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Land restoration in food security programmes: synergies with climate change mitigation

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ABSTRACT
Food-insecure households in many countries depend on international aid to alleviate acute shocks and chronic shortages. Some food security programmes (including Ethiopia's Productive Safety Net Program–PSNP – which provides a case study for this article) have integrated aid in exchange for labour on public works to reduce long-term dependence by investing in the productive capacity and resilience of communities. Using this approach, Ethiopia has embarked upon an ambitious national programme of land restoration and sustainable land management. Although the intent was to reduce poverty, here we show that an unintended co-benefit is the climate-change mitigation from reduced greenhouse gas (GHG) emissions and increased landscape carbon stocks. The article first shows that the total reduction in net GHG emissions from PSNP's land management at the national scale is estimated at 3.4 million Mg $CO_2e\ y^{-1}$ – approximately 1.5% of the emissions reductions in Ethiopia's Nationally Determined Contribution for the Paris Agreement. The article then explores some of the opportunities and constraints to scaling up of this impact.

Key policy insights

- Food security programmes (FSPs) can contribute to climate change mitigation by creating a vehicle for investment in land and ecosystem restoration.
- Maximizing mitigation, while enhancing but not compromising food security, requires that climate projections, and mitigation and adaptation responses should be mainstreamed into planning and implementation of FSPs at all levels.
- Cross-cutting oversight is required to integrate land restoration, climate policy, food security and disaster risk management into a coherent policy framework.
- Institutional barriers to optimal implementation should be addressed, such as incentive mechanisms that reward effort rather than results, and lack of centralized monitoring and evaluation of impacts on the physical environment.
- Project implementation can often be improved by adopting best management practices, such as using productive living livestock barriers where possible, and increasing the integration of agroforestry and non-timber forest products into landscape regeneration.

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1. Introduction

In December 2015, the 21st Conference of the Parties (COP 21) to the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Paris Agreement, in which governments agreed to restrict 'the increase in the global average temperature to well below 2°C above pre-industrial levels' (Rogelj et al., 2016; UN, 2016).

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However, at current global emission rates, the budget to keep warming below 2°C will be exceeded within approximately two decades (IPCC, 2014a). Accordingly, most scenarios that meet this target assume extensive removal of CO_2 from the atmosphere to recover from an overshoot of CO_2 emissions and to compensate for residual emissions. Thus, CO_2 removal by sequestering carbon in soils and trees is likely to be an essential element of any mitigation scenario that achieves safe climate stabilization (Griscom et al., 2017; Smith, 2016).

Some of the world's largest food security programmes (FSPs) include public works programmes focussed on restoring degraded land. Such land restoration is expected – over the long term – to contribute to increased food security, in addition to the direct cash or in-kind benefits of these programmes. The climate mitigation co-benefits of such programmes, however, remain under-studied. Examples of FSPs that include such land restoration works include Ethiopia's Productive Safety Net Programme (PSNP) and India's Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), which can provide useful learning opportunities about both their potential and possible pitfalls. In this study, Ethiopia's FSP provides a case study to quantify the climate change mitigation impacts that could be achieved through this approach.

1.1. Tackling land degradation in Ethiopia's FSP

Land degradation – which can be defined as the long-term loss or reduction of ecosystem services including provisioning services such as crop production (Safriel, 2007; Safriel et al., 2006) – is a global problem, adversely affecting the livelihoods and food security of billions of people. It has been estimated that the annual costs of land degradation are about US$231 billion per year, of which approximately half are due to losses of local provisioning services from reduced productive capacity and half due to the wider societal impacts of external ecosystem services (particularly the impact of declining carbon stocks in soils and biomass on global climate change via the associated CO_2 emissions) (Nkonya et al., 2016). Thus, the global community bears a substantial fraction of the cost of land degradation, and is accordingly a beneficiary of efforts to address this problem.

