Towards a system-specific framework for the sustainability evaluation of low-input ruminant meat production systems in developing countries

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Abstract

The concept of sustainability is associated with numerous evaluation approaches making various claims. To their credit, the evaluation approaches contributed to the evolution of the concept from a rather vague and mostly qualitative notion to progressively being defined in more quantitative terms. The diversity of low-input ruminant meat production systems make the use of a single blueprint for sustainability evaluation completely impractical. Most sustainability evaluation approaches fail to adequately and accurately take account of the realities of the low-input production systems. The multifunctionality of ruminant livestock in these systems is omitted from evaluations due to the complexity surrounding its evaluation. Certain ecological benefits of the system such as, carbon sequestered by grazing ruminant livestock, are rarely considered to partially offset some negative carbon and water footprints. Development of a holistic and transdisciplinary system-specific approach that effectively address the complexity and realities of the low-input production could be important. This review examines the strength and weaknesses of currently available sustainability evaluation frameworks and suggest parameters for a system-specific evaluation framework for low-input ruminant meat production.

Keywords: sustainability evaluation approaches, low-input systems, optimization, multiple functions, ruminants

1. Introduction

Low-input food production systems are anticipated to take a proactive role in feeding a growing global human population of more urban based citizens with higher incomes (Thornton et al., 2014). The systems constitute about 85% of the world's farms and are mainly concentrated in developing countries where they are managed by smallholder farmers (Graeub et al., 2016). The majority of the farms are located in marginal areas where crop production is restricted by biophysical and socioeconomic conditions leaving livestock production as the most preferred alternative livelihoods strategy (Christopher, 2009). Ruminant livestock in low-input production systems are raised on rangelands mainly under continuous grazing management with minimum use of external inputs (Tada et al., 2012). These attributes ensure that low-input ruminant meat production systems potentially operate within the prescripts of sustainable livestock production, but, poor management inherently derails this potential (Häni et al., 2003).

The commonly accepted dimensions of evaluating sustainability of production systems are ecological enhancement, economic viability and social solidarity (Olde et al., 2016). In the context of low-input ruminant systems, the economic viability is largely compromised by the low market value of livestock (Tada et al., 2012). Poor rangeland management, which often leads to overgrazing adversely affects the ecological stewardship. Social solidarity is limited by low social capital and gender imbalances in ruminant livestock production (William et al., 2001; Marandure et al., 2017). As such, uncertainty exist over the capacity of the low input systems to respond to increasing global demand for meat (Thornton et al., 2014). Essentially, the perception that the smallholder ruminant production systems in developing countries are not sustainable is widely debated (Ayantunde et al., 2011). Such debates bring the issue of the relevance of tools used to measure sustainability to the fore. A critical analysis of currently available approaches with respect to their relevance in evaluating the sustainability of low-input ruminant production systems, thus, contributes tremendously to such debates. Most sustainability evaluation approaches in use at present are not sensitive to some realities of low-input ruminant production systems (Swanepoel et al., 2008; Bernués et al., 2011). The current review discloses the shortcomings of available sustainability evaluation frameworks in adequately and accurately taking account of complexities inherent in low-input ruminant systems and suggests some key components of a new system-specific approach.

2. The concept of sustainability and importance of its evaluation

Low-input ruminant production systems are expected to provide affordable healthy and safe animal products without damaging the environment (Hoffmann, 2011). This is a principle of sustainable production which conforms to producing more food without using more bio-resources, land, water and energy (Herrero et al., 2010). In contrast, high-input systems are characterised by intensive use of external inputs including fossil fuels and other chemical inputs that contribute to high yields per unit area (Ran et al., 2015). The intensive use of chemicals is associated with severe trade-offs with various environmental, economic and social aspects which compromises the sustainability of high-input systems (Lebacq et al., 2013). More elaborately, sustainability refers to 'using natural, social and human capital assets, combined with the use of best available technologies and inputs (i.e., best genotypes and best ecological management) that minimize or eliminate harm to the environment' (Pretty et al., 2011). The logic of sustainable production is meeting the large, current and future, demand for livestock products without expanding into vulnerable ecosystems (Naylor, 2009; Rockstrom et al., 2009). With sustainable production, the sensitive issues concerning food security, poverty alleviation and social security of farmers in low-input systems can be adequately addressed (Thamaga-Chitja & Morojele, 2014). The benefits of sustainable production, however, should be evaluated using appropriate methods relevant to the system being examined.

