas. This can be achieved by increasing the use of fertilisers and pesticides. Overall, however, this would lead to an increase in greenhouse gas and particulate matter emissions in the region. The environmental analysis shows that these two factors contribute most to human health effects. Due to the increased use of pesticides, greater effects on human toxicity and ecotoxicity can also be expected. If intensification were accompanied by increased mechanisation, the contribution of cotton cultivation to resource depletion in the value chain would increase.

The authors argue that, based on the knowledge gained from the analysis of the local cotton cultivation systems, it can be reasonably concluded that eco-efficiency cannot be improved substantially by further intensifying cotton cultivation. It is further argued that the limited use of cotton growth regulators is paradoxical, considering the limited and declining fertility of soils. By allowing cotton plants to grow freely (cotton is a shrub species), therefore depleting the nutrients in the soil and not subsequently returning them, failure to regulate cotton plant growth does contribute to reversing the relationship between cotton farming and soil fertility.

In order to ensure the long-term sustainability of cotton cultivation in Cameroon, the effective preservation of soil fertility is essential, which requires a more efficient use of existing organic fertilisers and a level in production intensity that is adapted to the regenerative capacity of the local ecosystem resources.

Discussion: Trade-offs and Win-wins

Trade-off situations can be defined as when the social conditions are improved at the expense of the environmental impact. The opposite, when environmental conditions are improved at the expense of social conditions could also be a trade-off. However, in practice, the former type of trade-off is more typical, particularly in a developing country, when the human actors prioritise short-term social and economic benefits over longer term environmental benefits. A win-win situation is when improving the social outcomes or conditions also connects with a reduced environmental impact, or when a practice which reduces the environmental impact also brings some social improvement.

Trade-offs smallholder food crops

Some common themes emerged from the cases presented regarding smallholder food crops with regard to trade-offs, drivers, and several promising win-win opportunities for social and environmental sustainability.

The cases of maize in Zambia and sorghum and groundnuts in Northern Ghana, highlight two main areas of environmental impact and trade-offs with social sustainability; cultivation (including land clearing) and grain processing. Both cultivation and processing trade-offs offer considerable scope for introducing or promoting win-win options which will improve both environmental and social sustainability.

Land clearing for cultivation of maize in Zambia negatively impacts biodiversity and carbon sequestration, which are “traded off” for the social benefits of household food and nutrition as well as household income from the sale of grain. Cultivation of all three food crops in Zambia, Northern Ghana and Nigeria under extensive low input management, has an even greater environmental impact because of the much larger areas of land involved.

The socio-economic factors driving this trade-off are multiple and complex. They include population pressure and the household development cycle (which involves household migration to less populated areas and clearing of new land); increasing integration of smallholders into the wider society and economy (selling grain to meet cash needs including education and health); uncertainty about future grain and input prices (influence of world prices for imported inputs, export markets, government intervention, exchange rates); limited availability of yield enhancing inputs (e.g. groundnut seed of improved varieties); unaffordability of yield enhancing inputs (e.g. certified seed and chemical fertiliser); limited availability of key inputs (improved seed, agro-chemicals, labour saving implements and animal draught power) on favourable terms of credit.

In summary, the greater environmental impact arising from land clearing and/or extensive low input crop production is traded for the lower risks or less strenuous tasks involved compared with using higher external input levels and more labour intensive cultivation methods. This is typically the case for poorer farming households which government and donor supported programmes purport to target. On the one hand, extensive low input cultivation can provide poorer farming households with “affordable and lower risk” food security and income. On the other hand, more intensive cultivation methods with higher levels of purchased inputs can, potentially, reduce environmental impact and improve social sustainability for these households. However, there are significant barriers to more widespread uptake of more intensive methods and purchased inputs. Many rural households often cannot afford to purchase yield enhancing inputs and more sophisticated farming equipment (e.g. rippers to improve soil structure). Taking a loan to buy inputs can be risky in cases where market prices and/or climatic conditions are unpredictable. Some of the low cost intensive methods (such as composting, earlier and more frequent weeding, non-chemical pest control) require additional labour which is often in limited supply in poorer households.