Ethiopia has suffered recurrent drought and food crises for centuries (Béné, Devereux, & Sabates-Wheeler, 2012; Pankhurst, 1989). Responses to food insecurity were historically dominated by emergency food aid (Béné et al., 2012; Wiseman, Domelen, & Coll-Black, 2010), with between 5 and 14 million Ethiopian food aid beneficiaries annually between 1998 and 2005 (Béné et al., 2012; Devereux, Sabates-Wheeler, Tefera, & Taye, 2006). Concerns about the capacity of emergency aid to alleviate chronic poverty led to a consensus between the Ethiopian Government and its international development partners on the need to reform the emergency food aid system in favour of a safety net system that also builds infrastructure and natural capital (Béné et al., 2012; Wiseman et al., 2010). Therefore, Ethiopia launched the PSNP in 2005 to respond to the needs of food-insecure households while creating productive investments that promote rural economic growth and environmental rehabilitation (Béné et al., 2012; Wiseman et al., 2010; World Bank, 2013). A fundamental strategy adopted by the PSNP to address these objectives is the linking of food and cash transfers to vulnerable households with provision of labour on public works. These public works focus on building social infrastructures such as roads, schools and clinics, and also – the main topic of this article – on rehabilitation of degraded land to enhance societal and ecosystem resilience (Wiseman et al., 2010; World Bank, 2013).

Within this context, Ethiopia's PSNP has conducted land management interventions on approximately 600,000 ha that could also have the potential to reduce greenhouse gas (GHG) emissions and sequester carbon in biomass and soils. These interventions include soil and water conservation (SWC) measures, including terracing, embankments, gully check dams, water-infiltration trenches, wells and ponds, irrigation and drainage. There are also improved cropping practices, including increased use of manure and compost, improved crop varieties, diversified cropping systems, multi-purpose leguminous cover crops and multi-strata agroforestry systems that can protect farmlands while providing additional food and fodder (Berhane et al., 2011; Desta, Carucci, Wendem-Agenehu, & Abebe, 2005; Wiseman et al., 2010). Other sustainable land management (SLM) practices include degraded land rehabilitation and marginal-land reclamation measures, such as area enclosures[1] (AEs) from which livestock are excluded, natural regeneration of indigenous grass, shrub and tree species, and establishment of wood lots and forests.

Ethiopia's PSNP has been credited with (i) reducing soil erosion and aquatic sediment loading; (ii) increasing woody biomass and forage production; (iii) increasing water availability and quality; (iv) increasing ground water recharge and improved downstream base flow of streams; (v) increasing soil carbon storage; (vi) increasing biodiversity, (vii) enhancing livelihoods and access to social services; and (viii) increasing Ethiopia's gross domestic product by about 1% by stimulating both production and demand (Berhane et al., 2011; Béné et al., 2012; Filipski et al., 2016; Tongul & Hobson, 2013; Wiseman et al., 2010; World Bank, 2013). Despite being widely credited with these beneficial impacts, it has also been observed that in some areas diversion of labour into public works by PSNP may lead to reduced investment in SLM on smallholders' own land (Adimassu & Kessler, 2015). However, all of these studies are based on limited spatial and temporal data. This deficiency of inter-annual data at the national scale leaves high uncertainty in the overall impacts of PSNP. The capacity of PSNP to reduce and offset GHG emissions, which has not previously been rigorously quantified, forms the focus of this investigation, in which we present the most comprehensive assessment to-date of the climate impact of PSNP's land-management public works.

2. Methods

2.1. Description of the study area

Ethiopia is located in the Horn of Africa, extending between latitudes 3.4 and 15°N and elevations from 125 m below to 4533 m above mean sea level. Given this wide geographic extent, Ethiopia contains a wide range of agro-ecological zones. Mean annual temperature varies from 3.3°C to 32.3°C (23 ± 4, mean ± 1 s.d.), precipitation ranges between 24 and 2081 (785 ± 436) mm yr^{-1}, and potential evapotranspiration ranges between 844 and 2281 (1621 ± 244) mm yr^{-1}. The 28 survey sites of this study were distributed across the 6 Regional States of Ethiopia in which PSNP is active (Tigray, Afar, Amhara, Somali, SNNPR[2] and Oromia), over a range of distinct agro-ecological zones. The total area of the study sites was 7200 ha (approximately 1.2% of the total area of SLM public works conducted by PSNP). Mean annual temperature at the survey locations varied between 15°C and 30°C, annual precipitation varied between 24 and 1520 mm, potential evapotranspiration in the range of 1250–1950 mm and net primary production from 0.8 to 9.1 Mg C ha^{-1} yr^{-1} (Supplementary Figure 1).