Sustainability evaluations are fundamental decision making support tools (Lebacq et al., 2013) which inform on appropriate alternative technologies that facilitate ‘cleaner’ production (Kebebe et al., 2015). In essence, sustainability evaluations set benchmarks upon which production systems are appraised and compared, and where context specific research questions are formulated (Christian et al., 2009; Fleishhauera et al., 2001). Evaluations also facilitate awareness about externalities of prevailing production systems (Fleishhauera et al., 2001). Moreover, linkages between perceptions of farmers regarding their local challenges and the services provided by stakeholders can be ascertained through sustainability evaluations (Fleishhauera et al., 2001). In addition, stakeholders’ engagement during evaluations promote sustainability awareness, lateral knowledge sharing and the capacity of producers to independently address future problems (Fleishhauera et al., 2001; Fraser et al., 2006). As an initial step, a baseline description of the attributes of low-input ruminant systems is essential to give guidance to interventions.

3. Characteristics of low-input ruminant meat production systems

Low-input ruminant systems in developing countries are commonly referred to as smallholder production, low income farming, resource poor farming or low technology farming systems (Calcaterra, 2013). The systems are subdivided into, communal (subsistence) and small-scale (subsistence-cum-commercial) (Lahiff, 2001). In the communal sector, ruminant production is often restricted to small, marginalised areas (Lahiff, 2001). Individual households keep small herds of cattle, sheep and goats comprising of mostly indigenous breeds, although, in cattle non-descript crossbreds with exotic breeds are dominant (Kosgey et al., 2008; Nqeno et al., 2011). These animals continuously graze on communal rangelands and often have free access to crop residues in the early dry season. Animals receive little or no commercial supplements in the dry season (Thamaga-Chitja & Morojele, 2014). Subsistence ruminant producers slaughter animals for household consumption and only sell to informal markets in emergencies such as, paying for medical and social expenses (such as funerals and weddings), school fees and other immediate bills (Musemwa et al., 2010).

Small-scale ruminant producers' access to resources including land and capital as well as level of technology indicate a commercial orientation although, some may still share common characteristics with communal producers (Lahiff, 2001). Thus, they are described as having one foot in the subsistence production sector and the other in the commercial production sector (Mabaya et al., 2011). Most small-scale ruminants producers are not engaged in farming full-time but have other primary professions (Meissner et al., 2013). Daily livestock management is often left to employed managers or trusted family members (Cousins, 2008). This creates employment opportunities which ultimately provide livelihoods to subordinate worker families (Ndoro et al., 2014). Otherwise, small-scale ruminant producers are market oriented, they relatively produce surplus meat for marketing through formal and informal markets (Swanepoel et al., 2008). Overall, neither the challenges nor opportunities for the communal and small-scale producers are uniform although some common generalisations can be safely made (McDermott et al., 2010). Challenges and opportunities vary depending on assets, access to resources, knowledge, scale of production among other differences (Cousins, 2008).

4. Sustainability challenges and opportunities of low-input ruminant meat production systems

The most distinct sustainability challenge of any production system relates to the complexity presented by the triple-fold, multi-objective nature of the sustainability concept (Notenbaert et al., 2017). Ideally, all the ecological, economic and social objectives of sustainability have to be simultaneously achieved (Notenbaert et al., 2017). Practically achieving all the triple-fold goals is rare as trade-offs between the different objectives are often observed. At household level the ecological, economic and social impacts of low-input ruminant production may be considered insignificant but their aggregate influence is undoubtedly huge (Olde et al., 2016). A range of practical production changes are necessary as interventions to address genuine challenges in production systems (Cortez-Arriola et al., 2016). The interventions depend on effectiveness of the sustainable evaluations in pointing out system-specific challenges (Olde et al., 2016). Interventions are, however, often complicated by the baseline state of a system, its response to different circumstances and the number of interlinked activities (Gayatri et al., 2016). For simplicity, the sustainability challenges and opportunities of low-input ruminant systems in the current review will be discussed under the respective ecological, economic and social dimensions.