Win-win options for smallholder food crops

Win-win options to reduce the environmental impact and enhance smallholder livelihoods for the three food crops discussed which are more likely to be taken up at scale are those which limit the level of risk involved.

Improved seed availability: One example is making readily available at affordable prices improved varieties which do well under sub-optimal growing conditions. These can be higher yielding and the existing available varieties because of greater tolerance to low soil fertility, drought, pests and diseases. This will depend on well functioning and regulated systems for variety testing and an infrastructure seed supply, quality control, distribution and storage.

Appropriate farm tools: Another example is improved mechanical weeding tools which save labour and reduce yield losses arising from late weeding. This will help to reduce much of the drudgery which often falls on women who have multiple roles in their households, and/or on poor households who weed the crops of other households in exchange for cash or food. As with seed supply this type of win-win intervention depends on a functioning infrastructure for the supply, repair and maintenance of improved farm tools.

Appropriate external inputs on affordable credit: Intensification through more appropriate use of yield enhancing technologies such as chemical fertiliser, herbicides and pesticides is a more viable option when smallholders can obtain these on favourable credit terms backed by forward contracts. This would not involve large quantities of expensive imported inputs, but rather smaller quantities used strategically to address key constraints in local production systems. This could be facilitated through forward contracts with traders and favourable credit terms reduce the risk of credit default, as is the case with the contracted sorghum growers in Ghana.

The above types of win-win options require investment (public and/or private) and policy support in order to be taken up at scale. For example, the identification of an improved variety requires significant public investment in research and development, followed by investment (public and private) in seed production and distribution if it is to be available to smallholders on time and at scale. This is particularly challenging for the promotion of non-hybrid seed because seed companies make more profit from hybrid seed which has to be purchased every season.

Advisory services for local conditions with choices: A further aspect to consider is the need for agricultural services to be tailored to the local conditions and resources of the smallholders being targeted, rather than being offered as blueprints without flexibility and choice. The need is for an offer of choices, both of technology and also of credit and marketing options. Regarding technology this choice should include certified seed of more than one improved and locally proven variety, a choice of relevant chemical fertiliser types and other agro-chemicals (e.g. herbicides) and affordable labour-saving hand tools and equipment for draft animals and mechanical cultivation services where these are economically viable.

Planting trees on farm holdings: The negative environmental impact of clearing woodland for additional land for cultivation can be a serious issue in the medium to longer term. In the areas where woodland clearing has already taken place, win-win options require a supportive policy environment which provides smallholders with incentives for planting more trees on and around some of their land holdings. Planting trees as woodlots, boundary planting and in agroforestry formations in the medium term provide significant livelihood benefits of fuelwood and building materials, as well income from sale of timber, while contributing positively to carbon stocks.

Reducing post-harvest losses: Post-harvest loss is an issue which holds significant potential for developing win-wins in the relationship between environmental and social sustainability. This holds for all three food crops in the cases described, including maize in Nigeria with post-harvest losses of 15%. Post-harvest losses typically start in the field at harvest time, continue as the crop is transported and processed for storage, and continue further during storage (on-farm and in warehouses). Whatever measures can be promoted to reduce the level of post-harvest losses at any of these points will definitely pay off in terms of reducing environmental impact, and provided the measures are affordable and not too labour demanding they will also provide social benefits.

Grain quality control: Related to measures to reduce post harvest losses, a further win-win opportunity is measures to improve the quality of grain, or to pay more attention to introducing quality standards which enable the better quality of grain to be exported. In the case of all three crops the efforts to address grain quality issues are relatively minimal. Farmers do not usually receive premium prices for grain which is of higher quality, and the same applies to traders. The main method is for traders or millers to refuse to buy grain which they assess to be below their quality standard, rather than offer higher prices for grain of the highest standard. This is particularly important for groundnuts, where the aflatoxin issue is the major barrier to obtaining higher prices through export of groundnuts. Zambia has a policy of not allowing cultivation of GM crops and Nigeria produces only non GM maize. Zambian and Nigerian non GM maize could potentially receive a premium price if marketed and exported as such.