2.2. Site selection

The 9 Regional States of Ethiopia are subdivided into a total of 566 districts (woredas). The PSNP currently operates in 319 woredas and is set to expand to 411 woredas by 2020 (MOA, 2014). The 24 woredas included in this survey were apportioned among the Regional States in proportion to population and area, as follows: 5 in Oromia, 5 in SNNPR, 4 in Tigray, 4 in Amhara, 3 in Somali and 3 in Afar. The criteria and process of site selection are described in the online Supplementary Information (Appendix A).

Survey sites in the lowlands of Afar and Somali Regional States were characterized by pastoral and agro-pastoral livelihoods. Livelihoods in the highland sites were dominated by cereal production, with main crops and livestock varying with agro-ecological zone. The survey sites encompassed a broad range of SLM activities including AEs; cut-and-carry forage systems; various agroforestry systems (ranging from alley cropping, through multi-story forest gardens and multi-purpose forage trees, to silvopasture systems); integrated SWC; fertility management with organic fertilizers; rangeland restoration; afforestation, reforestation and avoided deforestation; improved cropping systems (cover crops, improved varieties, irrigation and perennial crops); livelihood and diet diversification; and erosion gully restoration. Tables of the intervention activities and agro-ecological parameters for each of the survey sites are provided in Appendix B of the online Supplementary Information.

2.3. Modelling approach

2.3.1. IPCC tiers

The Intergovernmental Panel on Climate Change (IPCC) categorizes GHG accounting methodologies into three tiers. Tier 1 and 2 methods for GHG accounting in the agriculture, forestry and other land use (AFOLU) sector utilize linear models that multiply activity data by emission factors (EFs). EFs are constant coefficients expressing the quantity of GHGs emitted per unit size of an activity. Tier 1 utilizes standard default values for the EFs. Tier 2 is similar to Tier 1 but with country- or location-specific EFs. Tier 3 describes more complex approaches such as dynamic models. In this project, a hybrid tier 1–tier 2 approach was used, with tier 2 factors applied where (a) tier 1 default values were either non-existent (such as for plant types not included in the IPCC databases); or (b) where tier 1 defaults were inappropriate due to local conditions being significantly different from the model default assumptions (see Supplementary Information, Appendix A for more details on the tier 2 EFs used).

2.3.2. Model platform

The GHG inventory was conducted using the Carbon Benefits Project (CBP) model (available at www.unep.org/cbp_pim), which implements the IPCC methodology with a geospatial front end linked to a spatial database of IPCC parameter values. Activity data and EFs are entered for each of three scenarios: the initial scenario (the situation before onset of project activities); the project scenario (the land use and management implemented by the project over the report period); and the baseline or business as usual (BAU) scenario which characterizes the counterfactual baseline of how the land would be expected to develop in the absence of the project. The CBP model estimates the overall GHG impact of land management activities relative to the BAU scenario. This relative impact is referred to as the 'carbon benefit'.

2.3.3. Accounting period

Although the survey sites varied in age from less than 1 year to over 20 years, a uniform 20-year accounting period was applied to all sites to predict the impact of PSNP activities over a 20-year period, irrespective of the actual start date of implementation at the sites. Observed management impacts on the older sites were used to constrain model assumptions about management impacts on the immature sites, such as the ratio of land apportioned to forage production versus woodland regeneration (Supplementary Information, Appendix A).

2.3.4. Land use and management data collection

Land use and management data were collected during site visits in 2013–2014 (see Appendix A of the online Supplementary Information for more details of the data collection methods).

2.3.5. System boundary

The analysis here includes all land use GHG emissions and sinks occurring within the geographical boundary of the PSNP public works study sites. It also includes (as detailed in the Supplementary Information, Appendix A) GHG emissions from livestock located outside of AEs that are fed on forage produced within the AEs. It excludes GHG impacts of other broader components of the PSNP such as increased fertilizer or livestock holdings driven by increases in household income from social safety net cash and food transfers. It also excludes GHG impacts of PSNP public works on infrastructure not related to land use, such as roads, schools or clinics. Therefore, the results presented here should be interpreted as a measure of the impact of including SLM public works within the PSNP, relative to PSNP without SLM.

