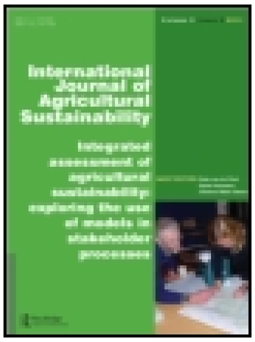

International Journal of Agricultural Sustainability

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tags20

Designing sustainable pathways for the livestock sector: the example of Atsbi, Ethiopia and Bama, Burkina Faso

Catherine Pfeifer , Joanne Morris , Jonathan Ensor , Salifou Ouédraogo-Koné , Dawit W. Mulatu & Mekonnen Wakeyo

INTERNATIONAL JOURNAL OF AGRICULTURAL SUSTAINABILITY
https://doi.org/10.1080/14735903.2020.1824419

Routledge
Taylor & Francis Group

OPEN ACCESS Check for updates

Designing sustainable pathways for the livestock sector: the example of Atsbi, Ethiopia and Bama, Burkina Faso

Catherine Pfeifer [a,b], Joanne Morris [c], Jonathan Ensor [c], Salifou Ouédraogo-Koné [d], Dawit W. Mulatu [e,f] and Mekonnen Wakeyo [f]

[a]Department of Socio-Economics, Research Institute for Organic Agriculture (FiBL), Frick, Switzerland; [b]Policies, Institutions and Livelihoods, International Livestock Research Institute (ILRI), Nairobi, Kenya; [c]Stockholm Environment Institute, Department of Environment and Geography, University of York, York, UK; [d]Institut du Développement Rural, Université Nazi Boni de Bobo-Dioulasso, Bobo-Dioulasso, Burkina Faso (IDR); [e]Environment and Climate Research Centre (ECRC), Policy Studies Institute (PSI), Addis Abeba, Ethiopia; [f]World Bank, Environment, Natural Resources and the Blue Economy Global Practice, Africa Region, Addis Abeba, Ethiopia

ABSTRACT
Demand for animal sourced food is predicted to double in the upcoming 20 years in Sub-Saharan Africa. This is simultaneously a big opportunity in terms of poverty reduction and a significant threat to the environment. The objective of this paper is to present an approach to co-create a set of viable and acceptable development pathways for the livestock sector that maximizes benefits from increased production, exploits the synergies between livestock and the environment, while minimizing the negative effects. It engages local stakeholders and actors into a computer-assisted participatory process, through which local trade-offs and synergies between livestock production, livelihood benefits and environmental impacts can be explored. Scenarios reached by consensus among local stakeholders challenge the dominant discourse of livestock intensification. They suggest that combining extensive and intensive modes enables increased production of animal sourced food with lower additional pressure on the environment than current production modes. The right combination of extensive and intensive production allows for an efficient use of the local biomass and feed resources, and offers opportunities to improve livelihoods for all stakeholders despite their differing economic circumstances, values and traditions.

KEYWORDS
Computer-assisted participatory process; serious gaming; livestock; environment; co-production

Introduction

Demand for animal-sourced food has been increasing in Sub-Saharan Africa and is predicted to double in the coming 20 years (Enahoro et al., 2018). Driving forces behind this trend include population growth leading to an overall higher demand for food, and an increase in incomes leading to a shift from plant-based diets towards more animal-based diets. This increasing demand for animal-sourced food is referred to as the livestock revolution (Delgado et al., 2001). It is simultaneously the biggest opportunity and one of the biggest threats to Sub-Saharan African countries.

Livestock is central to the livelihoods of poor communities in sub-Saharan Africa, both in rural and in urban settings (Randolph et al., 2007). In high-potential rural areas, livestock generally is part of an integrated mixed crop-livestock production system, while in low potential areas, usually lowland areas, livestock is at the core of the agro-pastoral and pastoral systems. Livestock bring multiple benefits to the poor. The first is the provision of high-quality food. There is growing evidence that livestock keeping households consume more animal-sourced food, have healthier diets and an increased well-being compared to those without livestock (Azzarri

CONTACT Catherine Pfeifer catherine.pfeifer@fibl.org Research Institute of Organic Agriculture (FiBL), Ackerstrasse 113 / Postfach 219, CH-5070 Frick, Switzerland
Supplemental data for this article can be accessed https://doi.org/10.1080/14735903.2020.1824419.

et al., 2015). Additionally, livestock generate income and often bring cash needed for health care, school fees, and agricultural inputs. It provides manure, which in the mixed crop-livestock system is often the only fertilizer available, as well as labour for ploughing and threshing (Moll, 2005). Finally, livestock serve as a financial instrument as well as contributing to social status (Randolph et al., 2007). When implemented in the right way, the livestock revolution could increase wellbeing of the rural poor across the continent (Delgado et al., 2001).

Yet, undeniably, livestock is also a major threat to the environment (de Vries & de Boer, 2010; Steinfeld et al., 2006). Livestock, in particular ruminants, generate 18% of anthropogenic global greenhouse gases (Herrero et al., 2009). Additionally, livestock require significant amounts of land and water for feed, putting natural resources under pressure. Livestock demand for land and water is already generating conflicts in dryland areas (Campbell et al., 2000; Pica-Ciamarra et al., 2007). In addition, more intensive livestock has a higher risk of animal diseases and zoonosis (Jones et al., 2013), a risk that is even higher for cross breed animals in Africa that are generally less suitable to the environment and are less resistant than indigenous breeds (Marshall et al., 2019).

The objective of this paper is to present an approach to co-creating a set of viable, acceptable and sustainable development pathways for the livestock sector. The approach aims at maximizing benefits from increased production, exploiting the synergies between livestock and the environment, while minimizing the negative effects. It engages local stakeholders into a computer-assisted participatory process in the form of a serious game, through which local trade-offs and synergies from livestock production, livelihood benefit and the environmental impacts can be explored. Learnings from this process help to identify local priorities and context specific policies that are needed to enhance livestock production in a sustainable manner. This paper analyses the computer-assisted multi-stakeholder process implemented on the Atsbi Plateau, Tigray in the Ethiopian highlands and Bama commune, in the periphery of Bobo-Dioulasso.

A computer assisted multi-stakeholder process to design sustainable transformation pathways

Modelling with stakeholders is an approach that aims to reduce complexity. It has proven a powerful tool that can enhance stakeholders understanding of a system through collaborative learning, and support decision makers to identify and clarify the impact of alternative solutions to a given problem (Voinov & Bousquet, 2010). Even when complexity is reduced, the non-linearity and multi-dimensionality behind the interaction between livestock and the environment remains. Assessing the impact of changes cannot be reliably assessed without some form of decision-support. Computer models can make long term effects visible in a transparent way (Van Paassen et al., 2007). These computer models can be used as a tool for serious gaming, with the aim of increasing social learning on sustainability (Ensor & Harvey, 2015; den Haan & Van der Voort, 2018).

Challenges to set up these models are manifold. Firstly, they need to be adapted to the audience (Brugnach et al., 2017; Jakeman et al., 2006) and speak their language. Secondly, they should be adaptable to the context in which they are used (Jakeman et al., 2006). In addition, they need to be operational quickly: decision-makers are unlikely to accept a significant delay before getting results. These models therefore need to balance accuracy of the output and the speed at which a context-specific tool can be set up. This implies a need for pragmatism: the processes that are modelled need to be simplified and where possible populated with secondary data that is detailed enough to be context specific. The CLEANED-R tool is such a model developed for simulating environmental impacts of the livestock sector in Sub-Saharan Africa.

Study area

This paper presents results from two different study areas, i.e. Atsbi in Ethiopia, and Bama in Burkina Faso, in which the overall approach has been applied.

Atsbi, Ethiopia

Atsbi is located in the Tigray region of Ethiopia (Figure 1). It is a highland plateau with about 600 mm of rainfall annually. The area represents classical crop-livestock mixed systems. The government is planning to develop dairy production as part of its agricultural transformation strategy and is bringing in new high performing livestock breeds (Shapiro et al., 2015). To feed these animals, the government promotes planted fodder such as alfalfa, or cow pea and an increased use of concentrated feed produced in the region.