4.1 Ecological sustainability challenges and opportunities

The ecological challenges of low-input ruminant production systems include; acute dry season feed shortages and poor grazing management (Moyo et al., 2008) leading to low plane of nutrition. As a result poor conditioned and emaciated animals wondering about in deteriorated marginal rangelands is a common sight in rural landscapes (Roy & Chan, 2012; Meissner et al., 2013). Such animals produce inferior carcasses and meat quality at slaughter, which in turn reduces food and income for the low-input producers (Mapiye et al., 2011; Tada et al., 2012).

The consequences of poor rangeland management have very little emotional appeal among low-input ruminant producers who largely perceive rangelands as a free resource capable of existing perpetually (Vavra, 1996; Nowers et al., 2013). As a consequence of the tragedy of the commons (Dube et al., 2016; Hardin, 1968) overstocking and overgrazing expose rangelands to soil erosion, biodiversity loss, bush encroachment and invasion by alien species among other negative effects (Bernues et al., 2005). In this regard, quality and quantity of rangeland biomass, species evenness, plant biodiversity, proportion of invasive species, soil cover, rangeland degradation and stocking rates are among the common ecological sustainability evaluation indicators (Rosa García et al., 2012). It is imperative therefore, that for low-input ruminant meat production systems, net primary productivity, vegetation palatability profiles and animal production parameters should be considered as key indicators.

Proper management of grazing ruminants can be an effective tool to moderate vegetation dynamics, and control bush encroachment in rangelands (Bernues et al., 2005). Ruminants also play a critical role in maintaining rangeland biodiversity and species evenness (Altieri, 1999) by facilitating seed dispersal (Hoffmann, 2011; Rook and Tallowin, 2003) and reducing dominant grass vigour to increase competitiveness of suppressed species (Tittonell et al., 2009; Herrero et al. 2010). The rangeland-livestock nexus enables agro-ecological systems to sponsor their own functioning and increase resource use efficiency (Altieri, 2002). Claims surrounding the perceived safety of livestock products from grazing ruminants also contribute to credence attributes of the low-input ruminant production system (Herrero et al., 2009).

The safety of rangeland-fed meat is centred on the little or no use of artificial fertilizers, pesticides, herbicides, antibiotics, genetically modified organisms, plant growth hormones and/or regulators in forage production, and little or no use of non-forage feed supplements (Chingala et al., 2017). These compounds have been associated with pesticide, herbicide and antibiotic resistance and risk of cancers among other diseases in humans. Furthermore, compared to grain-fed meat, rangeland-fed meat is rich in minerals (calcium, magnesium and potassium), omega-3 fatty acids, conjugated linoleic acids, vaccenic acid, Vitamins A and E, carotenoids and natural enzymes, which have human health benefits (Mapiye et al., 2011). Overall, food safety is a critical component of sustainability. Production practices that are perceived to produce ‘clean’ food, are more preferred by consumers (Loureiro and Umberger, 2007). It may, therefore, essential to include food safety as a sustainability indicator during evaluations.

Other ecological challenges of the system relate to poor animal breeding and health management (Scholtz et al., 2013; Marufu et al., 2011). An alternative sustainable production strategy suggested by Hoffmann (2011) is exploiting heterosis by breeding for improved feed conversion ratio (FCR) in combination with improved health management. Desirable characteristics of indigenous ruminant livestock include adaptation to adverse conditions of high parasitic (ticks and nematodes) infestations, disease prevalence, extreme climatic conditions (heat stress) and low nutrition levels (Scholtz et al., 2011). Owing to their adaptability, indigenous breeds are raised with little or no acaricides, anthelminthics, hormones and antibiotics and non-forage feed supplements, the potential for ecologically sustainable meat production from these breeds is high. Thus, the more adapted indigenous breeds are appropriate for use by marginalised livestock producers living under challenging ecological and socio-economic conditions (Scholtz et al., 2013). The desirable attributes of indigenous livestock provides raw materials in crossbreeding programs to improve the less desirable traits, such as, low reproductive rates and adaptability traits of the exotic breeds (Scholtz et al., 2011; Nyamushamba et al., 2017). The vast animal genetic diversity of indigenous livestock owned by the producers contributes towards the robustness of the low-input production system (Scholtz et al., 2013). Livestock species and breed diversity which essentially increase adaptive capacity and reduce vulnerability in low-input ruminant systems to weather variability and climate change is also important (Martin and Magne, 2015). Practical operational changes can reduce some of the ecological challenges highlighted and exploit the multiple benefits of ruminant livestock.