2.4. Statistical analyses

All statistical analyses were conducted using the R statistical programming language. Statistical power was calculated using the function 'pwr.t.test' in the R 'pwr' package, with an unbiased estimate of standardized mean difference effect size from the function 'mes' in the package 'compute.es'. *t*-Tests were conducted using R's 't.test' function. All box plots are standard Tukey box plots, showing the population median and interquartile range (IQR), with whiskers extending to the most extreme data points within 1.5 IQR of the 1st and 3rd quartiles.

3. Results

3.1. GHG sources and sinks

GHG fluxes from the land use and land management scenarios are shown in Figure 1, aggregated over all sites and disaggregated by source of emissions. Using a two-sided *t*-test, net GHG fluxes from the sites are significantly different in the PSNP scenario relative to BAU ($p = 2.6 \times 10^{-5}$, statistical power = 0.99).

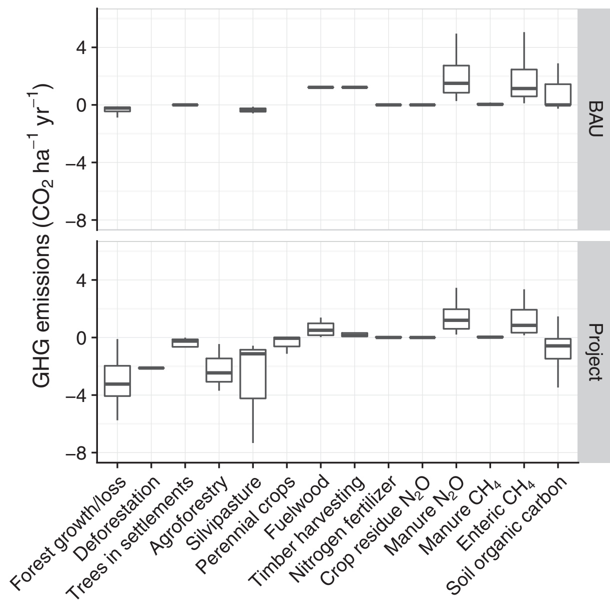

Figure 1. Greenhouse gas fluxes in the business as usual (BAU) and project scenarios aggregated over all the surveyed sites ($n = 28$), and broken down by source of emissions. Fluxes of all sites have been normalized to a per hectare basis, to facilitate comparison between sites, which vary in size.

In all scenarios, the largest source of GHG emissions is enteric methane (CH_4) from ruminant livestock. In aggregate, enteric methane together with other livestock-related GHG emissions (dominantly N_2O emissions from manure) make livestock the primary source of emissions in both the project and BAU scenarios. There is, however, significant variability and not all sites have substantial livestock emissions. Total livestock-related emissions from the public works sites were 42% lower in the project relative to BAU, due to the conversion of pasture into woodland regeneration within large fractions of the AEs.

Emissions related to fertilizer application (both organic and inorganic) are very low in all scenarios, due to the low application rates of fertilizer and organic matter that prevail among Ethiopian smallholder farms in general (Negassa, Gebrekidan, & Friesen, 2005; Nigussie & Kissi, 2012; Spielman, Kelemwork, & Alemu, 2011), and particularly on the degraded lands on which most of the public works are conducted. Furthermore, fertilizer rates do not vary much between scenarios, because PSNP's public works do not target fertilizer use as one of its interventions, meaning that PSNP sites have a negligible impact on fertilizer GHG emissions (although the overall impact of other components of the PSNP programme may affect fertilizer use – see Discussion).

In the initial and BAU scenarios, the only negative emissions sink (i.e. sequestration) is from forest carbon growth in those sites that have a forest component before intervention. In the initial and BAU scenarios, forest carbon growth, where it occurs, is less than 0.35 ± 0.3 Mg CO_2e ha^{-1} yr^{-1}. Due to SWC improvements in the project scenario, biomass sequesters 2.2 ± 1.6 Mg CO_2e ha^{-1} yr^{-1} in agroforestry sites, 2.9 ± 1.6 Mg CO_2e ha^{-1} yr^{-1} in forest sites and 3 ± 3.7 Mg CO_2e ha^{-1} yr^{-1} (mean ± 1 s.d.) in silvopasture sites.

