Carbon accounts of shifting cultivation: reductionist practices, contentious politics

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Abstract

Climate change mitigation policies concerned with the preservation of forest carbon stocks have increasingly fuelled conflict over access to forests with traditional shifting cultivators, who have been blamed to be among the central causes of greenhouse gas (GHG) emissions from deforestation. This paper addresses the adequacy of current carbon accounting practices for shifting agriculture and potential alternatives from a complex socio-ecological systems perspective. It is argued that from such a broader perspective, the currently predominant focus on plot-based changes in total ecosystem carbon stocks, such as through forest carbon accounts, is inadequate to assess systemic climate pressures resulting from different land use systems. Such proxies represent only a single snapshot of a comparatively small land area, which however is embedded into the larger spatial and temporal dynamics of not only land use but also livelihood systems. Hence, currently predominant assessment practices are too reductionist to grasp the wider system dynamics and to provide a reliable understanding that could support policies targeting a transition away from shifting agriculture. They further run danger of replacing democratic decision-making over socio-environmental futures with technical discussion on how to achieve rather abstract carbon values that lack political legitimacy on the ground. Policies based on such accounts are therefore not only politically contentious, fuelling conflict over access to forests, but further can be ineffective and sometimes even counterproductive for their initial objective of climate change mitigation.

Keywords

Slash and burn; shifting cultivation; climate change mitigation; land use change; rural livelihoods; carbon accounting; REDD+

1 Introduction

Over the last decades, old and controversial debates over the impacts of shifting cultivation on the environment have been powerfully renewed within the context of climate change. Rising concerns have been voiced that this practice, being one of the oldest forms of agriculture, may negatively affect forest carbon stocks and greenhouse gas emissions (Brady 1996; Fearnside 2000; Kotto-Same et al. 1997). Global partnerships such as the Alternatives to Slash and Burn (ASB) initiative were consequently established in order to identify and propose alternative land uses (ASB Climate Change Working Group 2000; Palm et al. 2004). Within the context of REDD+ (Reduction of Emissions from Deforestation and Forest Degradation), many governments have blamed shifting cultivation as major cause of forest loss, turning it into targets of policy intervention (Griffiths 2008; Fox et al. 2014; Erni 2009). No doubt, such policies and policy-oriented research programs have pushed a transformation of the lives, cultures and livelihoods of many people engaged in shifting cultivation across the world. Yet a disputed question remains: how much does shifting cultivation, compared to other land and livelihood systems, really contribute to climate change?

As some may argue, simply framing questions of the sustainability of shifting cultivation in that way should be avoided, as it may reduce related discussions to mere aspects of climate change mitigation, putting somehow abstract carbon values over the livelihoods, values and lives of shifting cultivators. From a climate justice perspective concerned with historic emissions (Roberts & Parks 2009), others would moreover add that shifting cultivators, coming generally from countries that are only now in the process of industrialization, have also least contributed to emitting fossil carbon to the atmosphere. From such a perspective, mitigation policies should consequently be more concerned with historic carbon emitters, i.e. industrialized countries, but not with shifting cultivation that have existed for thousands of years without 'messing up' the climate. All these are relevant concerns; yet it is still important, I believe, to understand how shifting cultivators may add (or not) pressures to climate change, not least because related debates have become of growing importance in research and policy and cannot be simply ignored. Sometimes, they have also turned into powerful political forces that currently redefine who can access and make use of forests, and who cannot (Griffiths 2008; Scheidel & Work 2016). Understanding the political implications of carbon accounting becomes therefore important, but requires in turn also to understand the practice and adequacy of current assessment methods (cf. Scoones et al. 2013). In this context, this article calls for a more nuanced understanding and assessment of pressures on climate change resulting from shifting agriculture and its alternatives, as it is done today.

To do so, I briefly review how a focus on total ecosystem carbon stocks, such as through forest carbon accounts, has turned into the currently predominant carbon accounting approach to address shifting agriculture. The article moves then on to discuss its adequacy from a complex social-ecological systems perspective. Complex system studies broadly understand social and ecological systems as coupled systems, whose different compartments are connected through feedback loops and sometimes non-linear processes that interact across different spatial and temporal scales (Liu et al. 2007; Giampietro 2003). Socio-ecological transition studies also consider systemic interaction between social and ecological systems, but in addition focus particularly on how social and ecological dynamics unfold over time, following certain trajectories of socio-ecological change (Fischer-Kowalski & Haberl 2007). As argued in the paper, from this perspective, the predominant focus on total ecosystem carbon stocks on a plot-based scale does not serve well as proxy to compare land use systems, as it represents only a single snapshot of a comparatively small land area, which however is embedded into the larger spatial and temporal dynamics of not only land use but also livelihood systems. It is too reductionist to grasp the wider system dynamics and to provide a reliable understanding to support policies targeting a transition away from shifting agriculture. Such policies are not only politically contentious by fuelling conflict over access to forests, but can be ineffective and sometimes even counterproductive for climate change mitigation, as illustrated presently.

The next section provides a brief overview on forms of shifting cultivation nowadays and the ways how it has been commonly assessed with regard to climate change pressures (Section 2). Section 3 introduces the conceptual approach of this paper, while Section 4 discusses how far current carbon assessment approaches are (un)able to account for the wider dynamics of both land use and livelihood systems. Section 5 concludes on the political implications that current assessments approaches entail, as well as on the need to move towards a more systemic understanding of shifting agriculture and pressures on climate change.

2 Shifting cultivation and pressures on climate change: current dynamics and assessment approaches

2.1 Shifting cultivation - from early origins to current dynamics

Forms of shifting cultivation represent one of the oldest agriculture practices and have been referred to under different names, such as swidden agriculture, rotational farming, or slash-and-burn agriculture, that were accompanied with similar but slightly different definitions (see Mertz et al. 2009 for a detailed description of the different terms)[1]. For the purpose of this paper, I refer to these similar forms here under the general term 'shifting cultivation'. Broadly speaking, the agricultural practice can be understood as an integrated agro-forestry system, which embraces three phases: forest conversion, cropping and forest fallow. During forest conversion, large parts of the vegetation from primary or secondary forests is cut, dried and then burned, leading to the release of nutrients into the soil and related increases of soil fertility, while also emitting greenhouse gases (GHG) into the atmosphere from burning and decay processes. During the cropping period, which originally spans a few years, agricultural plots are established for the production of food crops, usually with high yields, thanks to increased soil fertility from previous vegetation burning. During the fallow period, temporary plots are abandoned for at least a longer time as they were harvested and trees are able to regrow, sequestrating carbon from the atmosphere. Meanwhile, shifting cultivators move on to other spots to start this cycle again. Fallow periods may range from a few years (short-fallow) up to several decades (long-fallow), before they are again converted to cropping plots. This cycle is repeated across time and space, involving numerous faceted socio-cultural as well as ecological processes (Kleinman et al. 1995; Padoch & Pinedo-Vasquez 2010; Mertz et al. 2009).