Support to local level grain processing: Artisanal processing of grain for household use and for making products for local sale provides relatively straightforward opportunities for win-win solutions to reduce the negative environmental impact of using large amounts of firewood, and the impact on tree cover and carbon sequestration. Artisanal and household processing maize in Zambia, and sorghum and groundnuts in Ghana, is mostly done on open fires. Artisanal processing of groundnut paste, and non-alcoholic beer from sorghum and maize for sale provides an important means of livelihood for large numbers of rural women and some poorer women in urban areas. Affordable energy saving technology for cooking family meals, brewing and roasting is a win-win option which is relatively easy to scale up and has a quick and lasting impact on energy use efficiency. This will reduce environmental impact while improving the livelihoods of the rural women, cutting their costs (labour or cash) for firewood or charcoal use and in some cases making the processing safer and easier for the women involved. This may require some policy and other support, for example removing any taxes on materials needed for manufacture of energy saving stoves and roasting equipment, providing information and training on the manufacture and use of the energy saving equipment, introducing quality standards for manufacture, and possibly some form of subsidy of the manufacturing process in rural areas due to the relatively low uptake in rural areas (Stevens et al, 2018).

Trade-offs and win-win options for smallholder cotton

The cotton cases had somewhat different types of trade-offs and drivers. It was more difficult to identify clear win-win options in the case of smallholder cotton. However, compared with commercial cotton, small holder cotton was relatively more socially sustainable and potentially had lower environmental impact.

There were some social and environmental issues arising from land-use changes in both Ethiopian and Cameroon cotton VCs. Both cases illustrate negative environmental impact arising from changing land use as a result of pressure to extend cultivation into areas previously used for grazing by livestock and/or game animals. Both cases also document negative social impact of land-use change and population movement in the form of ethnic conflict and hostile feelings between displaced pastoralists claiming indigenous rights and incoming smallholders moving to farm from other farming areas.

The two VCA4D studies did not include an analysis of the relative environmental impact of the change of land use from grazing to cotton production. The studies instead looked at the relative environmental impact of different levels of management by different categories of farmers. In both cases cotton production was assessed as being more environmentally and socially sustainable under the small-scale lower management levels, compared with the higher management levels found on larger and more commercialised cotton farms, particularly those in Ethiopia.

The case of cotton also illustrates the importance of significant investment in, or existence of, the infra-structure and institutional mechanisms needed for sustaining smallholder cotton production.

In Ethiopia, a very well established indigenous textile manufacturing sector has provided a well developed market for cotton trading and transportation which functions effectively for all parties and operates with minimal government or major external private sector involvement. However, limited adherence to the social contracts applying to the commercial companies growing cotton, and limited enforcement of these contracts by the government, contributes to the negative social impacts of large-scale commercial cotton growing compared with small-scale cotton production.

In Cameroon a well established and well regarded cotton parastatal company, which operates with government support, plays a key role in servicing smallholders and providing stability in an area of the country where government services are weak and there is political instability. This company provides benefits beyond income and markets for smallholders, and has made a valuable contribution to the development of social capital among smallholder communities.

In both cases smallholder cotton grown with relatively low levels of external inputs serves as a valued rotation crop, on the same fields as basic food crops in relatively remote areas. A recent comparative study of smallholder agriculture in Africa found that smallholder cotton farmers in Mali were more food secure than farmers who did not grow cotton. This suggests that where a favourable institutional and physical infrastructure is in place, smallholder cotton, grown in rotation with food crops, can positively contribute to smallholder livelihoods, while also improving longer term soil fertility and potentially reducing the need to clear new land specifically for a cash crop.

Does this case comparison indicate that cotton, as non-food cash crop, differs significantly from the food crops described in terms of trade-offs and potential win-win situations? While a more in-depth and exhaustive analysis would be needed to provide a comprehensive answer to this question, the cases discussed above indicate that there is a difference.