The area is also known for its highland sheep, a breed that secures a premium price in the nearby

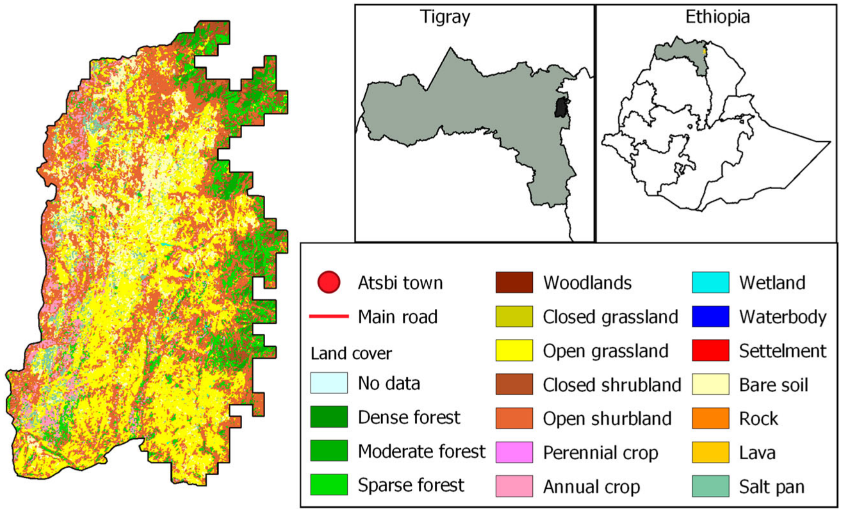

Figure 1. Land cover of the Atsbi Plateau in Tigray Ethiopia.
Source: (RCMRD-SERVIR Africa, 2015).

cities. Yet, sheep are often ignored by policy makers and not seen as part of the development of the area, despite the potential of sheep to support the poor (Legese et al., 2014). Current livestock feed consists of crop residues from barley, wheat and grass while concentrates are rarely fed (Hagos et al., 2014). The tenure system allocates 0.5 ha of land per adult under a 99-year lease. Because there are more people than available land, many remain landless. The government promotes crossbreed dairy cows, kept in zero grazing units, as an alternative for landless people.

Bama, Burkina Faso

Bama is located 20 km North of Bobo-Dioulasso, in western Burkina Faso (Figure 2). Given its proximity to the city, there are competing claims on land. There are a growing number of sedentary farmers, who are producing both staple and animal sourced food for the city and have converted open grassland to enclosed cropland, including in areas which are traditionally used as a transhumance route from Mali to Ghana. Agro-pastoralists have a homestead in this area, but most of their livestock are in transhumance for the major part of the year. They manage risks by splitting their herds into sub-herds that are managed in different ways, especially during the dry season. The dairy herd is a herd of 15–25 lactating animals that remain at the homestead with the wife and children, providing income from milk for the family throughout the year. The rest of the animals are split into sub-herds (called *wéré* in Fulani) of about 100 animals that each go on one of several transhumance routes, with different herders. Some of these animals go only on the so-called short transhumance (a movement that remains within the study area), while others undertake a long transhumance (these animals leave the study area). Finally, there are pastoralists that just cross through the area with animals, having a homestead outside of the study area or have a fully nomadic life (no homestead at all).

The government is finalizing the implementation of pastoral routes and zones across Burkina Faso, one of which was under development in the study area at the time of the study in 2018. The routes and zones aim at guaranteeing possible migration routes for pastoralists and ensuring that the area does not get converted to cropland (Gonin & Tallet, 2012). With the increasing number of non-pastoral cattle, the pastoral zones are increasingly used by sedentary famers, decreasing grass availability for agropastoralists and pastoralists crossing the area (Gonin, 2016). Hence, Bama is in the middle of a conflict, which at the beginning of this research project made it impossible for pastoralists and sedentary farmers to come together at the start of the co-production process.

The CLEANED-R tool

The CLEANED-R tool is an operationalization of the Comprehensive Livestock Environment Assessment for improved Nutrition, secured Environment and

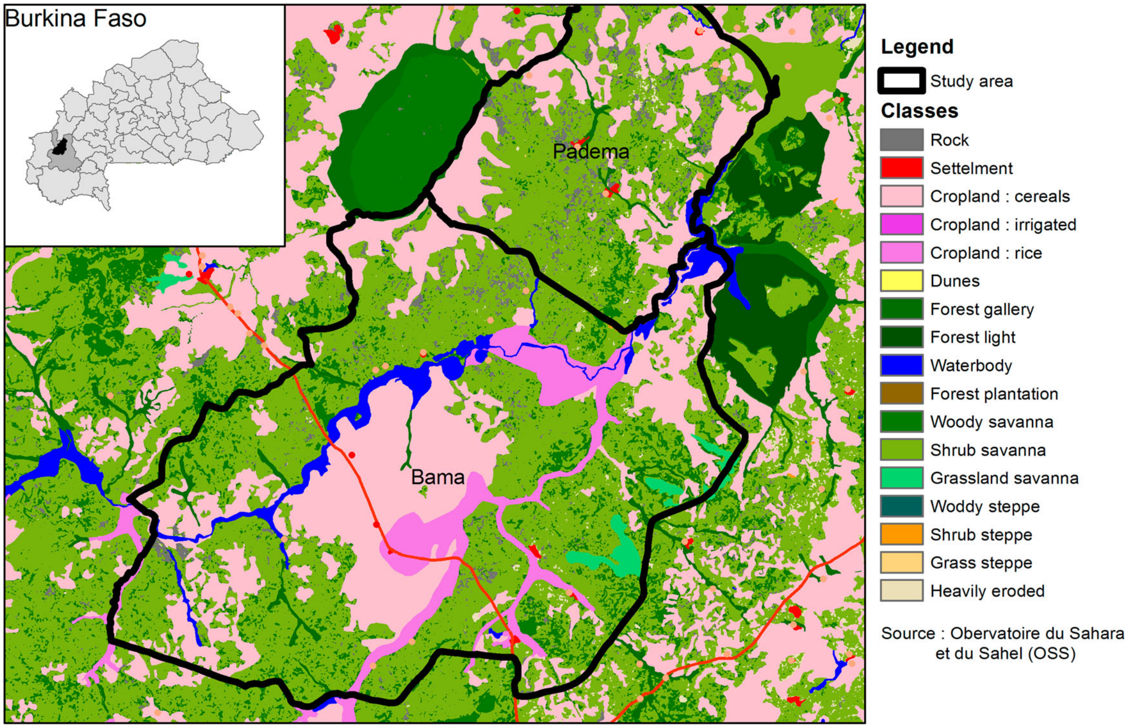

Figure 2. Land cover of the Bama, Haut-Bassin, Burkina Faso.
Source: (Observatoire du Sahara et du Sahel (OSS), 2015).

sustainable Development framework (Notenbaert et al., 2016) at the landscape scale. It simulates changes in livestock numbers and practices, mainly in terms of what is fed to livestock (the feed basket). In order to be context specific and quickly adjustable the CLEANED-R tool combines open access geographical data with data collected through interviews and stakeholder engagement.

General set up of the CLEANED-R tool

The CLEANED-R tool is a spatially explicit simulation tool that computes environmental impacts, namely water use, greenhouse gas emissions, biodiversity loss and nitrogen balance of a given area based on livestock production parameters that are user-defined (Pfeifer et al., 2016). Supplementary material S1 explains in detail the functioning of the tool and S2 gives the base run set up for each country, which is a quantitative description of the study area.

Model outputs are: total production and biomass required for production. When more biomass is needed than the study area can produce, the excess biomass is reported as 'imports required'. In the water module, water needed to grow the total biomass demand is computed, recognizing that different feed and fodder require different amounts of water due to evapotranspiration rates (Allen et al., 1998; Haileslassie et al., 2009). This module reports water usage per animal, per litre of milk or per kilogram of meat, and the ratio of water required to the actual rainfall (representing the pressure of livestock on water resources in the area). Greenhouse gas emissions are computed based on IPCC inventories and report greenhouse gas emissions per animal, by kg of milk or meat and for the whole area (Eggleston et al., 2006). Biodiversity reports a species diversity index as well as how many critically endangered species lose some of their habitat when land use is changed, based on IUCN's red list (IUCN, 2017). The soil nitrogen balance in based on Smaling et al. (1993) and contains a RUSLE erosion model (Renard et al., 1991). Erosion was mapped out for Africa based on secondary data using the approach proposed by Claessens et al. (2008), yet made use of more up-to-date geographical layers. This included the SoilGrids data (Hengl et al., 2015), with the computational approaches proposed by Panagos et al. (2015)

as well as a novel rainfall erosivity map (Vrieling et al., 2010).