For decades, shifting agriculture was perceived as *"…the greatest obstacle not only to the immediate increase of agricultural production, but also to the conservation of the production potential for the future, in the form of soils and forests… [N]ot only a backward type of agricultural*

[1] Shifting agriculture needs to be separated from other forms of fire use for the establishment of permanent agriculture, such as small-scale forest clearance for permanent agriculture, to large-scale forest clearance for the establishment of permanent industrial plantations. The term 'slash-and-burn agriculture' has sometimes become a misleading 'catch-all' category in both policies and academic papers (e.g., Tacconi & Vayda 2006; Varma 2003).

practice…[but] also a backward stage of culture in general" (FAO Staff 1957, cited in Mertz et al. 2009). Many subsequent national policies were influenced by this kind of understanding (Fox et al. 2009). However, others argued that shifting agriculture, particularly as original agricultural practice towards which such criticism was initially targeted, was in fact among the most sustainable agricultural practices. It can be understood to be in 'ecological equilibrium' when the ratio of fallow years/cropping years is high enough to allow for a recovery of biomass stocks, species composition and its related ecological functions, as well as when carbon emissions during burning could be offset through carbon sequestration during fallow regrowth[2]. Moreover, it could sustain soil fertility and high yields completely independent of chemical and fossil-fuel based agro-inputs, such as machinery, synthetic fertilizers and pesticides (Kleinman et al. 1995; Tinker et al. 1996; Fearnside 2000). Shifting agriculture within its original configuration is therefore among the most climate friendly agricultural systems.

Yet nowadays, many shifting cultivation systems would not classify as being in such ecological equilibrium as they are increasingly characterized by declining ratios of fallow years/cropping years, often provoked through growing external and internal pressure on land resources (van Vliet et al. 2012). Along this changing ecological equilibrium, also a reconfiguration of livelihoods is occurring, and shifting agriculture has often turned from being an 'integral' livelihood system to a 'partial' livelihood activity, supplemented with numerous other land use and livelihood activities (Cramb et al. 2009; Mertz et al. 2009). Several review studies showed that systems moving away from shifting agriculture have moved mainly towards perennial cropping such as rubber, timber or fruit trees, and/or to annual cropping on permanent plots such as through paddy rice cultivation (Schmidt-Vogt et al. 2009; van Vliet et al. 2012). Such changes entail an increasing use of livestock, synthetic fertilizers and other agro-inputs and production of cash crops for the market (Leisz et al. 2007). They can also entail increasing labor engagement in other, often non-rural sectors. While these changes and intensification of land uses have often been accompanied by rising incomes, higher education and larger social networking, they are also often characterized by increased conflicts over land, out-migration and loss of cultural identity (van Vliet et al. 2012). In some cases shifting agriculture remains a central component of the livelihood system; in other cases it has become rather a safety net when other rural and non-rural livelihood strategies fall short (Cramb et al. 2009).

2.2 Current assessment practices: the challenge of accounting climate rucksacks of shifting cultivation

This large diversity of current forms of shifting agriculture as both a land and livelihood system brings also a diversity of implications for understanding their climate change pressures with it. The initial question of how much shifting agriculture contributes to climate change through release of GHG emissions, compared to other land and livelihood systems, becomes in fact a complex issue. First, there is no general way to define which type of shifting agricultural system would be a meaningful proxy for comparison. Second, the choice of an alternative to which it should be compared is also not straightforward. Natural undisturbed forests, often used as baseline for comparison (e.g. Palm et al. 2004) are not adequate comparisons, as shifting cultivation systems are not forests, but rather agricultural system with integrated forest use (Mertz et al. 2009). Also, one

[2] Trace gases such as CH_4 or N_2O resulting from decay processes of shifting cultivation are net additions of trace gases into the atmosphere, which however are also present in undisturbed natural forests. The Global Warming Potential (GWP) associated to trace gases can be even higher in natural forests than in slash-and-burn agricultural systems (Palm et al. 2004).

cannot ignore the people involved in shifting agriculture and replace a livelihood landscape with a natural forest.

Alternatives that are commonly proposed by related research and policy, range from fostering a transition from shifting to managed agro-forestry, over different types of tree plantations (rubber, eucalyptus), to permanent agriculture for food and cash crop production (Ziegler et al. 2012), to a complete stop of any agricultural undertaking and people's engagement in a new economic sector. Comparing the pressures on climate change between shifting agriculture and one of these alternatives hence need to account on the one side for the different forms of shifting agriculture, as well as for the different alternative trajectories. Only then meaningful comparisons can be made regarding how one system performs over the other in terms of GHG rucksacks. So far, this issue has been approached by comparing two or three types of shifting agriculture with a few types of other land uses. The main factor for distinguishing shifting system has been generally fallow length, i.e., short term vs long-term fallow, whereas different alternatives covered a range of tree plantation types and agricultural systems.

Since concerns over emissions from shifting agriculture have globally emerged during the 1990s, many case studies have followed that assessed and compared different land use systems. Most of them have focused on differences in total ecosystem carbon (TEC) stocks of the particular land use area under assessment, accounting, with different methods and accuracy for its components aboveground carbon (AGC), belowground carbon (BGC) and soil organic carbon (SOC) (e.g., Inoue et al. 2010; Tschakert et al. 2007; Kotto-Same et al. 1997). Very few studies focused systematically on the long term GHG flow dynamics resulting from the broader agricultural changes taking place following a decline in shifting agriculture, such as through emissions from new livestock, fertilization techniques, paddy rice production, manure management and the like (Leisz et al. 2007). In this context, the distinction between short-term and long-term fallow systems is only relevant to assess differences in TEC, but not to indicate differences in GHG emissions associated to the broader land use and livelihood systems of shifting cultivation.