Cotton is potentially less sustainable, both environmentally and socially, in cases like Ethiopia where the focus is on large scale commercial production, based on mono-cropping. The long term environmental costs are relatively high, while the social costs of displacement of communities and potentially harsh working conditions for employees are also high. The three food crops discussed are largely grown by smallholders for household use and for sale into the national market with relatively little large-scale commercial production dependent on major capital investment. The challenge with the three food crops is that the infrastructure to support input supply and marketing services are relatively undeveloped.

Conclusions

This paper has focused on smallholder crop VCs based on relatively more extensive rainfed cropping systems in five African countries. The extensive nature of the production stage of these VCs raises similar concerns with regard to negative environmental impact, which often conflict with social pressures relating to the security and risks relating to food, income, health and in some cases access to land.

The expansion of cultivation into forest areas, virgin land and natural pastures for both food and cash crops, and a reduction in traditional fallowing periods, results in environmental degradation, while also enabling households to improve their food, income (especially in the short/medium term) and land security.

This trade-off between the environmental and social impacts does require to be addressed by appropriate policy measures if these value chains are to be more sustainable in the medium and longer term. In most cases environmental protection policies which require strong enforcement will not work well because of the limited capacity to enforce and in some cases political will to do so. Policies for environmental protection should instead focus on providing incentives backed up with strong educational elements. Policies relating to agricultural services should be well thought out and informed by longer term considerations, both environmental and socio-economic. This implies a commitment by national governments to longer term investments in and support to the relevant institutions and infrastructure required to achieve more sustainable smallholder crop value chains. Behavioural change will be involved at various levels, hence the importance of having clear policies and investment in skills training and education of the main actors, so they can make informed choices which are informed by a good understanding of both environmental and social impact.

The policies to support these value chains will also need to be well informed by international trends, given that local economies are increasingly integrated into, and subject to international shocks and trends. A case in point is the current increase in energy prices, with major knock-on effects for fertilizer costs, as well as costs relating to transportation and industrial processing of the crops produced in these value chains.

The post-harvest and processing stages of some of the value chains also provide good opportunities for achieving win-win outcomes. For example, reducing post-harvest losses has a positive impact on the environment, particularly for the food grain crops, while also improving incomes and food security for smallholders. Improving the quality control of grain, particularly groundnut aflatoxins, promises to significantly improve prices paid for groundnuts while at the same time improve health outcomes, both for the households consuming these for their food, and for urban consumers. Local processing of the grain crops often requires large quantities of firewood and involves women working in sub-optimal conditions with a risk to their health from fumes. Improved methods and technologies for local processing could not only reduce the environmental impact by reducing the amount of firewood needed, but also reduce the health risks for the women involved.

A final point relates to how the VCA4D methodology is used, particularly the scale at which environmental impacts are assessed, and how the interaction between environmental and social impacts are assessed.

References

Abdul Rahman, N., Larbi, A., Kotu, B., Kizito, F., & Hoeschle-Zeledon, I. (2020). Evaluating Sustainable Intensification of Groundnut Production in Northern Ghana Using the Sustainable Intensification Assessment Framework Approach. *Sustainability*, *12*(15), 5970. https://www.google.com/search?q=groundnut+production+in+northern+ghana&rlz=1C1CHBF_en-GBGB983GB983&oq=groundnut+production+in+northern+ghana&aqs=chrome..69i57j33i160l2.11466j0j15&sourceid=chrome&ie=UTF-8

Arndt, C., K. Pauw and J. Thurlow (2014). The economywide impacts and risks of Malawi's farm input subsidy programme. Helsinki: UNU-WIDER. WIDER Working Paper 2014/099.http://www.wider.unu.edu/publications/working-papers/2014/en_GB/wp2014-099

Bartlett, L., & Vavrus, F. (2017). Comparative case studies: An innovative approach. *Nordic Journal of Comparative and International Education (NJCIE)*, *1*(1).

Chambers, R. and Conway, G. (1991) Sustainable Rural Livelihoods: practical concepts of the 21st Century. IDS Discussion Paper 296. https://www.ids.ac.uk/download.php?file=files/Dp296.pdf

Dawson N, Martin A and Sikor T. (2016) Green revolution in sub-Saharan Africa: implications of imposed innovation for the wellbeing of rural smallholders. World Development 78: 204–218.