In the BAU scenario, progressive land degradation makes soil carbon loss a significant source of emissions with soils projected to lose a total of 7 ± 1 Mg C ha^{-1} (26 ± 4 Mg CO_2e ha^{-1}) over the project life. Conversely, in the project scenario, soil organic carbon is predicted to sequester 4.9 ± 2.1 Mg C ha^{-1} (18 ± 8 Mg CO_2e ha^{-1}) over the project life (mean ± 1 s.e.).

3.2. Carbon benefits

The carbon benefits (defined as the incremental difference between GHG emissions in the Project and BAU scenarios) are shown in Figure 2. Reduced emissions or sequestrations are shown as positive benefits, whereas negative benefits indicate increased emissions under the project scenario. The mean carbon benefit of all sites was

5.7 Mg CO_2e ha^{-1} yr^{-1}. Biomass and soil organic carbon accounted for 40% and 38% of this total, respectively, followed by livestock which accounted for 22%. PSNP impacts on other GHGs attributable to fertilizer (mineral and organic) and fire provided only a negligible (−0.03 ± 0.07 Mg CO_2e ha^{-1} yr^{-1}) contribution to overall carbon benefits. The substantial variability between sites in each of these flux types gave rise to a wide range in the total benefits with the standard deviation, 6.1 Mg CO_2e ha^{-1} yr^{-1}, being larger than the mean value.

Net carbon benefits in the sites ranged from −19 to +12 Mg CO_2e ha^{-1} yr^{-1}. The causes of this variability included (i) differences in land use; (ii) differences in management and implementation (e.g. types of trees planted, quantity of firewood and timber extraction allowed, and how effectively livestock are excluded from enclosures); and (iii) climatic and soil variation between sites (e.g. more arid zones have lower productivity, and sandy soils mostly store less carbon). Although some of this variability is due to bioclimatic/soil parameters that cannot be controlled, much of it can be accounted for by differences in management and implementation, with activity areas converted to woodland or agroforestry showing highest carbon benefits (Figure 3).

Increasing biomass stocks decreased net GHG emissions at all sites, with two exceptions – both in pastoral areas in Afar Regional State. One such site in Dubya Woreda involved conversion of *Prosopis juliflora* shrubland to irrigated cropland. *P. juliflora* was introduced to the Afar Region in the late 1970s; since then it has established itself as an aggressive weed on 3600 km^2 (particularly along the Awash River Valley), where it forms dense single-species thickets that restrict livestock movement and access to underlying vegetation, and excludes more palatable native vegetation types (Wakie, Evangelista, Jarnevich, & Laituri, 2014). Attempts at *P. juliflora* eradication form a substantial part of PSNP activity in these areas. The other site in which project activities increased net emissions was in Chifra Woreda, where rangeland improvement was conducted by AE for hay production. The resulting increase in fodder production raised the livestock carrying capacity of the land, which in turn led to an increase in livestock emissions that were slightly greater than the accumulation rate of soil organic carbon stocks.

Percentage change in tree cover within the project area accounted for 51% of the variation in net carbon benefits. For every percentage point increase in land under tree cover (including forest, woodland, shrubland and agroforestry), a corresponding decrease in net emissions of 0.12 Mg CO_2e ha^{-1} yr^{-1} was found ($p = 2.2 \times 10^{-5}$, $R^2 = 0.51$).

4. Discussion

The most accurate way to extrapolate carbon benefits from the survey sites to the entire PSNP would be to use a stratified approach using the area of land converted, disaggregated by type of land cover and agro-ecological zone. However, disaggregated statistics at the national scale were not available, and we therefore based the