The individual case studies were soon accompanied by review studies. The first one available on this issue was produced by the ASB programme, summarizing results from their own case studies (ASB Climate Change Working Group 2000; Palm et al. 2004). The review study looked at both plot based changes in time-averaged carbon stocks, stored in vegetation and soils, as well at changes in GHG emissions through different land uses. Much of GHG emission data were estimated due to a lack of available data (ibid) and further did not include a systematic assessment of GHG sources the way that for example Leisz et al. (2007) did later on. The review study argued that increases in the Global Warming Potential (GWP) caused by declining forest carbon stocks outpace well the GWP of GHG emissions from other land management practices. Therefore, assessments of changes in carbon stocks represented the most important proxy to discuss the climate sustainability of different land use options. Their results indicated that tree-based systems performed relatively well, whereas short-term shifting cultivation should and could be incentivized to transition towards tree-based systems such as rubber or oil palm plantations (Palm et al. 2004). Other review studies followed that compared a large number of up to 250 cases, representing the most extensive ones available (Bruun et al. 2009; Ziegler et al. 2012). They focused only on carbon stocks as proxy of comparison and emphasized the comparatively good performance of long-term fallow systems over other alternatives, including different types of tree plantations. However, there is lack of solid data and knowledge, they argued, to support policy recommendations that would take effect on people's lives.

Beyond scientific studies focusing on shifting agriculture, ecosystem carbon stock measures have also turned into key proxies within more practical assessments. For example, the potential of tree plantations for climate change mitigation under the afforestation/reforestation projects of the Clean Development Mechanisms (A/R CDM) are primarily assessed in terms of their ecosystem carbon stock gains. The only GHGs that need to accounted for are those from burning biomass, e.g. for land prepration, but not those from machinery use, fertilizers, infrastructure development and the like (UNFCCC 2013). Also across many governmental and NGO actorsc concerned with forests, 'forest carbon stocks' has become the key term in discussions on the climate change and forest uses. While detailed knowledge of TEC for different land uses growing rapidly, the next section argues that this currently predominant focus is not only insufficient, but can be misleading, as it only represents a one-dimensional snapshot of a complex land use and livelihood system.

3 Why total ecosystem carbon (TEC) measures can be misleading: insights from complex socio-ecological systems studies

Complex system studies provide a framework to conceptualize and understand how changes in one system component, i.e., change in agricultural practices, may trigger feedback loops and changes in other system components, i.e., land use and livelihood systems, across spatial and temporal scales (Giampietro 2003). Socio-ecological transition studies particularly look at how both social and ecological systems interfere with each other, unfolding over time, following certain trajectories of socio-ecological change (Fischer-Kowalski et al. 2011; Fischer-Kowalski & Haberl 2007). Such more systemic approaches on land use have are much related to so-called 'landscape approaches' or 'carbon leakage' studies, focusing on how interventions in one part of the landscape may lead to spillovers and unexpected changes in other parts of the same landscape (Hunsberger et al. 2015; Barker et al. 2007).

From a complex socio-ecological system perspective, the central implication for studying transitions from shifting to alternative systems is that a change in one system component, such as a stop in shifting agriculture in one land use system, needs to be expected to come along with changes in other system compartments, such as changes in related land use and livelihood systems, over the long-term, and over larger spatial scales. Changes in TEC of rather small land plots need therefore to be tracked to changes in carbon stocks and GHG flows of the larger system in which they are embedded, as schematically illustrated in Figure 1. From that view, TEC values for a given land area provide insights on one relevant variable (Figure 1: a), but are unable to track the broader changes happening in other components. The problem with focusing only on a part of the whole, is not only that the obtained picture may be incomplete, but rather that the obtained picture of the part can be even contrary to the dynamics of the whole (Giampietro 2003)[3].

[3] A popular example of how different system representations yield different conclusions on its identity is the Indian parable of the elephant and the blind men touching different parts of it. The first blind man, touching the trunk, says it's a big snake. The second blind man touching the food says it's a trunk of a tree. The third blind man, touching his ear, says it is a big piece of leather. The parable evokes that someone cannot understand the whole through only looking at some parts of the whole.