Defining the boundary of the Ethiopian case study was straightforward as the Atsbi Plateau (higher than 2200 m) offers a natural bio-physical and socio-economic boundary. In Burkina Faso, where people and livestock are moving, the boundary was set at the limit of the area that animals from households with a homestead in Bama commune make use of during the short transhumance. This included the pastoral zone in the neighbouring commune Padema, which is part of the long transhumance route between Mali and Ghana and at the centre of many ongoing conflicts.

Due to its relatively rough calibration based on secondary data, the CLEANED-R tool does not report environmental pressure accurately. However, patterns identified by comparing different scenarios to a base run provides an indication of the amplitude of the change. Outputs from the tool are always 'relative change indicators', a percentage change compared to a base run scenario.

Contextualizing CLEANED-R from a farmer's perspective

In each site a reconnaissance tour that included a transect drive and key informant interviews took place. These interviews enabled understanding the local livestock sector. Results from these interviews fed into a participatory stakeholder workshop, in which stakeholders described the different ways of livestock keeping in the area. A detailed overview of the stakeholder engagement throughout the project as well as description of the participants is presented in the supplementary material (S3). To come up with the livestock grouping that is used in CLEANED-R, facilitation techniques were used to enable a social learning process. In particular, the snowballing facilitation technique, also known as 1-2-4-all, was applied (Lamoureux & White, 2015): participants were asked in groups of two to identify different ways of keeping livestock in the area. Once they agree, they find another group and try to agree. The process ends when two big groups have an agreement. If the two big groups do not have the same categories, a facilitated consensus building process takes place. This approach allows the complexity of the local livestock keeping system to be reduced, without reducing the diversity that is relevant to local livestock keepers. Then groups of participants described these different ways of keeping livestock. The agreed upon livestock groupings provided information to CLEANED-R on how to define the livestock categories for the study area. The participants' categories were slightly modified to compute environmental impacts correctly. In this manner, local understanding of livestock keeping systems were introduced into the tool, without imposing a pre-determined livestock model. The participants' description of these categories served to calibrate the baseline of the CLEANED-R tool, in combination with existing statistics (i.e. Demographic Health Survey data (Institut National de la Statistique et de la Demographie - INSD/Burkina Faso and ICF International, 2012)), national census data and existing geographical layers such as global livestock distribution (Gilbert et al., 2018) or population distribution (Tatem, 2017).

Defining the options for sustainability pathways in the CLEANED-R tool

Possible pathways were defined based on a combination of local and expert knowledge. Participants in the first workshop envisioned how livestock will be kept in future. These visions are often over-optimistic and were adjusted to realistic improved ways of keeping livestock by local livestock experts. For each site and each livestock category a selection of locally appropriate combinations of feeding strategy, veterinary services and livestock breeds were combined into so-called pre-sets, i.e. combined realistic practice changes that are locally adapted. Each of the pre-set livestock alternatives were represented on a separate vignette card for use in the Transformation Game. Feeds that form part of the feed basket are either locally grown or brought in from the wider region of the study area, and have a strong focus on the use of crop residues and locally planted fodder.

The transformation game

The Transformation Game was developed for this project and is the operationalization of the CLEANED-R tool in a participatory process as a serious game. A game board is developed, representing the interface of the CLEANED-R tool. The pre-sets defined in CLEANED-R are presented in the form of 'vignette' game cards that describe a pre-set combination of practices in the local language, together with images (Figure 3). Participants are able to represent the number of livestock that they wish to associate with each livestock category using plastic bricks. The game board itself is in two sections

ABR: Animaux (agro-pastoraux) transhumant (grande et petite transhumance) (Ap)

Alive weight (kg)	lwes	200
Milk production (kg/cow/year)		0
Dressing percentage	des	0.38
Feed basket wet season		
Natural grass	efng1	100
Cereal crop residue	efrc1	0
Rice crop residue	efrr1	0
Legume crop residue	efrl1	0
Planted fodder	efpf1	0
Concentrate – bran	efconc1	0
Concentrate – oil seed cake	efconos1	0
Feed basket dry season		
Natural grass	efng2	40
Cereal crop residue	efrc2	40
Rice crop residue	efrr2	20
Legume crop residue	efrl2	0
Planted fodder	efpf2	0
Concentrate – bran	efconc2	0
Concentrate – oil seed cake	efconos2	0
Manure management		
% in lagoon	es_lagoon_perc	0
% as liquid slurry	es_liquidslurry_perc	0
% as solid storage	es_solidstorage_perc	0
% as drylot	es_drylot_perc	0
% left on pasture	es_pasture_perc	100
% daily spread	es_dailyspread_perc	0
% in digester	es_digester_perc	0
% used as fuel	es_fuel_perc	0
% other management	es_other_perc	0

Figure 3. Example of a vignette card showing the title and illustration on the front (left) and the CLEANED-R parameters on the reverse side (right).

(Figure 4). In the lower part, the starting point is represented, with a game card and the appropriate number of bricks for each livestock category. On the upper part, space is provided to define a new scenario by selecting from the available vignette cards and bricks, to define a new number of livestock in each combination of practices (Figure 4). This set-up allows for a visual representation of the CLEANED-R tool and enables discussion among the players of the game (Figure 5).

The game is played in two separate rounds as part of a stakeholder workshop (S4). In the first round each specific group of stakeholders, farmers, processors and traders, governmental representatives and knowledge partners and high-level decision makers, work in their own group. They discuss the base run and define how much livestock would be optimal, and how it should be kept, in the future. The CLEANED-R tool then computes the environmental impact of each group scenario to be discussed. In a consolidation phase, facilitators create starting point scenarios for the second round that summarize the major patterns found in the different stakeholder specific scenarios. This step reduces the number of scenarios and avoids a sense of ownership that participants might have about their own scenario. In the second round, participants from the initial stakeholder groups are mixed and start developing new scenarios based on the output of the consolidated scenario: the different ambitions and visions of the stakeholders need to be renegotiated at this stage to define a future that is acceptable for all players in the game.

Beyond the environmental indicators from CLEANED-R, stakeholder-defined socio-economic indicators of well-being are discussed. This allows environmental, socio-economic and institutional dimensions of the scenario to be explored, identifying trade-offs and synergies. Generally, the mixed stakeholder groups played with different scenarios, negotiating where conflict emerged. This is where trade-offs are found and creativity is required to find a solution that fits all players. When a group manages to converge towards a preferred scenario, experts are present to check that the scenario that satisfies the ambitions of the local people also lies within the carrying capacity of the area. If this were not the case, the experts would disagree, pointing to the overexploitation. In this way, preferred scenarios that developed into a consensus were also sustainable pathways. However, note that not every group was able to reach consensus during the short time within which the Transformation Game was played.

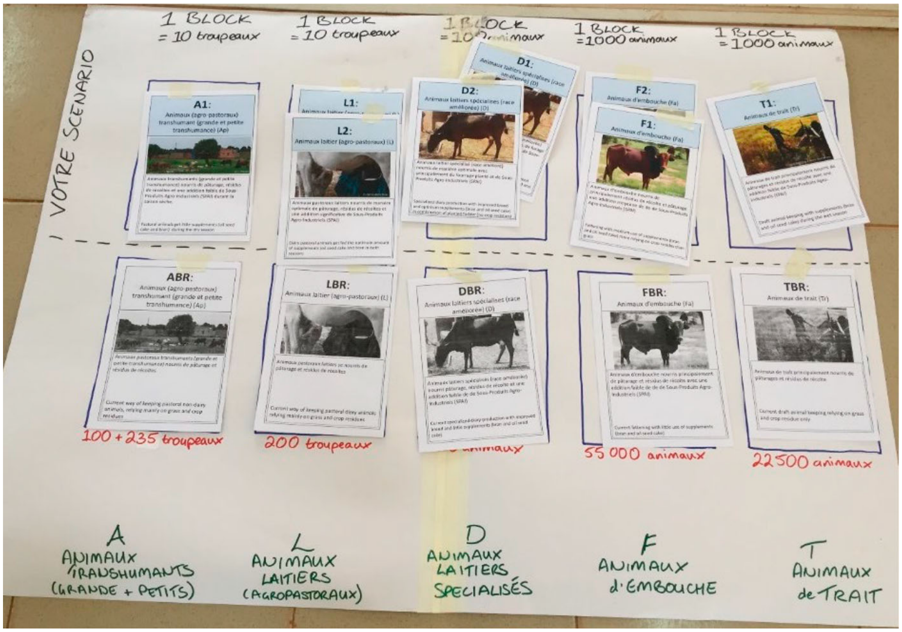

Figure 4. Game board used in Burkina Faso. Vignette cards can be placed in the top row by participants to select their future scenario.