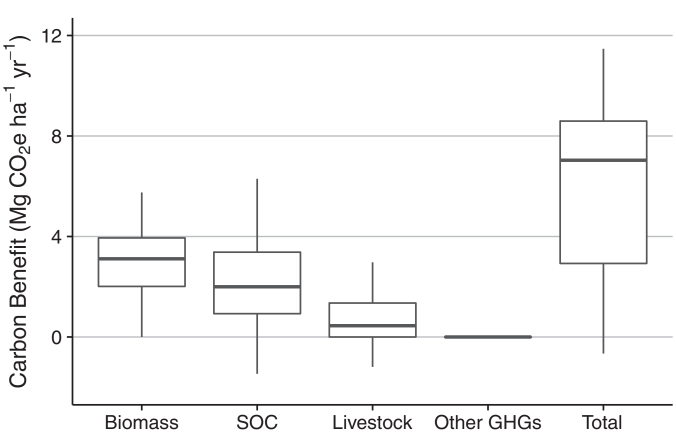

Figure 2. Summary of carbon benefits aggregated over all study sites ($n = 28$). Positive carbon benefits indicate a net reduction in greenhouse-gas emissions. Black dots indicate median values, and boxes show interquartile range. Outliers not shown.
Note: SOC, soil organic carbon; GHG, greenhouse gas.

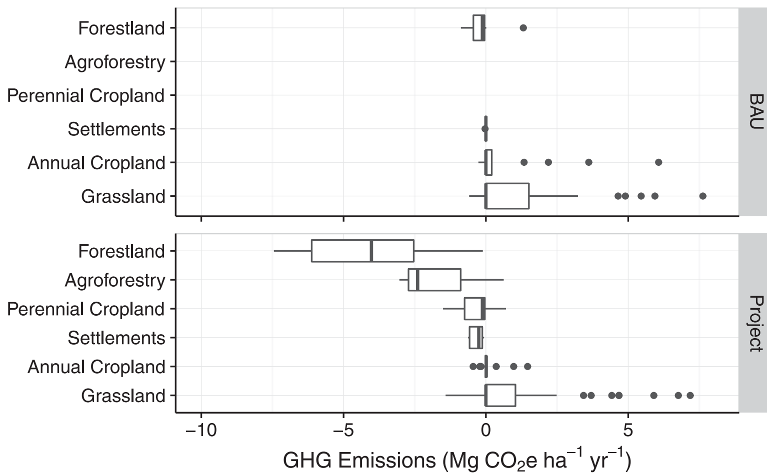

Figure 3. Net greenhouse gas fluxes from study sites, aggregated by land use.
Note: BAU, business as usual; GHG, greenhouse gas.

extrapolation on the most accurate statistic available at the national scale, which was that PSNP has implemented 600,000 ha of AEs. Multiplying the mean carbon benefit of 5.7 ± 1.2 Mg CO_2e ha^{-1} yr^{-1} of the survey sites by this aggregate land area would imply a total carbon benefit of the PSNP's land-management public works of 3.4 ± 0.7 Tg CO_2e yr^{-1} (mean ± 1 s.e.; teragrams CO_2 equivalent; 1 Tg = 1 million tonnes). Note that some caution should be attached to this estimate, because the site selection for our survey was not completely randomized, as the woredas were selected without regard to the needs of a quantitative biophysical survey (see description of site selection in Supplementary Information, Appendix A). Nonetheless, there was some randomization in this procedure, because the selection criteria were related to operational aspects of the socio-economic studies of the CSI project, and as such had no known bias towards woredas with higher- or lower-performing SLM interventions. Notwithstanding the fact that this selection procedure had no bias that we are aware of, it could introduce an additional, but difficult to quantify, level of uncertainty into these estimates. Further uncertainties which are also difficult to quantify may also be introduced by the construction of the BAU scenarios, which as counterfactuals cannot be rigorously measured (Buchholz, Prisley, Marland, Canham, & Sampson, 2014; Hudiburg, Law, Wirth, & Luyssaert, 2011).

Individual countries' pledged contributions towards the Paris agreement goals are specified in their nationally determined contributions (NDCs). Ethiopia's NDC establishes a plan to limit net GHG emissions to 145 Tg CO_2e yr^{-1} in 2030, which it estimates to be a 64% reduction from the 400 Tg CO_2e yr^{-1} expected under BAU. Ethiopia's NDC identifies 220 Tg CO_2e yr^{-1} of climate change mitigation to come from the AFOLU sector (86% of the total abatement potential identified). Thus, the 3.4 Tg CO_2e yr^{-1} mitigation provided by PSNP is equivalent to 1.5% of the quantity assumed in the NDC to be provided within the AFOLU sector, even though the NDC anticipated no expectation of a contribution to come from safety net programmes. Given that PSNP currently encompasses 56% of the woredas in the country, the ecosystem restoration activities conducted within PSNP should be an integral aspect of Ethiopia's land-based climate-change mitigation strategy. The results presented here demonstrate that although PSNP was not designed for this purpose, its public works already contribute to building carbon stocks at a large scale.