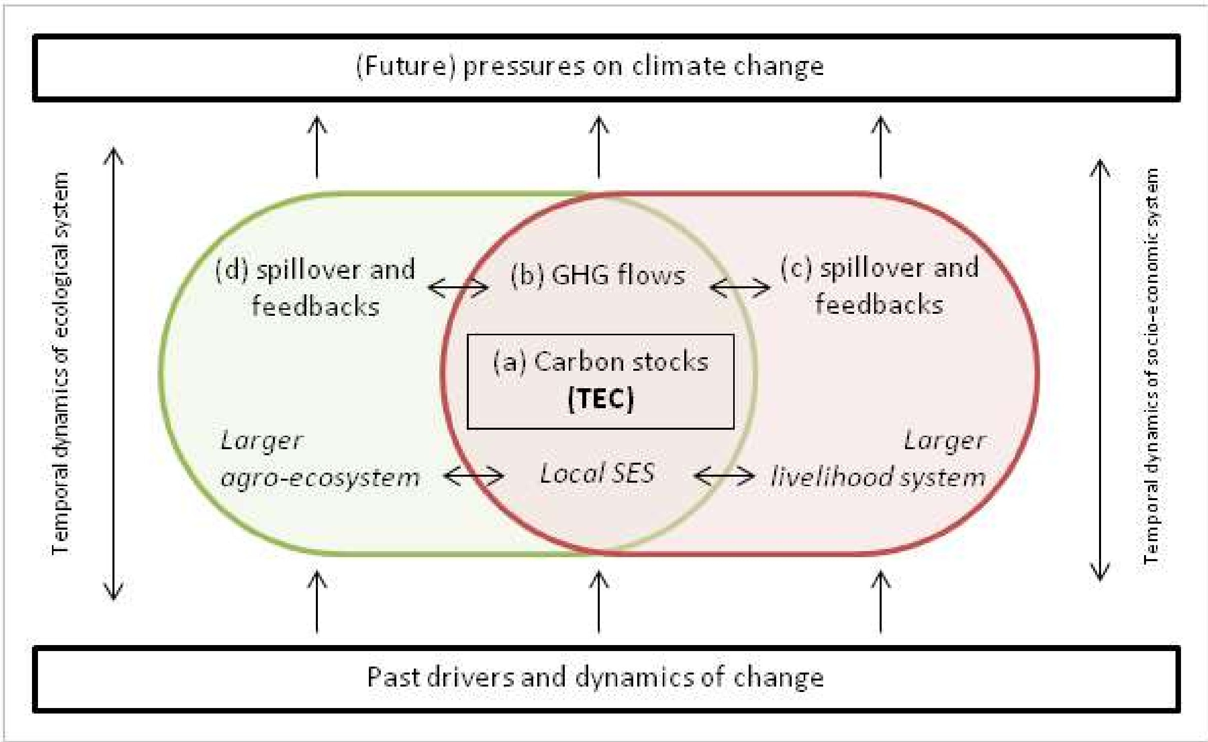

Figure 1: Carbon stocks and GHG emissions of shifting systems and alternatives, understood as local socio-ecological systems embedded in the larger ecological and socio-economic dynamics. SES = Socio-ecological system. GHG = Greenhouse gases. Broadly adapted from (Erb 2012; Fischer-Kowalski 1997).

Take for example the case of Austria, a country whose forest carbon dynamics are particularly well studied over the last centuries (Erb et al. 2008; Erb et al. 2013). After a period of deforestation due to pre-industrial agricultural expansion, forest regrowth occurred during the early 19th century as part of a forest transition known from many other industrialized countries (Mather 1992; Rudel et al. 2005). Forest regrowth contributed to vast increases in terrestrial carbon stocks at the country level. This was however intrinsically linked to broader socio-ecological changes, namely agricultural industrialization, spatial differentiation and the development of new industries, which came along with a massive increase of fossil energy use, leading over the long-term to a net release of carbon to the atmosphere. While forest carbon stocks have increased notably in Austria, GHG flows from associated system changes have increased even more due to a transition from an agrarian to an industrial mode of subsistence (Krausmann 2006; Erb et al. 2008). Austria is therefore an illustrative case, showing that a broader picture than a single focus on terrestrial carbon stocks for a given time and area is needed, if one wants to understand the long-term climate change pressures resulting from certain trajectories of socio-ecological change.

For the study of climate pressures from shifting cultivation and its alternatives, three implications can be derived from this approach. Firstly, and more obviously, a focus on *carbon stocks* as a proxy is not sufficient but also detailed changes in *GHG flows* beyond forest released and sequestered carbon need to be considered. While this is common for national GHG inventories, at the local level, this means accounting for trace gases from slash-and-burn, permanent agriculture, landscape infrastructure changes, new livestock, new labor practices, fertilizer application, manure management and so on. This is not a straightforward task due to many site-specific ecological process and complex system boundaries that may span over large areas and several decades for the case of shifting agriculture[4]. Only few detailed studies, such as one on Vietnam from Leisz et al. (2007) are available on this. But moreover, it implies also to understand how the changing land use system interacts structurally with other socio-economic sectors, such as through associated GHG rucksacks of upstream (e.g. production and transport of agrochemicals, machinery, and other inputs) and downstream (e.g. transportation, packaging and retail of final products) requirements. Section 3.1 provides a detailed discussion on this as well as some examples of why this is relevant to consider.

Secondly, changes in land use systems are ultimately coupled with changes in associated livelihood systems (Figure 1: c). No matter if shifting agriculture is an integral or partial livelihood activity, transitioning away from it will entail a reconfiguration of peoples' livelihood profiles, which may relate to subsequent engagement in other rural and non-rural sectors, seasonal or permanent rural-urban migration, and the like (van Vliet et al. 2012). Livelihoods are commonly referred to as the set of assets and activities that a person or household has at its disposal to gain and sustain a living (Ellis 1998; Scoones 1998). They can also be viewed in terms of their production and consumption activities, whereas both sets of activities are intrinsically linked to different sets of GHG rucksacks. To my knowledge, there is no single study available that considers the climate pressures resulting from livelihood changes beyond the impacts of agricultural practices. Section 3.2 will address some considerations on this issue.

Finally, also a long-term perspective is needed, as the dynamics of land use and livelihood systems and its implications for carbon stocks and GHG flows unfold only over time, as seen with the example of Austria's forests. Moreover, such a perspective needs to be sensitive to different temporal ecological and socio-economic dynamics (Figure 1: c,d). For instance, carbon sequestration potentials from regrowth areas decrease over time when forests reach their natural carbon stock limits, whereas direct and indirect GHG flows that follow the adoption of permanent agricultural practices or new livelihood profiles may be enduring or even increasing over time. This aspect needs to be considered when looking at both land use and livelihood system changes, as discussed in the next two subsections.

3.1 GHG emissions from changes and feedback loops within local and wider land use systems

This subsection turns now to describe how new sources of GHG flows can result from changes and feedback loops within the local but also wider land use system and related socio-economic sectors. Rather than comparing different system types, the approach taken here is to trace conceptually how GHG emissions tend to change along gradual transitions in shifting cultivation occurring in different dimensions: from shifting to permanent agriculture; from making use of renewable to industrialized

[4] The estimation of GHG emissions from shifting cultivation and its alternative is complicated due to many site-specific ecological process, as well as system boundaries that span over large areas and several decades (Tinker et al. 1996). For example, forest GHG and carbon stock estimates change whether dynamic or linear growth models are assumed (Leisz et al. 2007), as well as in relation to the amount of charcoal formation, removing carbon from the carbon cycle (Fearnside 2000). GHG emissions depend further on the degree of vegetation burned, burning efficiency, assumptions regarding degree of flaming (emitting largely $C0_2$) and smoldering (emitting substantial trace gases), soil heating and related impacts on soil gas releases, and the like (Fearnside 2000). Similar, alternatives, such as permanent agriculture, usually have many new site-specific sources of GHG flows, such as for example from new livestock, flooded paddy rice fields, fertilizer applications, or new machineries (Leisz et al. 2007).

agro-inputs; and finally from agricultural livelihoods to the increasing engagement with non-rural livelihood activities. All different types of mixtures between these gradients can be imagined and current promotions of alternatives tend to incentivize such transitions. The rationale underlying the promotion of such alternatives is basically a land-sparing argument (Matson & Vitousek 2006): that smaller land requirements associated to the practice of more permanent forms of agriculture and forestry would allow for forest regrowth on former fallow areas and hence recovery of TEC stocks (Palm et al. 2004). While studies on the emission reduction potential of land sparing generally include a detailed assessment of GHG rucksacks associated to changes in agricultural practices (Lamb et al. 2016), it is surprising how most studies on emissions of shifting agriculture and alternatives compare them predominantly based on changes in TEC stocks.