Results

Site-specific CLEANED-R adjustments

For the Atsbi Plateau, livestock categories were: improved dairy cow, local dairy cow (from a dual-purpose breed), fattening cattle (from dual-purpose breed), sheep and draft animal (used for labour). The pre-sets represented increased levels of expensive concentrates, relating to different levels of increased production across the categories. The local dual-purpose animals were split per practice, namely those animals kept for milk that have a different dietary requirement to those kept for fattening. For both groups, two pre-sets were defined, the first based on a home-grown feed basket drawing on local planted fodder rather than concentrates, and

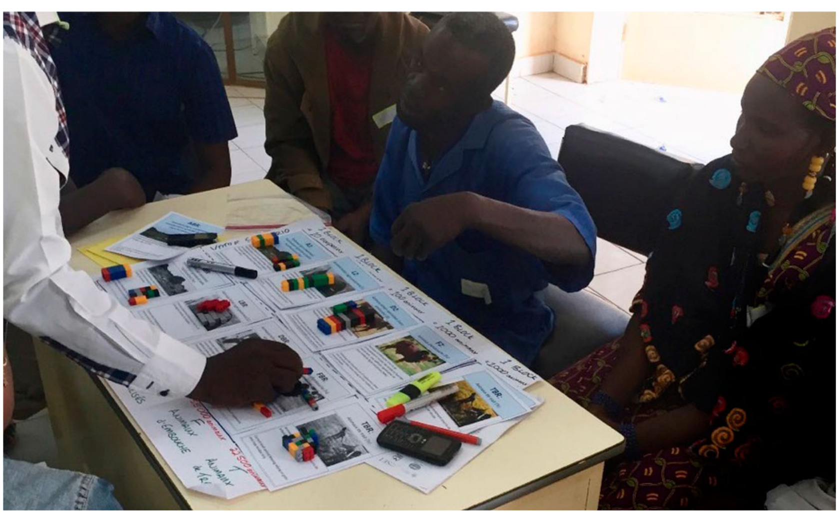

Figure 5. The game being played in Burkina Faso. Participants are selecting the number of bricks that they want to assign to each vignette, representing the number of animals.

the second, a bought-in feed basket based on more concentrates. The production gain from both options where similar. This set-up was chosen to explore the trade-offs between staple food production and planted fodder and enable a discussion over preferred land use at farm scale. The sheep-keeping options were similar but adjusted to sheep dietary requirements and focussed on natural grass, as the sheep usually graze on the hills in the study area. Finally, draft animals only had one option that represented a slight improvement in the feed.

In Burkina Faso, agreeing on the livestock categories was a challenge as the pastoralist participants refused to talk about livestock numbers. As a result, agro-pastoral livestock was represented in terms of sub-herds, a structure proposed by the pastoral communities themselves. Three categories were distinguished, the long transhumance sub-herds that leave the area part of the year; the short transhumance sub-herds, that leave the homestead but remain within the study area; and the dairy sub-herds that remain around the homestead. The number of sub-herds and the number of animals per sub-herd for the base run in CLEANED-R was as defined by the representatives of the pastoral system. Finally an additional livestock category allowed to account for pastoral livestock that only pass through the area by assuming the 200,000 pastoral animals are present during 2 months of the year. For the sedentary farmers, the cattle were split by their purpose – namely dairy, fattening and draft. For all animals, except draft, two pre-sets were defined at two levels of increasingly improved feed, and therefore improved production. For sedentary dairy cattle, the change compared to the base line was the biggest, as it also corresponded to the introduction of improved genetics, i.e. crossbreeds with a higher percentage of foreign blood. In the other livestock categories, the pre-set represented improved feeding and veterinary practices without a breed change. This set-up allows the discussion on livestock keeping practices for different livestock types and livestock keeping strategy along an intensification gradient.

These livestock categories do not capture the whole complexity of herd management, as found in alternative livestock simulation models like the global livestock environmental assessment model (GLEAM) (FAO, 2018). They however enable complexity to be reduced without loss of meaning for the stakeholders. Moreover, they are set up to compute the environmental impact assessment without distorting results compared to models that are more complex.

Sustainability pathways: the co-created scenarios

The Transformation Game enabled participants to discuss, learn from each other, identify synergies and to balance trade-offs. Not all groups that participated in the game were able to reach consensus. Flowcharts describing the evolution from stakeholder-specific scenarios to the final agreement is mapped out in supplementary material S4. However, in both sites, at least one group could reach consensus, suggesting that it is possible to balance the trade-offs. The reason why some groups could not find a consensus is mainly due to time restrictions of the workshop. In Ethiopia, it was possible to mix the different stakeholder groups for the second round into gender specific groups. The women group and one of the men's groups reached consensus, while the second men's group did not reach agreement. In Burkina Faso, both stakeholder specific and mixed groups were mixed gender, and only one of the two mixed groups managed to reach consensus.

Because the CLEANED-R tool can only identify patterns by comparing different scenarios to a base run providing an indication of the direction and magnitude of the change, this section presents the relative results in terms of percentage change from the base run. The absolute data is presented in supplementary material (S5), however these numbers need to be treated with caution as they are an artefact of the parametrisation of the CLEANED-R tool. Participants in the workshops were only presented with relative change data on which to base their discussion.

Atsbi, Ethiopia

Table 1 summarizes the agreed scenarios in Atsbi in terms of the desired livestock keeping practices and associated number of animals.

In terms of numbers of animals, there is a move from dual-purpose cattle to more specialized dairy cattle. This results in a reduction of both dual-purpose dairy and fattening animals as improved dairy cattle will increase up to 30-fold (from 500 in the base run to 15,000 in the women's scenario and 12,000 to the men's scenario). Also, the number of draft animals is halved, with the work of these

Table 1. The agreed scenarios in Ethiopia.

Livestock category	Base run number	Women's group		Men's group	
		Vignette	Number of animals	Vignette	Number of animals
Dual-purpose dairy cattle	22,000	Home grown feed basket	10,000	Commercial feed basket	8000
Dual-purpose fattening and rearing cattle	19,000	Home grown feed basket	9000	Commercial feed basket	5000
Draft cattle	10,000	Base	5000	Improved	5000
Specialized dairy cattle	500	Home grown feed basket	15,000	Home grown feed basket	12,000
Sheep	100,000	Home grown feed basket	150,000	Commercial feed basket	95,000

animals anticipated to be replaced by small tractors. Yet half will remain mainly for ploughing hilly locations. Sheep remain important: the women's group increased the number of sheep from 100,000–150,000 heads while the men's group reduced them by 5000 heads. In terms of livestock keeping practices, women chose home-grown feed baskets while men preferred the commercial ones.

The change of the agreed scenario shows a clear trend to more milk with an increase of +101% in the women scenario and +75.5% in the men scenario, to more sheep meat with +125% and +42.5% respectively and less cattle meat production namely −44% and −59.5% respectively as shown in Figure 6. In terms of land use, there is a trend towards less land for livestock, with more concentrates being relied on in the agreed scenario feed baskets. Only the women's scenario, which relies on home-grown feed baskets, would need more cropland (+20.6%), on which the fodder would be grown, while land for grass decreases by −58% and −68% respectively. This results in a reduction of staple crops production (wheat, barley, teff) of −10% in the women scenario and −5% in the man scenario and represents a bigger trade-off in terms of food security. At the same time, the men's scenario has a decrease in dependency on grass and crop input. They rely on concentrates and agro-industrial by products, from both the study area and the wider region. In all cases there is a drastic increase of feed and fodder production (over 2000%) because there is almost no planted fodder today.

In terms of water, less water is used, namely −4.25% in the women's scenario and −6.5% in men's scenario resulting from the move to concentrates (brans and oil seed cakes from the region), as water use in the CLEANED-R tool is allocated to the primary use for crop growing and not to agri-industrial by-products. The reduction is less important for the women's scenario, which makes use of a homegrown feed basket that requires water.