Ruminants convert some idling marginal resources like fibrous forages and crop residues into forms that can enter the human food chain (Randolph et al., 2007). This transforms unproductive marginal land for productive use by enhancing soil fertility through animal dung and urine (Chaudhry, 2008). Herrero et al. (2009) reported that on average, livestock manure nutrients account for 14% nitrogen, 25% phosphorus and 40% potassium of total soil nutrients, although, there are soil type and production system variations. This attribute upholds the importance of ruminants in rangeland-based and crop-livestock systems as providers of alternative fertilizers with lower environmental and economic footprints (Herrero et al., 2009). Rangeland reinforcements with legumes also have associated environmental benefits of fixing nitrogen into the soil, thereby, enhancing soil fertility, plant and animal production (Moyo et al., 2008; Selemani et al., 2013).

Ruminant livestock are reported to be the major contributor to anthropogenic greenhouse gas (GHG) emissions producing an estimated 18% of the world’s total emissions (FAO, 2006; Vavra, 1996). Of this percentage, about 34% is attributed to CO_2 release as a result of deforestation during land-use conversion for livestock feed production or rangeland extension and 31% is attributed to N_2O release from manure and slurry dumps. The GHG emissions contribute to the ‘greenhouse effect’ which later exerts extreme climatic conditions that affect livestock production (Nardone et al., 2010). However, massive land-use conversion for livestock production and accumulation of manure and slurry dumps are mainly associated with industrial (feedlot) livestock production. It would be less appropriate to assign the same proportion of GHG emission to extensive livestock production systems. Pitesky et al. (2009)

and Scholtz et al. (2013) questioned the blanket assignment of deforestation to livestock feed production alone and not to other agricultural activities. In low-input livestock production systems, rangelands are managed in their natural state and dung and urine are distributed evenly during grazing and contribute to positive environmental footprints (Herrero et al., 2009). Thus, the GHG emissions proportion attributed to enteric rumen fermentation can be logically extended to grazing ruminant livestock in low-input systems (Bernués et al., 2011).

The GHG emission estimate fail to consider that deposition of livestock dung and urine in rangelands promotes sequestration of nutrients, including carbon, into the soil and reduces volatilization of GHG (Herrero et al., 2009; Scholtz et al., 2013). It is therefore, prudent to include carbon sequestration levels or soil organic matter level as ecological indicators in sustainability evaluations which will then be discussed in relation to GHG emissions.

Increasing use efficiency of available resources including livestock must be prioritized as it results in reductions in the environmental footprint (FAO, 2006). Herrero et al. (2009) suggested that improving livestock diets through rangeland management and supplementation with crops and crop by-products can increase livestock products per unit of methane produced. Alongside GHG emissions, livestock production is estimated to use 8% of the global freshwater supply (Beede, 2012). Of the total water footprint of livestock, only 1% is used to nourish animals, service farm operations and for products processing. The bulk of the water is used to irrigate pastures and feed crops for use in industrial livestock production (Doreau et al., 2012). This component of livestock water use cannot be attributed to low-input ruminant production systems as they are rain-fed systems, hence, their low water footprint (Doreau et al., 2012). The water use efficiency of producing one kilogram of animal protein is not different from that of plant protein (Beede, 2012). Exceptions are soybean that is produced more water efficiently than milk, goat meat and chicken and egg protein whose water efficiency is greater than all plant proteins (Beede, 2012). Sustainability evaluations can provide system-specific guidelines to improve precision in resource-use and minimize environmental degradation (Pretty, 2008). Unfortunately, negative ecological impacts of ruminant livestock production are not reflected in market prices of livestock products. The negative ecological impacts are considered external or non-market costs (Pretty, 2008).