Changes in the local land use systems caused by transitions away from shifting agriculture manifest in alterations of vegetation cover and related carbon stocks, but also in changes in landscape infrastructure, fertilization practices, labor deployment patterns, livestock, and ultimately changes in the orientation of production; i.e., from subsistence to market crops. Plot-based terrestrial carbon stocks assessments, commonly used as proxy to assess climate change pressures, are particularly relevant to understand pressures from changes in vegetation cover, yet they are unable to track any of the other basic dimensions of change, listed in Table 1.

Table 1: The adequacy of TEC indicators to track basic dimensions of change in land use systems, caused by transitions away from shifting agriculture. For references, see table.

Dimensions of change	CC relevant changes within local land use system	GHG emissions from changes in local land use system	GHG emissions from feedbacks in broader socio-ecological system	Temporal dynamics	Adequacy of plot-based TEC indicator
a) Vegetation cover	Forest regrowth on some areas reserved for land sparing. Changes in vegetation cover on other land areas now used by former shifting cultivators for new livelihood activities.	Changes in terrestrial carbon stocks cause carbon emissions or sequestration. Type of transition strongly matters: i.e. from long vs. short fallow to tree crops vs. annual crops. **Effects on carbon emissions can be positive or negative** (Ziegler et al. 2012). Carbon sequestration limited to regrowth period: high during first decades, then slows drastically down (Bruun et al. 2009).	Potential leakage: forced stop of shifting cultivation, or displaced shifting cultivators, may cause carbon emissions elsewhere from forest encroachment to establish new livelihoods in other areas (Angelsen & Wertz-Kanounnikoff 2008).	<u>Immediate:</u> Forest carbon stock losses <u>Medium:</u> Regrowth of former fallow areas, limited in time. <u>Long-term:</u> Potential leakage and forest encroachment elsewhere.	YES for local land use system. NO for broader socio-ecological system
b) Landscape infrastructure	Changes in the landscape infrastructure from temporary to permanent fields, sometimes spatial differentiation from upland to lowland agriculture. New GHG flows from new cropping systems. Example: Methane (CH4) from flooded rice paddies.	Changes in landscape infrastructure can produce new GHG sources. Example: Methane emissions from rice paddies, depending on characteristics: i.e. flooding/dry and amount of applied plant residuals. Low in traditional upland shifting cultivation. Up to 200kg of CH4 (without organic amendments) in continuously flooded rice systems: CH4 from 4 ha correspond to a **GWP of 16,800 kg of CO2/yr**. **This equals emissions from around 130,000 km/yr of driving a European passenger car***.	(i) Potential spatial differentiation of agricultural production in lowland areas. Increased decoupling of production and consumption areas. Increased distance transports. (ii) Higher production capacity may trigger higher consumption patterns due to increased resource available. This often leads to further land use intensification (Erb 2012; Scheidel & Krausmann 2011).	<u>Immediate:</u> On-site trace gases, e.g. from rice paddies. <u>Long-term:</u> Spatial differentiation; consumption-production feedback loops; further land use intensification within broader system	NO
c) Fertilization practices	Fertilization through burning biomass replaced by synthetic and/or organic fertilizers. Intensification necessary to increase area-efficiency for land sparing. Both synthetic and organic fertilizers have new GHG sources.	(i) Synthetic fertilizers: New trace gases from application, i.e. N20. Example: Applying 100 kg of N fertilizer/ha/yr to 4 ha of paddy fields produces ca. 5 kg of N20, equivalent to a **GWP of 1,550 kg CO2/yr (corresponds to ca. 12,000km/yr*).** (ii) Organic fertilizers: New trace gases from application, i.e. N2O. Example: 3 cattle and 3 pigs produce on average 168kg of N excretion, corresponding to 2.1 kg of generated N20 emissions, or a **GWP of 650kg of CO2/yr (corresponds to 5,000km/yr*).**	Upstream fertilizer production and transport add significant amounts of GWP. Snyder et al. (2009) estimates around 4kg of CO_2/1kg of N fertilizer, whereas Leisz et. al (2007), accounting also for CH_4 and N_2O rucksacks estimates a GWP of 7.6 kg of CO_2 equivalents/1kg of supplied mineral N fertilizer. Example: 4 ha with 100kg of N/ha entail **upstream GWP between 1,600 to more than 3,000 kg of CO2 equivalents/yr (corresponds to 12,000 – 23,000km/yr*).**	<u>Immediate:</u> On-site trace gases and upstream GHG rucksacks <u>Long-term:</u> Growing dependence on industrial fertilizers.	NO

c) Labor deployment	Activities change and new requirements for field preparation, harvest, transport of produce, etc emerge. Labor productivity supported by draught animals and/or agricultural machinery (small tractors, etc.).	(i) New draught animals emit new trace gases. Example: Maintenance of 3 non-dairy cattle produces 132kg CH_4/yr, through enteric fermentation, having a **GWP of 2,772 kg of CO2 (corresponds to ca. 21,000km/yr *).** (ii) New machinery has new (fossil) carbon rucksacks. In terms of energy consumption and GWP, two-wheel tractors perform worse than draught animals (Spugnoli & Dainelli 2013; see also Cerutti et al. 2014)	Upstream: New GHG emissions from production and transport of machinery (Spugnoli & Dainelli 2013; see also Cerutti et al. 2014)	<u>Immediate:</u> GHG emissions from machinery and draught animals. <u>Long-term:</u> growing dependence on external inputs (fossil fuels, machinery)	NO
d) Livestock	New livestock raising and maintenance for emerging labor requirements, changes in food production, or market sale.	New livestock entails substantial trace gas emissions through enteric fermentation (CH_4), manure management and application (N_2O). See above examples on GHG emissions from draught animals and manure use. In addition, also buffalos, dairy cattle, sheeps and poultry need to be considered (enteric fermentation, manure management).	Downstream GHG emissions from transport, packaging, retail if livestock products are sold on (distant) markets.	<u>Immediate:</u> GHG emissions from livestock raising and maintenance. <u>Long-term:</u> growing meet consumption; dependence on (distant) markets and transport	NO
e) Changes from food to market crop production	Food needs to be imported to local system. Market crops need to be exported from local system.	Food imports have climate rucksacks in form of embodied area and embodied GHG from production elsewhere, retailing and transport. Embodied area needs to be subtracted from area spared for forest regrowth (indirect leakage). GHG rucksacks and embodied area depend on origin and type of food. Exported crops and products have GHG rucksacks from transport, packaging retailing, etc. Life Cycle Assessments (LCA) (Brentrup et al. 2004; Dalgaard et al. 2008) or MuSIASEM analyses (Giampietro & Mayumi 2009) applied to agricultural products may help to understand better energy and GHG implications.		<u>Immediate</u>: GHG rucksacks of imports to and exports from farming system <u>Long-term:</u> Increasing dependence on distantly produced food/crops.	NO