In terms of greenhouse gases, the men's group managed to find a scenario with improved production without increasing emissions from livestock, while the women's scenario will increase the total greenhouse gas emissions by +22%. It is interesting to notice that greenhouse emissions per animal is increasing, due to the improved feed basket as well as animals growing heavier. However, in terms of product (milk or meat) the emissions are reducing: there is an efficiency gain in the agricultural production by +15% in the women or +17% in the men's scenario in terms of litres of milk as well as by +4.4% in the women's scenario in terms of meat produced.

Finally, in terms of soil, the women's scenario has more animals and therefore more manure, therefore more greenhouse gases but also more soil nitrogen input. Soil nitrogen balance is improved by +80% while in the man's scenario it is worsened by −54%.

Bama, Burkina Faso

In Bama, the discussion focused on balancing the interests of sedentary farmers and the agro-pastoralists. The sedentary farmers keep a similar number of animals but switch to the high performing breed that is mainly fed on concentrates and planted fodder (Table 2). The agro-pastoralists, however, increase the number of moving animals rather than intensifying their production. As both sedentary farmers and agro-pastoralists keep fattening animals, the slightly improved feed basket was chosen, as sedentary farmers are more likely to switch to a commercial feed basket while pastoralist are less likely to change the feed basket. Pastoralists accepted slightly improving the feed to their dairy herd that remains at the homestead and to not increase the number of

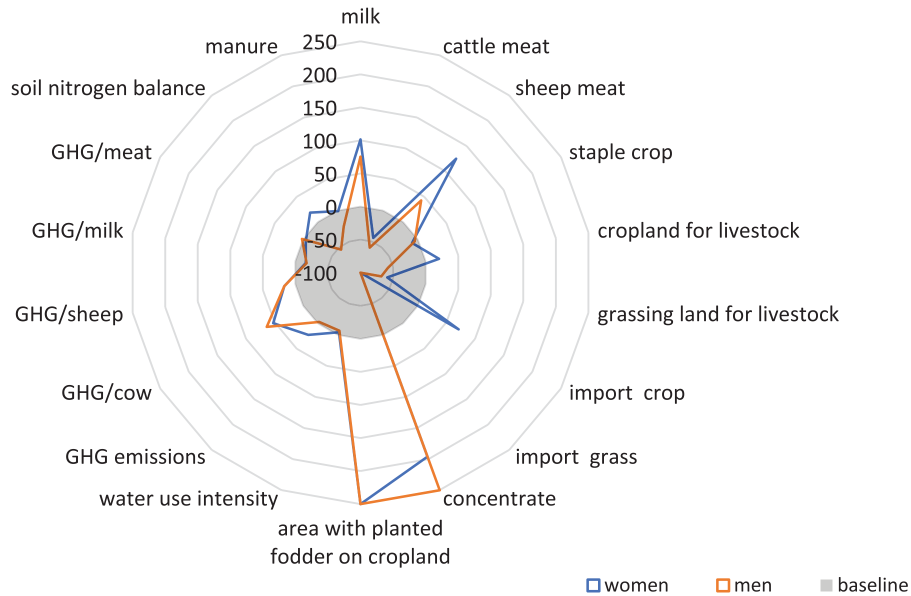

Figure 6. Percent change of the agreed scenario compared to the base run in Atsbi, Ethiopia (concentrate and area with planted fodder were truncated to 250% for presentational reasons).

sub-herds nor the number of animals within those herds, despite their wish not to intensify.

In terms of production, the agreed scenario drastically increased the production of meat and milk in the area (Figure 7). Milk is doubled and meat tripled. This production gain is the result from a shift from natural grass to slightly more crop residue, and much more concentrates (+917%) and planted fodder (area changing from 0 to 72 ha) for the sedentary animals. The land necessary to feed these animals increases by 400%, yet this can happen on existing cropland as no imports are necessary. Planted fodder competes with staple food, and this explains the 14% reduction in staple food production. Yet demand for grass increases too, as animals that are more pastoral are consuming more than the grass that the sedentary animals consumed in the base run. Also, the water use efficiency measure suggests an improvement by +50%.

In terms of greenhouse gas emissions, more animals lead to more emissions, and bigger and better fed animals to higher emissions per animal. However, as in Ethiopia, the efficiency of the production is improved, seen in the per unit of production of milk and meat by +60% and +18% respectively. Also, the soil nitrogen balance is slightly improved owing to more available manure in the area.

Discussion

Trade-offs and synergies in the sustainability pathway

In Ethiopia, in both agreed scenarios production was increased, suggesting better incomes are possible, allowing households to buy food when needed, rather than relying on food aid. This increased

Table 2. The agreed scenarios in Burkina Faso.

		Agreed scenarios	
Livestock category	Base run number	Vignette	Number of sub-herd/animals
Transhumant sub-herds (120 animals)	100	base	200
Long transhumance			
Short transhumance	238		300
Dairy sub-herds (20 animals)	200	Slightly improved feed	200
Specialized dairy	1400	Improved feed	1400
Fattening cattle	55,000	Slightly improved feed	110,000
Draft animals	22,500	Improved feed	17,000

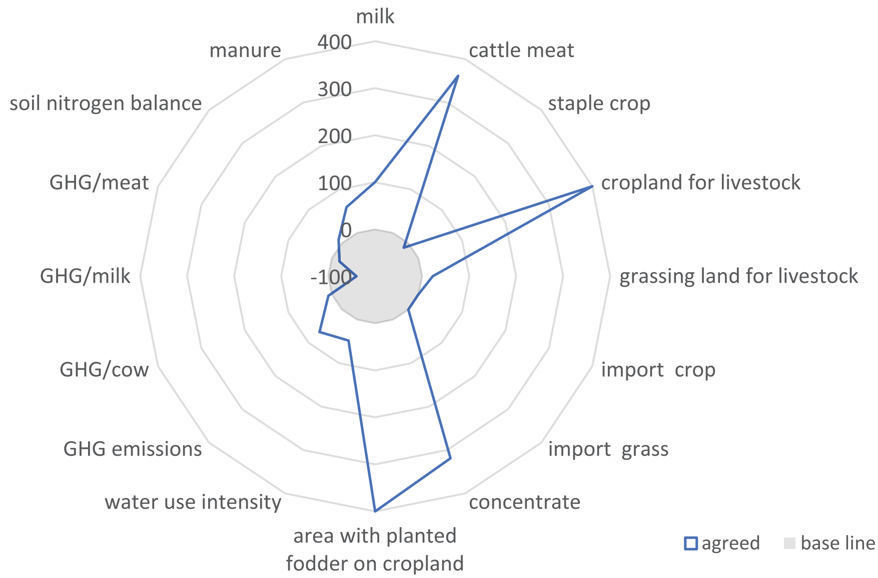

Figure 7. Percent change of the agreed scenario compared to the base run in Bama, Burkina Faso (concentrate and area with planted fodder were truncated to 400% for presentational reasons).

production does not necessarily come with higher environmental impacts. Greenhouse gas (GHG) emissions can be reduced in terms of units of milk and meat produced. However, the lack of increase of overall GHG emissions in the men's scenario, as well as the mild increase in the women's scenario, is due to moving from draft animals to tractors. The GHG emissions from tractors are not accounted for, which are likely to offset the GHG reduction, as tractors produce 17 times more GHG than draft animals for the same amount of power (Spugnoli & Dainelli, 2013). As such GHG remains a trade-off with production, but our results support the view that efficiency gains, in terms of emission per unit of milk, can be made (Herrero et al., 2016). More animals also improve the nutrients available in the region and improve the soil nitrogen balance. This is particularly important as soils are shallow and depleted (Zingore et al., 2008). More manure can increase the productivity of crops in the area and is part of a more efficient agricultural system compared to reliance on inorganic fertilizer (Place et al., 2003). However, the reliance on inputs from outside the study area complicates the picture. Import of planted fodder and grass from outside the area can be reduced if locally available agro-industrial by-products are better utilized. In the Ethiopian case, this includes local bran, and residues from local brewing. Yet some of these products, particularly sunflower oil seed cakes, come from factories in the lowland of region of Tigray (Legese et al., 2014), where no dairying takes place. This implies that the competition for the oil seed cakes is still low, yet might increase as dairy farming is developing further in the country. Finally, the scenario is perceived both by men and by women to enhance women's empowerment by putting the people's priorities at the centre of development. This is in particular through improving sheep production, an activity that is particularly attractive to women and the poor (Udo et al., 2011).