4.2 Economic sustainability challenges and opportunities

Poor access to stable and reliable markets, lack of marketing information, inferior production infrastructure, lack of finance and institutional support are among the economic sustainability challenges of the low-input ruminant production systems in developing countries (Coetzee et al., 2004; Lubungu et al., 2012). For most low-input ruminant producers with no access to formal financial institutions, livestock provide opportunities to save or accumulate capital. They also guarantee financial security and help finance their planned and unplanned expenditure (Coetzee et al., 2004). Marketing of ruminants usually occurs in times of desperate need for cash often in emergencies (Musemwa et al., 2010). Sustainability evaluations expressed as economic well-being based on the cost-benefit analysis, however, often fail to adequately and holistically consider production goals and other important non-monetary values bestowed to livestock (Hoffmann, 2011; Mezher et al., 2011).

Common economic indicators used in sustainability evaluations include, livestock income, net total farm income, resource use efficiency, livestock productivity, total farm productivity and total livestock market offtake (Bernués et al., 2011). Toro-Mujica et al. (2012) suggested that evaluations should go beyond focusing on conventional commercial turnover principles, cost-benefit analyses and production-based valuations to avoid excluding other non-monetary roles of ruminants such as draft power and production of manure which are prioritised by low-input ruminant producers. Conventional management or production-based indicators often miss some common realities prioritised by low-input ruminant producers (William et al., 2001). Instead, practice-based indicators such as, system input, self-sufficiency and diversity of income are more sensitive to the realities of low-input ruminant producers. Proportion of locally sourced to externally acquired inputs gives an indication of the input self-sufficiency which improves resilience of the system (Escribano et al., 2006). Usually the less dependent the system is on subsidies, donations, external inputs or grants, the greater the system's self-reliance (Escribano et al., 2006). As mentioned earlier, rangeland-fed meat is becoming an important form of value-addition in several countries worldwide, due to increased demand for healthier foods. In most developing countries, consumers are willing to pay a premium for rangeland-fed meat (Loureiro and Umberger, 2007) thereby, contributing towards the economic dimension of sustainability. However, a study by Marandure et al. (2016b) revealed that South African consumers are price sensitive and not willing to pay a premium for rangeland-fed beef. Thus, premium payments may not be a relevant economic indicator in low-input ruminant production systems. Carbon sequestration might provide an alternative income in the future through rebate payment of ecosystem services (Herrero et al., 2009). However, this will require incentive systems, institutional linkages, policy reforms, carbon stocks monitoring techniques and verification protocols to be first established (Herrero et al., 2009). For most developing countries, however, the conditions are not yet in place to measure and develop a payment system for ecological stewardship.

It is common practice among low-input producers in developing countries to reduce risks by diversifying their livestock production activities, and in the process, income. Diversity is reflected in the combination of crops grown, livestock species and breeds kept, other on-farm activities (e.g., crafting, smelting and equipment repairs) and off-farm activities. Bernués et al. (2011) described the diversity in low-input ruminant systems with regards to use of resources, degree of intensification, species and orientation of production. In this regard, diversity of income can be considered as an important economic indicator in sustainability evaluations of low-input ruminant livestock production systems. The total economic value of livestock on hand can also be a more appropriate economic indicator than profitability. However, the role of ruminants as direct income sources is inferior to other socio-cultural roles in these systems (Randolph et al., 2007). Musemwa & Mushunje (2008) argue that imposing market oriented goals will reduce the importance of some of the social roles of livestock.

4.3 Social sustainability challenges and opportunities

Low-input ruminant producers in developing countries thrive to achieve household food security and improved livelihoods (Ainslie et al., 2002). The potential of ruminants as vehicles for improved household food security is through rapid recycling of non-food biomass (Herrero et al., 2009). Livelihoods options are offered by large ruminants, especially cattle, providing draft power that is used for ploughing, transportation of goods and often hired for cash or kind (Swanepoel et al., 2008). Cattle are estimated to constitute about two thirds of large ruminant livestock used to provide draft power in low-input farming systems in developing countries (Herrero et al., 2013). Bernués et al. (2011) described the role of low-input ruminant production systems as satisfying societal ethical concerns about food production or demands for public goods such as landscape and biodiversity.