Note: CC=Climate change; SES=Socio-ecological system; TEC=Total Ecosystem Carbon; GWP=Global Warming Potential, expressed in CO2 equivalents. Example calculations are simple and only for illustrative purposes. They are based on GWP conversion factors of 21 for CH4 and 310 for N2O; and single emissions factors for different agricultural practices, taken from Leisz et al. (2007). For more detailed methods, the reader is referred to IPCC (2006). *Comparison to CO2 emission from driving a passenger car in the European Union (EU) are also only for illustrative purposes and based on the current maximum allowed limit of 130g CO2/km for new cars, referring to the generation of CO2 during its use (and not production) of the car.

For example, in Southeast Asia, where transitions in shifting cultivation are currently taking place (Schmidt-Vogt et al. 2009) and where paddy rice is the single most important food staple crop, the integration of permanent paddy rice plots into livelihood systems represents a change in the landscape infrastructure that comes along with new GHG sources. Methane (CH_4) emissions from rice paddies depend on production characteristics, i.e. flooding/or dry cultivation and the amount of plant residuals. It is low in traditional upland shifting cultivation, but can reach up to 200kg of CH_4/ha in continuously flooded rice systems, not accounting for organic amendments (Leisz et al. 2007). To illustrate this, methane (CH_4) emitted from 4ha of continuously flooded paddies can amount to about 800kg, which corresponds to a GWP of 16,800 kg of CO2. This is equivalent to emissions from driving a passenger car in Europe for more than 130,000 km/yr (see Table 1). In the worst case, these permanent 4 ha could moreover be associated to significant leakage, if they come from previous forest areas cleared by former shifting agricultural who either were displaced or forced to stop traditional shifting agriculture. Plot-based TEC values are obviously unable to cover such processes.

Beyond changes in the landscape infrastructure, the increased area-efficiency of agricultural production has become possible by subsidizing land and labor productivity with additional external inputs. Land productivity is increased through agro-chemicals, i.e. fertilizers and pesticides, which have substantial fossil energy and GHG rucksacks associated to their production, transport and application (Snyder et al. 2009). Labor productivity is boosted by the adoption of either new draught animals, or fossil fuelled machinery, whereas both options have significant fossil energy and GHG rucksacks attached (Table 1). The increased area-efficiency of permanent agricultural systems has generally led to a decreased energy-efficiency through growing use of fossil energy to subsidize land and labor(Arizpe et al. 2011; Giampietro et al. 1999; Pimentel & Pimentel 2008). This in turn has also translated into a decreased fossil-carbon efficiency of agricultural systems, as well aware claimed by transnational agrarian movement la Via Campesina (Martinez-Alier 2011).

Such changes in GHG rucksacks have been partly ignored in studies on shifting agriculture, because in the past there has been a lack of solid empirical data on them and further it was argued that they are by far outweighed by the large potential of carbon sequestration through forest regrowth on previous fallow areas (Palm et al. 2004). But the detail, scale and timeframe with which these GHG emissions are accounted for, matters. Regarding the latter, the capacity of sequestrating carbon from forest regrowth is limited in time due to ecological cycles, being particularly high in the first decades, but then slows rapidly down (Bruun et al. 2009). GHG emissions from newly adopted agricultural practices in turn can be assumed to be maintained, if not increasing over the years. Only one study could be found that empirically assessed a large number of such new sources of GHG flows for different farming system trajectories in Vietnam (Leisz et al. 2007). It concluded that forest regrowth following a stop in shifting agriculture can only outweigh the addition of new GHG gases over the first 20 years after transition. Afterwards, these new agricultural systems turn into net GHG emitters.

Moreover, a transition away from shifting agriculture can be expected to alter the way how (former) shifting cultivators interact with the larger agricultural sector. Within shifting agriculture as a long-fallow integral livelihood system, most production inputs (i.e. labor, land, nutrient flows) and outputs (i.e. generated biomass products) are provided and consumed locally, within a largely closed and renewable carbon and nutrient cycle (Kleinman et al. 1995). Transitions to patterns of permanent area-efficient agriculture come along with an opening of this cycle and related structural dependencies on other sectors. They are created through an increasing need of agro-chemicals, machinery and sometimes also additional off-farm labor, all commonly provided by fossil-fuelled industries and means of (fossil-fuelled) transport. An increasing share of the produced outputs, being either food or cash crops, is generally traded to more distant areas, requiring increased (fossil-fueled) transport, packaging and retail (see Table 1; and Eva et al. 2016 forthcoming book)[5]. Finally, from a socio-ecological perspective, also new feedback loops between production and consumption compartments emerge. Historically, increased agricultural production through intensification has often incentivized increased consumption in other sectors and regions through growing (food) resource supply, usually available at a cheaper price. But growing consumption and steadily increasing demand in turn has often just triggered further land use intensification and expansion (e.g., Scheidel & Krausmann 2011). These more systemic changes occurring at larger spatial scales, are usually not considered in 'land sparing through intensification' debates (Erb 2012).