In Burkina Faso, conflict between pastoralists and sedentary farmers was at the centre of the Transformation Game. The realization that not everyone needs to intensify production was critical to reaching consensus. Key to this agreement was a recognition that more intensive production requires inputs such as agro-industrial by-products in sedentary production, which releases the pressure on grass and the crop-residues for the pastoral world. This is in line with findings found in Diarisso et al. (2015). Overall, everyone is getting a better income through improved production of the sedentary animals or by a larger number of pastoral animals. However, the use of local resources, water, grass and cropland is increasing too. Bama is a relatively wet and therefore currently a feed exporting area. Therefore, the intensification of sedentary animals does not push the area outside of its carrying capacity. Also, cotton oil-seed cakes are processed in the peri-urban area of Bobo Dioulasso and their utilization as feed therefore represents an efficient treatment of local waste.

All stakeholders appreciated this scenario as it increases the production for all, while solving a major conflict in the area. However, it remains unclear if the increased pressure on natural resources is realistic, especially in view of climate change. Indeed, agro-pastoralists today already perceive changes that may be attributable to climate change (Kima et al., 2015). Critical to success will be pasture land management, which is partly a task for the government but also for the pastoral communities themselves (Gonin & Gautier, 2016).

The transformation game as a way to design sustainable pathways

The Transformation Game supported stakeholder engagement in a manner that allowed farmers, who usually are less educated and less eloquent, to enter into discussions at the same level as experts. It allowed all stakeholders to build a common language around livestock transformations. The CLEANED-R tool was meant to bring science into this debate and quickly became a boundary object: no-one fully understood the workings of the CLEANED-R 'black-box', but everybody agreed to accept its output as a neutral basis for discussion. Yet, this was only possible because participants recognized their context within the tool and game, and therefore were ready to engage with it and trust the result (Morris et al., this issue).

Putting people at the centre of transformation, using the computer assisted stakeholder process, allowed a diversity of views to permeate the intensification discussion and shift participants' viewpoints and paradigm during the game. This normative learning is a relatively rare achievement of games aiming at social learning on sustainable natural resources (den Haan & Van der Voort, 2018). It was achieved by identifying the locally relevant livestock categories, regardless of the mainstream intensification discourse, and including livestock practices that were considered sub-optimal by influential stakeholders before the process. In Atsbi, Ethiopia, this meant including sheep production into the game despite of dairy intensification discourse influenced by the Ethiopian livestock master plan (Shapiro et al., 2015). In Bama, Burkina Faso, this meant adjusting the game to agro-pastoralism, while mainstream discourse of intensification of the dryland ignores them (Gonin et al., 2019).

Results suggest that transformation towards sustainable livestock systems that can feed the growing population in Sub-Saharan Africa will, at least in some cases, require the combination of more intensive, efficient and commercial production *alongside* more extensive practices, such as agro-pastoralism or sheep production. There is a need to acknowledge that intensifying livestock production will not look the same everywhere, and that sustainability needs to address the rights and interests of all livestock keepers – sedentary and pastoralist, male and female, wealthy and poor – in the search for transformation. As such, extensive production methods and the voice of less powerful groups should not be crowded out by dominant discourses of intensification, but be given an equal space in any livestock development planning process. For those associated with the process in Bama, Burkina Faso, this implies that the pastoral routes and zones need to be safeguarded and that better schemes to increase the quality of grass in these areas are needed. For those in Atsbi, Ethiopia, this means that sheep production systems are not overlooked in the development of the area and the master plan is not implemented without reference to context and a perspective on equity in outcomes; extension services, veterinary services and market development initiatives should, therefore, not just focus on milk but also on sheep. Unlocking the premium market for the Atsbi sheep could be an effective manner to increase both incomes and economic resilience of usually marginalized populations.

Also, there is not one optimal pathway, but rather a range of possible ways to sustainably develop the livestock sector in sub-Saharan Africa. The Ethiopian case has no clear agreement on fattening animals nor on the level to which increasing greenhouse gases is acceptable – and whether different stakeholders would accept different levels. In Burkina Faso, though a smart combination of both production systems can be sustained, there will be more pressure on all resources: the government has an important role in regulating access and maintaining pastoral zones. It remains unclear how much water and grass will be available and what change in greenhouse gas emissions will be acceptable to different stakeholders. These results suggest that there is no single optimal sustainable development pathway; rather, there are a diversity of paths that local stakeholders are willing to travel and trade-offs they are willing to accept.

Policies should support general patterns when they can be identified, and focus on ensuring there is flexibility in implementation so that this diversity can be recognized and equitable development supported. To do so, policies should create more space for social learning and create structures for innovation. Serious gaming, such as the Transformation game, is one option to achieve this as well as enhancing innovation (Edwards et al., 2019).

Limitations and future work

Most sedentary livestock keepers are willing to plant fodder crops with better dietary qualities for livestock, even if staple food production is reduced. Participants make the implicit assumption that more production means more income. Yet, as production increases, prices are likely to fall. The long term price may be defined by how easy it will be to bring milk and meat to a growing urban market with increased income (Oosting et al., 2014). In Bama, 20 km away from the biggest city, this might be of a lesser issue than in Ethiopia, where better infrastructure would be needed to facilitate transportation from Atsbi to Mekelle. The CLEANED-R tool could therefore be improved if there were a cost benefit module that allows local downscaling of different economic scenarios.

In addition, the livestock sector will require more concentrates that, currently, are often agro-industrial by-products that come from the region. They therefore represent an optimal use of the available biomass. Yet, today concentrates are often exported for use in a different location. Sustainable intensification that relies on concentrates might therefore lead to shortages in other locations, precipitating further conflict in already unstable regions. Because the CLEANED-R tool captures the local scale only, these effects that play out in the broader region are not accounted for, so a new way to introduce these feedbacks needs to be considered. This is why next steps would be to include higher level policy makers into the process to identify trade-offs at a higher scale and develop action plans to implement necessary changes to achieve the agreed pathways.

Conclusion

This paper presents an approach to co-creating sustainable intensification pathways for transformation for the livestock sector in sub Saharan Africa. The approach makes use of a computer-assisted game based on the CLEANED-R tool. This tool simulates generic environmental impacts for different livestock categories, and is adapted to the local context by combining open access spatial data with stakeholder knowledge. The approach was applied in the Ethiopian highland in a mixed-crop system as well as in the Burkina Faso lowlands within an agro-pastoral and pastoral setting. In both areas unexpected benefits from diverse livestock keeping systems challenge the dominant discourse of livestock intensification. Incomes from and amounts of animal-sourced food could be increased with limited or no additional pressure on the environment thanks to a more efficient use of the local biomass and feed resources. Next to income benefit, the combination of more intensive and extensive production systems allows all stakeholders to improve livelihoods within their economic circumstances, values and traditions.

Acknowledgments

We thank the Institut de l'Environnement et de Recherches Agricoles du Burkina Faso (INERA) and Environment and Climate Research Centre (ECRC) at Policy Studies Institute (PSI) for supporting this work at the Burkina Faso and Ethiopia sites respectively. We extend our gratitude to all participants who engaged with our learning process and interviews. Particular thanks go to the facilitators who led the stakeholder groups in the workshops. We also want to thank Dr Barbara Rischkowsky from ICARDA for her continuous support as well as the editor and reviewers for their valuable comments.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The Research and Learning for Sustainable intensification of Smallholder livestock value chains (ResLeSS) research project was funded by DFID SAIRLA S79 from the Sustainable Intensification Research and Learning in Africa (SAIRLA) programme. The views expressed in this paper are those of the authors and do not necessarily reflect the UK government's official policies. The CLEANED-R tool development was additionally supported by the CGIAR Research Program on Livestock and Fish as well as the CGIAR Research Program on Livestock at the International Livestock Research Institute (ILRI). ILRI thanks all donors and organizations that globally support its work through their contributions to the CGIAR Trust Fund.

Data availability

Data derived from public domain resources.

The data and codes that support the findings of this study are available in Github at https://github.com/ilri/CLEANED-R. These data were derived from the following resources available in the public domain:

Soilgrids: https://soilgrids.org.

Global Agro-Ecological Zones: https://gaez.fao.org.

Regional Center for Mapping of Ressources for Development: https://opendata.rcmrd.org.

WorldClim: https://worldclim.org/.