Denning, G., P. Kabambe, P. Sanchez, A. Malik, R. Flor, R. Harawa, P. Nkhoma, C. Zamba, C. Banda, C. Magombo, M. Keating, J. Wangila and J. Sachs (2009). Input subsidies to improve smallholder maize productivity in Malawi: Toward an African green revolution. PLoS Biology 7(1): 2-10.

Dercon, S. (2014b). Is green growth good for the poor? Washington, D.C.: World Bank. Policy Research Working Paper 6936. Retrieved on 23 September 2014 from https://openknowledge.worldbank.org/bitstream/handle/10986/18822/WPS6936.pdf?sequence=1.

Fabre P., Dabat M-H., Orlandoni O. (2021). Methodological brief for agri-based value chain analysis. Frame and tools – Key features. Version 2 – February 2021, 44p.

https://europa.eu/capacity4dev/value-chain-analysis-for-development-vca4d-/wiki/1-vca4d-methodology

Fok, M., Meier, M., Nicolay, G., Balarabe, O., Calaque, R., 2019. Cotton value Chain Analysis in Cameroon. Report for the European Union, DG-DEVCO. Value Chain Analysis for Development Project (VCA4D CTR 2016/375-804), 122 p + annexes.

Fusillier J-L, Sutherland A., Villani R., Chapoto A.., 2021. Maize Value Chain Analysis in Zambia. Report for the European Union, DG-INTPA Value Chain Analysis for Development Project (VCA4D CTR 2016/375-804), 222p + annexes.

Griffiths, G., Adolph, B., Chapman, A., Davies, J., Devenish, A., Jellason, N., Kanja, K., Kwenye, J., Manzoor, A., Mwitwa, J., Newbold, T., Phiri, D., Robinson, E., Zurek, M. (2022). Future trade-offs to 2050: land cover change, biodiversity and agriculture in Zambia. IIED, London Sentinel, London https://pubs.iied.org/20896g

Kaarbo, J., & Beasley, R. K. (1999). A practical guide to the comparative case study method in political psychology. *Political psychology*, *20*(2), 369-391.

Kleih, U., Bosco, S., Kumar, R., Apeeliga, J., Lalani, B., Yawlui, S., 2020, Groundnuts Value Chain Analysis in Ghana. Report for the European Union, DG-DEVCO. Value Chain Analysis for Development Project (VCA4D CTR 2016/375-804), 150p + annexes.

Kotu BH, Nurudeen AR, Muthoni F, Hoeschle-Zeledon I, Kizito F (2022) Potential impact of groundnut production technology on welfare of smallholder farmers in Ghana. PLOS ONE 17(1): e0260877. https://doi.org/10.1371/journal.pone.0260877

Haupt, J. and C. Lawrence (2012). Unexpected connections: Income inequality and environmental degradation‘. Shaping Tomorrow‘s World, 13 February 2012. Retrieved on 4 November 2014 from
http://www.shapingtomorrowsworld.org/hauptInequality.html#_ENREF_53

Howe C, Suich H, Vira B, et al. (2014) Creating win-wins from trade-offs? Ecosystem services for human well-being: a meta-analysis of ecosystem service trade-offs and synergies in the real world. Global Environmental Change 28: 263–275.

Jarvis, A., Lau, C., Cook, S., Wollenberg, E., Hansen, J., Bonilla, O., & Challinor, A. (2011). An integrated adaptation and mitigation framework for developing agricultural research: synergies and trade-offs. *Experimental Agriculture*, *47*(2), 185-203.
https://www.cambridge.org/core/journals/experimental-agriculture/article/abs/an-integrated-adaptation-and-mitigation-framework-for-developing-agricultural-research-synergies-and-tradeoffs/70B777AF192A4CB94453516DE7159140

Jellason, N. P., Robinson, E. J., Chapman, A. S., Neina, D., Devenish, A. J., Po, J. Y., & Adolph, B. (2021). A systematic review of drivers and constraints on agricultural expansion in sub-Saharan Africa. *Land*, *10*(3), 332.https://pubs.iied.org/20941g

Mainali, B., Luukkanen, J., Silveira, S., & Kaivo-oja, J. (2018). Evaluating synergies and trade-offs among Sustainable Development Goals (SDGs): Explorative analyses of development paths in South Asia and Sub-Saharan Africa. *Sustainability*, *10*(3), 815.