In summary, a stop in shifting cultivation, fomented by transitions to more permanent and industrialized forms of agriculture, may produce spillover effects and further trigger gradually a transition towards more climate adverse socio-ecological systems in the long-term through a subsequent integration of land and labor into the fossil-fuelled and resource intensive economy (c.f., Fischer-Kowalski et al. 2011; Fischer-Kowalski & Haberl 2007). 'Carbon leakage', defined as the increase of CO2 emissions in one country, caused by mitigation policies in another country, i.e. due to re-allocation of polluting industries (Barker et al. 2007), need to be considered also between economic sectors and through systemic interactions. Such kind of 'systemic or sectoral carbon leakage' can be expected to occur after transitions away from shifting agriculture, and require going beyond assessments of TEC. How can such systemic long-term changes and socio-ecological trajectories be considered in studies that address the climate impacts of shifting agriculture? Tracking such questions, conceptually as well as empirically, is not straightforward. But they are fundamental to avoid that current climate change mitigation policies targeting transitions away from shifting agriculture do not just incentivize to repeat a historic pathway of industrialization of land use that has become part of the problem of human-driven climate change in the first place.

3.2 New climate pressures from changes and feedback loops within livelihood systems

Such land use transitions do not happen in a social vacuum, but are associated to local and immediate changes in livelihood systems, as well as to long-term and broader changes in social systems in which they are embedded. With a systemic change from integral shifting agriculture towards more partial shifting cultivation and/or permanent agriculture, both production and consumption activities of livelihoods can be expected to decouple increasingly from the purely agricultural domain. Blurring boundaries between the rural and the urban are related to the fact that few rural livelihoods remain nowadays purely agricultural, but rather new ruralities have emerged, based on diversified livelihoods profiles that engage with other socio-economic sectors through new labor markets, migration, remittances, NGOs, as well as emerging needs, wants and (material) lifestyle aspirations (Hecht 2010; Ravera et al. 2014; Kay 2008; Scoones 1998).

On the production side of rural livelihoods, agriculture, although being central, remains seldom the only array of productive activities assuring life and income and also shifting cultivators engage increasingly in productive activities outside the agricultural sector (Mertz et al. 2009; Cramb

[5] Shifting to other renewable energy sources in order to avoid repetition of the fossil-fuelled path is only partly a realistic option. Small-scale farming technology (such as small tractors, transport) is currently completely depended on fossil-energy, and there is no sign of transitioning towards renewable energy sources for small-scale machinery in so-called 'developing countries'. Moreover, an increasing use of renewable energy just shifts the problem elsewhere, as renewable energy generation requires large areal requirements to capture renewable energy flows (Scheidel & Sorman 2012). Consider for example the large loss of forests that were replaced by large dam reservoirs in Asia to produce renewable hydro-electricity.

et al. 2009). The higher land and labor productivity – which would be required to spare out areas for forest regrowth - the more labor is available to engage in other economic sectors. Many of the new jobs, ranging from small-scale petty trades and services provision (e.g. motor-taxi drivers, etc.) to employment in larger construction sites, agribusiness, garment factories, extractive industries and the like, are however embedded within the industrial, fossil-fuelled economy that actively drives fossil carbon emissions. All these new productive activities may be seasonal for some, but may also become full-time activities for others, over the long-term. Hence, largely environmental incomes that were traditionally obtained through livelihoods operating in a largely closed and renewable carbon cycle are subsequently replaced or supplemented by incomes through industries heavily depended on fossil fuels and emissions. A shift to more permanent agriculture can thus be expected to go together with a subsequent integration of people's productive activities into the currently fossil-fuelled economy, unfolding progressively over time.

Incomes received through REDD+ schemes, financed by carbon offsets traded on a global carbon market, do not change these dynamics. In fact, they replace locally produced environmental incomes by incomes derived from global, fossil-carbon emissions dependent sectors. From this view, REDD+ may just further inscribe globally and fossil-fuel produced incomes into local people's life. Furthermore, in addition to receiving REDD+ payments, communities will likely engage also in further productive and new consumption activities, some of them possible thanks to these new incomes. Such new livelihood activities, some outlined above, have also new GHG rucksacks. Finally, REDD+ payments are also limited to the amount of carbon that could be captured from fallow regrowth. In this view, it does not only provide temporary carbon storage, but also only temporary (fossil-fuelled) incomes. It remains unclear what will happen after a forest has recovered and payments may stop. What will happen then with people's livelihood and forest land, which have then become depended on payments from the polluting industry?

Also on the consumption/reproduction side, related changes are expected to affect GHG sources. Changes away from shifting agriculture have been reported to be accompanied by rising income (van Vliet et al. 2012). Rising incomes, in turn, are generally correlated with a rise in GHG rucksacks and carbon footprints, due to changes in people's consumption patterns (Hertwich & Peters 2009). These may include changing dietary patterns (e.g. increased meat consumption), new shelter needs (e.g. construction of bigger, permanent houses), new private mobility footprints (e.g. motorbikes), new manufactured goods (e.g. TVs, clothes, motorbikes and related GHG rucksacks from production, packaging, transportation, operation and disposal), and an increasing dependence on the service sector (e.g. education, governmental services, etc.), which in turn depends on surplus produced elsewhere. Further empirical research would be required to really understand the scale of these new climate pressures arising from changes in livelihood profiles, which do not only depend on emerging consumption patterns, but also on the characteristics of underlying supply chains. Currently, the immediate livelihood impacts upon communities forced to change from shifting to permanent agriculture remain too poorly understood to make any generalizations (van Vliet et al. 2012). Yet taking integral shifting agriculture as baseline, a reasonable trend to be expected is that also consumption activities will increasingly decouple from a largely local, closed and renewable carbon cycle and become more and more part of the climate adverse global economy.

In any scenario, all these new production and consumption activities will have minimal GHG rucksacks during the first years of transitions, when compared with high-income, urban lifestyle profiles. So, the point here is not to blame small-farmers or former shifting agricultures, but rather that these newly produced GHG rucksacks associated to changing livelihood systems need to be considered, when trying to understand the GHG pressures resulting from transitions away from shifting cultivation. The question remains of how these livelihoods will develop in the long-term over a few generations, during which they may engage permanently in the industrial and service sector. Will they follow a socio-ecological transition of industrialization observed in countries of the North (Fischer-Kowalski & Haberl 2007; Fischer-Kowalski et al. 2011), characterized by a subsequent integration of land and people into a fossil fuelled economy? This needs to be well understood to avoid that policies aiming to achieve reduction of emission do not foster a *de facto* introduction of new fossil-carbon emitters into the global economy.