SRTM Data: https://srtm.csi.cgiar.org/srtmdata/.

LAI modis data: https://doi.org/10.5067/MODIS/MOD15A2H.006.

Notes on contributors

Catherine Pfeifer is a spatial analyst, previously a scientist at the International Livestock Research Institute (ILRI), Nairobi, Kenya, and now a senior scientist in the Department of Socio-Economic Sciences, Research Institute of Organic Agriculture (FiBL), Switzerland. She is the modeller of the CLEANED-R tool.

Joanne Morris is a research associate at the Stockholm Environment Institute in the Department of Environment and Geography, University of York, UK, with research interests in resource management in agricultural systems.

Jonathan Ensor is a Senior Research Fellow at the Stockholm Environment Institute in the Department of Environment and Geography, University of York, UK, with research interests in processes that can lead to increasingly equitable and resilient human development. He was principal investigator for the ResLeSS project.

Salifou Ouédraogo-Koné is a lecturer and researcher at the Université Nazi BONI of Burkina Faso in Bobo-Dioulasso, working in the area of animal nutrition, as well as the director of the Institute of Rural Development, Bobo-Dioulasso, Burkina Faso.

Dawit W. Mulatu is a research fellow at the Environment and Climate Research Center (ECRC), EfD-Ethiopia, in the Policy Studies Institute, Addis Ababa, Ethiopia, with an interest in resource and environmental economics as well as a consultant on environment and climate at the World Bank, Environment, Natural Resources and the Blue Economy Global Practice, Africa Region, Ethiopia.

Mekonnen Wakeyo is a Researcher in the Agriculture and Rural Development Research Center at the Policy Study Institute/PSI, Addis Ababa, Ethiopia, with interests in agricultural and environmental economics, natural resource and industrial economics.

ORCID

Catherine Pfeifer http://orcid.org/0000-0001-9738-8758
Joanne Morris http://orcid.org/0000-0002-0068-0515
Jonathan Ensor http://orcid.org/0000-0003-2402-5491
Salifou Ouédraogo-Koné http://orcid.org/0000-0002-2907-4922
Dawit W. Mulatu http://orcid.org/0000-0003-4758-1220
Mekonnen Wakeyo http://orcid.org/0000-0002-4434-3377

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration – guidelines for computing crop water requirements – FAO irrigation and drainage paper 56, p. 15.

Azzarri, C., Zezza, A., Haile, B., & Cross, E. (2015). Does livestock ownership affect animal source foods consumption and child nutritional status? Evidence from rural Uganda. *The Journal of Development Studies*, *51*(8), 1034–1059. https://doi.org/10.1080/00220388.2015.1018905

Brugnach, M., Craps, M., & Dewulf, A. (2017). Including indigenous peoples in climate change mitigation: Addressing issues of scale, knowledge and power. *Climatic Change*, *140*(1), 19–32. https://doi.org/10.1007/s10584-014-1280-3

Campbell, D. J., Gichohi, H., Mwangi, A., & Chege, L. (2000). Land use conflict in Kajiado District, Kenya. *Land Use Policy*, *17*(4), 337–348. https://doi.org/10.1016/S0264-8377(00)00038-7

Claessens, L., Van Breugel, P., Notenbaert, A., Herrero, M., & Van De Steeg, J. (2008). Mapping potential soil erosion in East Africa using the universal soil loss equation and secondary data. *IAHS Publication*, *325*, 398. https://hdl.handle.net/10568/1825.

Delgado, C., Rosegrant, M., Steinfeld, H., Ehui, S., & Courbois, C. (2001). Livestock to 2020: The next food revolution. *Outlook on Agriculture*, *30*(1), 27–29. https://doi.org/10.5367/000000001101293427

den Haan, R.-J., & Van der Voort, M. (2018). On evaluating social learning outcomes of serious games to collaboratively address sustainability problems: A literature review. *Sustainability*, *10*(12), 4529. https://doi.org/10.3390/su10124529

de Vries, M., & de Boer, I. J. M. (2010). Comparing environmental impacts for livestock products: A review of life cycle assessments. *Livest. Sci*, *128*(1–3), 1–11. https://doi.org/10.1016/j.livsci.2009.11.007

Diarisso, T., Corbeels, M., Andrieu, N., Djamen, P., & Tittonell, P. (2015). Biomass transfers and nutrient budgets of the agro-pastoral systems in a village territory in south-western Burkina Faso. *Nutrient Cycling in Agroecosystems*, *101*(3), 295–315. https://doi.org/10.1007/s10705-015-9679-4

Edwards, P., Sharma-Wallace, L., Wreford, A., Holt, L., Cradock-Henry, N. A., Flood, S., & Velarde, S. J. (2019). Tools for adaptive governance for complex social-ecological systems: A review of role-playing-games as serious games at the community-policy interface. *Environmental Research Letters*, *14*(11), 113002. https://doi.org/10.1088/1748-9326/ab4036

Eggleston, H. S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K.2006). *Chapter 10: Emissions from livestock and manure management*. IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programm, IGES, Japan.

Enahoro, D., Lannerstad, M., Pfeifer, C., & Dominguez-Salas, P. (2018). Contributions of livestock-derived foods to nutrient supply under changing demand in low- and middle-income countries. Glob. *Food Security*, *19*, 1–10. https://doi.org/10.1016/j.gfs.2018.08.002

Ensor, J., & Harvey, B. (2015). Social learning and climate change adaptation: Evidence for international development practice. *WIRES Climate Change*, *6*(5), 509–522. https://doi.org/10.1002/wcc.348

FAO. (2018). *Global livestock environmental assessment model, version 2.0* (Model description No. Revision 5). Food and Agriculture Organization of the United Nation.

Gilbert, M., Nicolas, G., Cinardi, G., Van Boeckel, T. P., Vanwambeke, S. O., Wint, G. R. W., & Robinson, T. P. (2018). Global distribution data for cattle, buffaloes, horses, sheep, goats, pigs, chickens and ducks in 2010. *Scientific Data*, *5*(1), 180227. https://doi.org/10.1038/sdata.2018.227

Gonin, A. (2016). Les éleveurs face à la territorialisation des brousses : repenser le foncier pastoral en Afrique de l'Ouest. *Anthropology and Geography*, *707*(1), 28–50. https://doi.org/10.3917/ag.707.0028

Gonin, A., Filoche, G., & Delville, P. L. (2019). Dynamics of access to pastoral resources in a farming area (Western Burkina Faso): Unveiling rights in open access regimes. *International Journal of the Commons*, *13*(2), 1049–1061. https://doi.org/10.5334/ijc.950

Gonin, A., & Gautier, D. (2016). *Herders' territorialities and social differentiation in Western Burkina Faso* [WWW Document]. https://doi.org/10.3197/np.2016.200105

Gonin, A., & Tallet, B. (2012). Changements spatiaux et pratiques pastorales: les nouvelles voies de la transhumance dans l'Ouest du Burkina Faso. *Cahiers Agricultures*, *21*(6), 448–454. https://doi.org/10.1684/agr.2012.0595

Hagos, F., GebreYohans, S., GebreMeskel, K., GebreYohanse, W., Zegey, T., Assfaw, M., & Wamatu, J. (2014). *Using FEAST to characterize the farming and livestock production systems and the potential to enhance livestock productivity through improved feeding in in Golgolnaele, Atsbi-Wonberta District, Tigray, Ethiopia (Report)*. International Center for Agricultural Research in the Dry Areas.

Haileslassie, A., Peden, D., Gebreselassie, S., Amede, T., & Descheemaeker, K. (2009). Livestock water productivity in mixed crop–livestock farming systems of the Blue Nile basin: Assessing variability and prospects for improvement. *Agricultural Systems*, *102*(1–3), 33–40. https://doi.org/10.1016/j.agsy.2009.06.006

Hengl, T., Heuvelink, G. B. M., Kempen, B., Leenaars, J. G. B., Walsh, M. G., Shepherd, K. D., Sila, A., MacMillan, R. A., Mendes de Jesus, J., Tamene, L., & Tondoh, J. E. (2015). Mapping soil properties of Africa at 250 m resolution: Random forests significantly improve current predictions. *PLOS ONE*, *10*(6), e0125814. https://doi.org/10.1371/journal.pone.0125814

Herrero, M., Henderson, B., Havlík, P., Thornton, P. K., Conant, R. T., Smith, P., Wirsenius, S., Hristov, A. N., Gerber, P., Gill, M., Butterbach-Bahl, K., Valin, H., Garnett, T., & Stehfest, E. (2016). Greenhouse gas mitigation potentials in the livestock sector. *Nature Climatic Change*, *6*, 452–461. https://doi.org/10.1038/nclimate2925

Herrero, M., Thornton, P. K., Gerber, P., & Reid, R. S. (2009). Livestock, livelihoods and the environment: Understanding the trade-offs. *Current Opinion in Environmental Sustainability*, *1*(2), 111–120. https://doi.org/10.1016/j.cosust.2009.10.003

Institut National de la Statistique et de la Demographie - INSD/ Burkina Faso, ICF International. (2012). Enquête Démographique et de Santé et à Indicateurs Multiples du Burkina Faso 2010. In Calverton (ed.). INSD et ICF International.