How much scaling up of climate change mitigation by PSNP's public works could practically be achieved remains uncertain. Some contribution can be provided by improving management and implementation of individual projects to bring the average carbon benefits closer to the higher levels that were observed in the better-performing survey sites. Although some of this variability is due to bioclimatic/soil parameters that cannot be controlled, much of it can be accounted for by differences in management and implementation, with percentage tree cover alone accounting for 51% of the variability. Thus, the substantial variability between sites indicates potential to increase carbon benefits by improved management and implementation. Observations at the survey sites indicated that implementation often could be improved. For example, AEs are often enforced only by community by-laws with physical barriers either absent or inadequate. Accordingly, evidence of livestock encroachment into AEs was sometimes observed, albeit at much reduced stocking densities compared to areas outside the AE. Furthermore, given that increased tree cover in the landscape corresponds to greater carbon benefits, opportunities to increase it further should be investigated. However, although increased tree cover is clearly beneficial in terms of carbon, soil conservation and ecosystem services, it can reduce the food production capacity of the landscape if it is expanded beyond marginal unproductive lands and the loss of forage is not compensated by an increase in other types of food stuffs. This highlights the need for managing opportunity costs when creating AEs and excluding traditional uses of the land by local communities. The greatest synergy between carbon benefits and food security was on sites with agroforestry, where diet and livelihood diversification were enhanced through introduction of fruit, honey and other non-timber forest products at the same time as carbon stocks were boosted through the increase in tree cover. If sites are to further increase their tree cover without adversely impacting food security, then more widespread adoption of agroforestry at the margins between upland reforestation and cropland on the lower slopes may be required.

Further scaling up beyond that which can be achieved by improved management will require a transition away from the sub-watershed projects by which PSNP is presently characterized, towards jurisdictional approaches that incentivize the sustainable management of landscapes over entire woredas, zones or regional states. Such incentivization could involve a number of possible financial and policy instruments, including Internationally Transferable Mitigation Outcomes (ITMOs) as defined under the Paris Agreement, emerging bilateral and multilateral climate funds such as the Green Climate Fund (GCF) or the current trend of the international donor community to increasingly link transfers to results-based financing (RBF) that demonstrates a climate impact. It should be borne in mind, when considering the climate mitigation potential of upscaling the public works programme in this manner, that the analysis presented here quantifies only the direct GHG impacts of the public works. Increasing the scale of the public works programme would entail an increase in cash and/or in-kind transfers, which could have broader economic impacts on GHG emissions such as leading to an increase in livestock holdings and/or fertilizer use. Some studies have found that cash and food transfers to households result in increased fertilizer use or livestock holdings (Adimassu & Kessler, 2015; Berhane, Gilligan, Hoddinott, Kumar, & Taffesse, 2014), whereas other studies have found no impact on fertilizer or livestock (Andersson, Mekonnen, & Stage, 2011). Impacts of upscaling PSNP on the wider economy, by stimulating both consumption and production and thus increasing GDP, may also have further indirect effects on GHG emissions (Filipski et al., 2016).