4 The politics of carbon accounting of shifting agriculture

Current carbon accounting practices, i.e. the predominant reliance on TEC values, focusing on shifting agriculture and its alternatives are just too narrow to understand the broader consequences of land use and livelihood changes for climate change over the long term. How useful are such data then and what are the consequences of employing them in policy?

A profound knowledge on TEC ranges for different vegetation cover types is definitely key to a sound understanding of GHG dynamics of different land use systems. However, a single and predominant focus one TEC is insufficient to inform policies that would take effect on the lives and livelihoods of thousands of people. As mentioned above, the central problem with using insufficient or too reductionist indicators is not just that they provide an incomplete picture of a part of the system, but rather that this picture representing the dynamics of one part of the system might be contrary to the dynamics of the whole (Giampietro 2003). The example of Austria's' forest carbon stocks changes shows well how their recovery was in fact related to an overall and substantial increase of GHG emissions (Erb et al. 2008). For the case of shifting agriculture, it is not clear how far a transition, that in spite of helping to recover local forest carbon stocks, may just incentivize a socio-ecological transition that in the long term contributes to more GHG emissions than those sequestered by the recovered forest. Clear-cut numbers such as TEC/ha values are indeed handy to make comparisons, but in this context a deeper understanding of the broader processes and consequences of transitions away from shifting cultivation is needed. Methodologically, this requires having much more in-depth case studies that address both qualitative as well as quantitative aspects of the dynamics of the whole, instead of focusing only on the numeric values of some parts of the system.

Beyond methodological concerns, the predominant focus on carbon stock values has also political implications. As Edelmann (2013) states, *"every dataset has an implicit epistemology behind it. Different kinds of datasets are created for different administrative, bureaucratic, political or other purposes and always contain systematic biases"*. The context in which the first studies on climate change pressures from shifting agriculture have emerged, i.e. through the Alternatives to Slash and Burn (ASB) programme, did certainly not start from a neutral viewpoint, but literally were based on the premise that the search for alternatives should be a 'global imperative' (Brady 1996). Climate concerns over shifting agriculture have in fact reinscribed pre-existing discriminations of shifting agriculture and translated sometimes into powerful political forces, defining who is legitimate to access and use forest land (Scheidel & Work 2016; Erni 2009; Fox 2000). In that context, particularly short-term views on forest carbon stocks can undermine shifting cultivators' access to forests, when considering only potential sequestration gains from a forced stop in shifting agriculture, but not the wider consequences on GHG emissions resulting from changing land and livelihood system as described above.

Finally, the predominant focus on such single values runs the danger of reducing debates on desired socio-environmental futures to managerial discussions of how to achieve certain technical values. Ecological economics for instance, had argued for decades that mainstream economic practices to assess environmental problems through mono-value approaches, i.e., monetary cost-benefits analysis, is too reductionist to account for non-commensurable social and ecological values of the environment. Instead, many ecological economists argued for a plurality of valuation languages, such as through multi-criteria evaluation (Martinez-Alier et al. 1998). Now, a predominance of monofunctional landscape assessments is reappearing, although coming now from the environmental disciplines. It manifests increasingly in reductionist carbon stock values per ha of a landscape (c.f., Corbera 2012), while tending to overlook the vast biological richness and cultural values that shifting cultivation sustains (e.g., Padoch & Pinedo-Vasquez 2010). On the ground, such a predominant focus on technical values can further obscure a nuanced analysis of the ultimate causes and drivers of deforestation, as could be derived from a political ecology or political economy perspective (Pollini 2009). They further haved started to pave the way for green grabs, in which optimisation of environmental values (e.g., TEC values) rules out other livelihood and land concerns (Fairhead et al. 2012; Scheidel & Work 2016 forthcoming). A predominant focus on carbon stock values runs therfore danger in shifting many policy debates towards rather technical discussions on how to meet these measurable values, while at the same time moving away from just and democratic decision-making regarding which socio-environmental futures are desirable and viable to be pursued (Ariza-Montobbio & Farrell 2012). Stepping back from reductionist assessment is therefore crucial.

5 Conclusions

Technical discussions over the amount of carbon stored in forests and agricultural landscapes have become increasingly prominent within land use policy. In that context, shifting cultivation has been increasingly assessed in terms of how it performs in terms of carbon stocks in relation to other land use alternatives. In this article, I have argued that the currently predominant focus on accounting landscape carbon stocks on a plot-based scale does however not serve well as proxy of comparison between different land use and livelihood systems, as it represents only a single snapshot of a comparatively small land area, which however is embedded into the larger spatial and temporal dynamics of complex socio-ecological systems. The problem with such 'snapshot indicators' is however that the provided picture of parts of the whole is not just incomplete, but in the worst case the obtained picture can be even contrary to the dynamics of the whole.

This requires methodological reflections on the usefulness of carbon stock values in absence of a deeper understanding of the broader consequences of land use and livelihood changes over the long term, but it has also political implications. Regarding the effectiveness of climate change concerned policies, too little is known to support policies that would incentivize a transition away from shifting cultivation. In some scenarios they could be even counterproductive, by triggering a transition in which people and land are increasingly integrated into a fossil-fuelled and resource intensive economy, whereas the benefits of carbon sequestration are limited to the area and period of fallow regrowth. Instead of a reduction of GHG emissions, such contentious policies would in fact foster the introduction of new GHG emitters into the global economy.

Shifting cultivators have faced historically persistent discrimination and current concerns over climate change have renewed such controversial debates in many national policies. In this context, carbon stock values have become more than a mere technical value, but sometimes have turned also into powerful political tools that define who is legitimate to use and access forests in certain ways. The ever growing importance of technical carbon stocks values in current sustainability and land use policies is therefore not only of methodological concern, but also runs the danger to increasingly substitute democratic decision-making processes about desired socio-environmental futures by rather technical discussions on how to achieve certain carbon values that do not even represent a well understanding of the situation. Use of such values in policy needs therefore to be rooted within a clear understanding of overall system dynamics, as well as recognition of how they relate to local desirability, legitimacy, conditions and needs.

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