IUCN. (2017). *The IUCN red list of threatened species. Version 2017-3* [WWW Document]. Retrieved December 1, 2017, https://www.iucnredlist.org.

Jakeman, A. J., Letcher, R. A., & Norton, J. P. (2006). Ten iterative steps in development and evaluation of environmental models. *Environmental Modelling & Software*, *21*(5), 602–614. https://doi.org/10.1016/j.envsoft.2006.01.004

Jones, B. A., Grace, D., Kock, R., Alonso, S., Rushton, J., Said, M. Y., McKeever, D., Mutua, F., Young, J., McDermott, J., & Pfeiffer, D. U. (2013). Zoonosis emergence linked to agricultural intensification and environmental change. *Proceedings of the National Academy of Science*, *110*(21), 8399–8404. https://doi.org/10.1073/pnas.1208059110

Kima, S. A., Okhimamhe, A. A., Kiema, A., Zampaligre, N., & Sule, I. (2015). Adapting to the impacts of climate change in the sub-humid zone of Burkina Faso, West Africa: Perceptions of agro-pastoralists. *Pastoralism*, *5*(1), 16. https://doi.org/10.1186/s13570-015-0034-9

Lamoureux, L., & White, N. (2015). Peeking behind the curtain: The realities of facilitation in development. *Knowledge Management for Development Journal*, *11*, 136–144.

Legese, G., Haile, A., Duncan, A. J., Dessie, T., Gizaw, S., & Rischkowsky, B. (2014). *Sheep and goat value chains in Ethiopia: A synthesis of opportunities and constraints* (ICARDA/ILRI Project Report). International Livestock Research Institute (ILRI).

Marshall, K., Gibson, J. P., Mwai, O., Mwacharo, J. M., Haile, A., Getachew, T., Mrode, R., & Kemp, S. J. (2019). Livestock genomics for developing countries – African examples in practice. *Front. Genet*, *10*, https://doi.org/10.3389/fgene.2019.00297

Moll, H. A. J. (2005). Costs and benefits of livestock systems and the role of market and nonmarket relationships. *Agricultural economics*, *32*(2), 181–193. https://doi.org/10.1111/j.0169-5150.2005.00210.x

Notenbaert, A., Lannerstad, M., Barron, J., Paul, B., Ran, Y., Fraval, S., Mugatha, S., & Herrero, M. (2016). *Using the CLEANED approach to assess the environmental impacts of livestock production 4*.

Observatoire du Sahara et du Sahel (OSS) (Ed.). 2015. *Burkina Faso: Atlas des cartes d'occupation du sol, Atlas des cartes d'occupation du sol. REPSAHEL*.

Oosting, S. J., Udo, H. M. J., & Viets, T. C. (2014). Development of livestock production in the tropics: Farm and farmers' perspectives. *Animal*, *8*(8), 1238–1248. https://doi.org/10.1017/S1751731114000548

Panagos, Panos, Borrelli, Pasquale, Poesen, Jean, Ballabio, Cristiano, Lugato, Emanuele, Meusburger, Katrin, Montanarella, Luca, & Alewell, Christine. (2015). The new assessment of soil loss by water erosion in Europe. *Environmental Science & Policy*, *54*, 438–447. https://doi.org/10.1016/j.envsci.2015.08.012

Pfeifer, C., Morris, J., & Lannerstad, M. (2016). *The CLEANED R simulation tool to assess the environmental impacts of livestock production* (Livestock and Fish Brief No. 18). International Livestock Research Institute (ILRI).

Pica-Ciamarra, U., Otte, J., Chilonda, P., 2007. *Livestock policies, land and rural conflicts in sub-Saharan Africa* (Research Report No. RR Nr. 07-04). Pro-Poor Livestock Policy Initiative. Food and Agriculture Organization of the United Nations.

Place, F., Barrett, C. B., Freeman, H. A., Ramisch, J. J., & Vanlauwe, B. (2003). Prospects for integrated soil fertility management

using organic and inorganic inputs: Evidence from smallholder African agricultural systems. *Food Policy, Special Issue on Input Use and Market Development in Sub-Saharan Africa*, *28*, 365–378. https://doi.org/10.1016/j.foodpol.2003.08.009
Randolph, T. F., Schelling, E., Grace, D., Nicholson, C. F., Leroy, J. L., Cole, D. C., Demment, M. W., Omore, A., Zinsstag, J., & Ruel, M. (2007). Invited review: Role of livestock in human nutrition and health for poverty reduction in developing countries. *Journal of Animal Science*, *85*(11), 2788–2800. https://doi.org/10.2527/jas.2007-0467
RCMRD-SERVIR Africa. (2015). *Ethiopia GHG project implemetation guide* (Project implementation guide No. Ethiopia). Regional Centre for Mapping of Resource for Development.
Renard, K. G., Foster, G. R., Weesies, G. A., & Porter, J. P. (1991). RUSLE: Revised universal soil loss equation. *Journal of Soil and Water Conservation*, *46*, 30–33. https://www.jswconline.org/content/46/1/30.
Shapiro, B. I., Gebru, G., Desta, S., Negassa, A., Negussie, K., Aboset, G., & Mechal, H. (2015). *Ethiopia livestock master plan* (ILRI Project Report). International Livestock Research Institute (ILRI).
Smaling, E. M. A., Stoorvogel, J. J., & Windmeijer, P. N. (1993). Calculating soil nutrient balances in Africa at different scales: II. District scale. *Fertility Research*, *35*(3), 237–250. https://doi.org/10.1007/BF00750642
Spugnoli, P., & Dainelli, R. (2013). Environmental comparison of draught animal and tractor power. *Sustainability science*, *8*(1), 61–72. https://doi.org/10.1007/s11625-012-0171-7
Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., & de Haan, C. (2006). *Livestock's long shadow: Environmental issues and options*. Food and Agriculture Organization of the United Nations.
Tatem, A. J. (2017). Worldpop, open data for spatial demography. *Scientific Data*, *4*(1), 170004. https://doi.org/10.1038/sdata.2017.4
Udo, H. M. J., Aklilu, H. A., Phong, L. T., Bosma, R. H., Budisatria, I. G. S., Patil, B. R., Samdup, T., & Bebe, B. O. (2011). Impact of intensification of different types of livestock production in smallholder crop-livestock systems. *Livestock Science*, *139*(1–2), 22–29. https://doi.org/10.1016/j.livsci.2011.03.020
Van Paassen, A., Roetter, R. P., Van Keulen, H., & Hoanh, C. T. (2007). Can computer models stimulate learning about sustainable land use? Experience with LUPAS in the humid (sub-)tropics of Asia. *Agric. Syst*, *94*(3), 874–887. https://doi.org/10.1016/j.agsy.2006.11.012
Voinov, A., & Bousquet, F. (2010). Modelling with stakeholders. *Environmental Modelling & Software, Thematic Issue - Modelling with Stakeholders*, *25*(11), 1268–1281. https://doi.org/10.1016/j.envsoft.2010.03.007
Vrieling, A., Sterk, G., & de Jong, S. M. (2010). Satellite-based estimation of rainfall erosivity for Africa. *Journal of Hydrology*, *395*(3–4), 235–241. https://doi.org/10.1016/j.jhydrol.2010.10.035
Zingore, S., Delve, R. J., Nyamangara, J., & Giller, K. E. (2008). Multiple benefits of manure: The key to maintenance of soil fertility and restoration of depleted sandy soils on African smallholder farms. *Nutrient Cycling in Agroecosystems*, *80*(3), 267–282. https://doi.org/10.1007/s10705-007-9142-2