It should also be noted that PSNP is only one of the large-scale programmes conducting SLM in Ethiopia. Other programmes include the Oromia Forested Landscape Programme (OFLP) and the Sustainable Land Management Programme (SLMP 2), which also uses a participatory watershed development approach to integrating SLM and SWC with social objectives, but with a geographic focus on more agriculturally productive areas than PSNP (Haregeweyn et al., 2015). The potential for scaling up of public works to provide a more substantial contribution towards Ethiopia's NDC should, therefore, take a coordinated and integrated approach that encompasses all the relevant national programmes. A final issue is the question of how climate change may affect FSPs in the future, and how climate change could affect the mitigation potential that has been estimated in this study. In the IPCC representative concentration pathway RCP8.5 (a scenario of continued high emissions), mean temperatures in East Africa are projected to rise between 4°C and 6°C by 2100 (IPCC, 2014b). Changes in mean precipitation over the same period are less certain, ranging between −10 and +40% (Elshamy, Seierstad, & Sorteberg, 2009; IPCC, 2014b), with a wide range of spatial variability in Ethiopia (Conway & Schipper, 2011). It is unclear whether the greater frequency of droughts over the last 30 years will persist (Lyon 2014), whereas increases in heavy precipitation have been projected with high certainty (Kundzewicz et al., 2014; Vizy & Cook, 2012). Under climate change scenarios such as this, the increased carbon stocks in trees and soils accumulated by PSNP could be vulnerable to future losses (Allen et al., 2010; Davidson & Janssens, 2006). Furthermore, the stability of entire food systems may be at increased risk from these changes to the climate, providing a strong rationale for investment in 'climate-smart agriculture' – adaptation and mitigation strategies that increase resilience to climate change, while also lowering the contribution of agriculture to GHG emissions (Lipper et al., 2014; Wheeler & Braun, 2013). While many of the practices already undertaken within PSNP, such as

SWC and agroforestry, can be considered climate smart in terms of providing adaptation and mitigation benefits in a food security context that is grounded in a participatory planning process involving smallholders and civil society (Chandra, McNamara, & Dargusch, 2017), there are clear opportunities for PSNP to become more climate smart by (a) mainstreaming an awareness and understanding of future climate projections into the planning process (Lipper et al., 2014); (b) using its landscape-scale approach to optimize potential synergies between adaptation and mitigation (Harvey et al., 2014) and by adopting a climate–food–energy–water nexus approach that formalizes consideration of the multiple synergies and trade-offs between these sectors and objectives (Rasul & Sharma, 2016).

5. Conclusions

Along with the pressing challenge of global climate change, developing countries must simultaneously address endemic poverty and malnutrition. One response mechanism is social safety net programmes – developed to provide poor, vulnerable and marginalized members of society with food and cash transfers to reduce negative impacts from economic, environmental or governance shocks and chronic food insecurity. Public works safety net programmes, in particular, are designed with the dual objectives of providing food security, and building and maintaining vital public assets. We have demonstrated here that such safety net programmes that include an element of public works on land and ecosystem restoration can lead to substantial climate change mitigation co-benefits. The lessons learned from the Ethiopian experience described here have the potential to inform safety net programmes in developing countries worldwide, creating an opportunity for social protection to also provide a mechanism to support international and national responses to climate change. It has been argued that international policies and international development organizations should facilitate development strategies with ancillary climate benefits (Davidson et al., 2003). The work described here highlights what is in many ways a success story that demonstrates this principle in action.

Further research to better quantify the social and economic trade-offs and co-benefits between land restoration works and food security will be required to fully realize the potential of such programmes worldwide to contribute to stabilizing the Earth's climate within safe limits. Realizing this full potential will require a number of policy issues to be addressed including (1) mainstreaming of climate change mitigation into the design and implementation of programmes at all levels; (2) scaling up of interventions from sub-watershed management to jurisdictions; (3) supporting this scaling up through international climate finance and funds; and (4) capacity building to increase the in-country expertise that will be required for this mainstreaming and up-scaling. Furthermore, realizing the full potential of such programmes will require that some of the barriers to optimal implementation are addressed, such as incentive mechanisms that reward effort on public works rather than results, lack of monitoring and evaluation of impacts on the physical environment, improving the quality of livestock barriers and increasing the integration of agroforestry into woodland regeneration projects. Nonetheless, it is clear from this work on the food security–climate nexus that social safety nets can play an important role in climate change mitigation, while also saving livelihoods and lives – an unintended, positive synergy that has not previously been broadly considered.

Notes

1. Areas of land from which livestock have been excluded are referred to as 'area enclosures' in Ethiopia, a term that we adopt here. Note that such areas are sometimes referred to as 'livestock exclosures' in other countries.
2. Southern Nations, Nationalities and Peoples' Region.

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