Malerba, D. (2020). The trade-off between poverty reduction and carbon emissions, and the role of economic growth and inequality: an empirical cross-country analysis using a novel indicator. *Social Indicators Research*, *150*(2), 587-615.

Martin, A., Coolsaet, B., Corbera, E., Dawson, N., Fisher, J., Franks, P., ... & Ryan, C. (2018). Land use intensification: The promise of sustainability and the reality of trade-offs.

Neina, D., Mwitwa, J., Adolph, B. (2022). The nexus between soil degradation and agricultural expansion in Zambia. IIED, LondonSentinel, London https://pubs.iied.org/20941g

Nicolay, G; Estur, G; Walsh, C; Desalegn, P, 2020. Cotton Value Chain Analysis in Ethiopia. Report for the European Union, DG-DEVCO. Value Chain Analysis for Development Project (VCA4D CTR 2016/375-804), 128 p + annexes.

Onumah, G., Dhamankar, M., Ponsioen, T., Bello, M., (2021), Maize Value Chain Analysis in Nigeria. Report for the European Union, INTPA/F3. Value Chain Analysis for Development Project (VCA4D CTR 2016/375-804), 155p + annexes.

Onumah, G., Plaisier, C., Villani, R., Komlaga, G., 2020, Sorghum Value Chain Analysis in Ghana. Report for the European Union, DG-DEVCO. Value Chain Analysis for Development Project (VCA4D CTR 2016/375-804), 168 p + annexes.

Onumah, G., Sutherland, A., Guerreiro de Brito, A., Chapoto, A., Farrall, H. 2018. Egg Value Chain Analysis in Zambia. Report for the European Union, DG-DEVCO. Value Chain Analysis for Development Project (VCA4D CTR 2016/375-804), 172p + annexes

Rasmussen LV, Bierbaum R, Oldekop JA, et al. (2017a) Bridging the practitioner–researcher divide: indicators to track environmental, economic, and sociocultural sustainability of agricultural commodity production. Global Environmental Change 42: 33–46.

Schreckenberg, K., Poudyal, M., & Mace, G. (2018). *Ecosystem services and poverty alleviation: trade-offs and governance* (p. 352). Taylor & Francis. file:///C:/Users/Alistair/Downloads/648753%20(2).pdf

Scherer, L., Behrens, P., de Koning, A., Heijungs, R., Sprecher, B., & Tukker, A. (2018). Trade-offs between social and environmental Sustainable Development Goals. *Environmental science & policy*, *90*, 65-72.

Oppong-Sekyere, D, Asumboya, G and Yintii, B. (2018) Sorghum Production Practices: A Case Study of Four Districts in Navrongo, Ghana. Journal of Basic and Applied Scientific Research. 8(7)1-15
https://www.textroad.com/pdf/JBASR/J.%20Basic.%20Appl.%20Sci.%20Res.,%208(7)1-15,%202018.pdf

Sheahan, M., Black, R., & Jayne, T. S. (2013). Are Kenyan farmers under-utilizing fertilizer? Implications for input intensification strategies and research. *Food Policy*, *41*, 39-52. https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=Sheahan+et+al.+%282013%29&btnG=

Stevens, L., Santangelo, E., Muzee, K., Clifford, M., & Jewitt, S. (2020). Market mapping for improved cookstoves: barriers and opportunities in East Africa. *Development in Practice*, *30*(1), 37-51.
https://www.tandfonline.com/doi/full/10.1080/09614524.2019.1658717?cookieSet=1

Zulu-Mbata, O., Chapoto, A., & Hichaambwa, M. (2016). Determinants of conservation agriculture adoption among Zambian smallholder farmers (No. 1093-2016-88059). https://ageconsearch.umn.edu/record/251855/