The livelihoods options in the low-input systems do not seem to be attractive to the young generation. Many low-input societies, including ruminant production systems, show a common trend of youths migration to urban cities to seek employment in the commercial sector (Lahiff, 2001). A similar trend was also reported among small-scale livestock farmers in the mountainous areas of the European and Mediterranean basins (Bernués et al., 2011). The youths shun livestock management duties, such as herding, which they consider harsh and not satisfactorily rewarding (Dapaah et al., 2001; Nqeno et al., 2011). The implications are that ruminants production is abandoned or left for the elderly pensioners who often lack the energy and willpower to improve production (Dapaah et al., 2001). The result is lack of intergenerational succession which substantively threaten the sustainability of low-input ruminants production systems (Bernues et al., 2005). In this regard, continuity of the low-input ruminant production can be used as an important social indicator of the system. According to Bernués et al. (2011) continuity is determined by existence of children in the household that are willing to inherit livestock production activities. Willingness to inherit livestock production activities was found to be positively correlated to the value of available farm assets and negatively correlated to the opportunity cost for off-farm employment (Bernués et al., 2011).

Small-scale livestock farmers from the European and Mediterranean basin mentioned excessive dependency on premiums, continuous abandonment of marginal areas and concentration in more favourable areas as threats to the future of ruminants production (Bernués et al., 2011). Similarly, ruminants production in low-input systems of developing countries is stalled by excessive dependency on donations and government grants (Thornton et al., 2007). Donations and grants provide alternative income source which may discourage farmers from actively engaging in agricultural activities. Marandure et al. (2017) found that pensions and social grants were the most common sources of income for low-input cattle producers in South Africa. The culture of dependency on social grants need to be replaced by local-based livelihoods options (Cousins, 2007). Sustainability evaluations are critical to point out the existence of any inappropriate policies or institutional obstructions in this regard

(Bennett et al., 2007). Some critical factors of low-input ruminant livestock production developed by Bernués et al. (2011) are listed in Table 1.

The societal perspective assesses whether low-input ruminant systems contribute to overall sustainable development of the society (WCED, 1987). Cultural norms in many societies in developing countries associate ownership of ruminants with social well-being (Swanepoel et al., 2008). This notion is confirmed by numerous studies that reported a positive correlation between livestock ownership and household food security (Chikura, 2006; Ndhleve et al., 2012; Melorose et al., 2015). In addition, Dapaah et al. (2001) reported enhanced household social status for families with high livestock holding and strengthened social bonds developed through sharing of livestock for food (i.e., meat and milk), draft power, breeding and socio-cultural purposes. In this regard, livestock numbers can be used as a social indicator representing the diverse and complex potential roles of livestock.

Ruminants owned by women contribute to gender balance through elevating their social status (Njuki et al., 2011). Elevated social status often translate to access or even authority over a broader base of community resources (Njuki et al., 2011). Other significant roles of ruminants in socio-cultural practices include payment of bride price, wedding gifts, inheritance, ancestor communion and circumcision presents (Coetzee, 1998). Normally, young adults or newly married couples are given livestock as starting capital to their new independent lives. Ruminants also have uses in veneration of ancestral spirits, installation of spirit-mediums, appeasing avenging spirits, exorcism of evil spirits and payment for services rendered by traditional healers (Mapiye et al., 2009; Tembo et al., 2014). Additionally, livestock have an aesthetic value of contributing to a diverse and pleasing rural landscape (Fleishhauera et al., 2001).

Currently available sustainability evaluation approaches ignore the unique credence attributes of low-input ruminants production systems in developing countries (Atanga et al., 2013). The credence attributes of the social dimension of sustainability relate to animal welfare aspects of more natural animal rearing, limited handling, and spacious housing practices. Current research shows that stress-free livestock that are allowed to express their natural behaviour are healthier (Horgan and Gavinelli, 2006), thus more productive in terms of quantity and quality. The quality of meat from rangeland-fed ruminants is also enhanced by limited use of external chemicals as mentioned earlier, thereby, contributing to food safety. Another credence attribute is that grazing ruminants are considered to contribute to a magnificently pleasant rural landscape (Herrero et al., 2009). Kosgey et al. (2006) referred to such non-monetary credence roles as 'intangible' or 'Z-goods'. The challenge in evaluating the complex non-monetary roles of livestock to enable their inclusion in sustainability evaluations. Thompson & Nardone (1999) suggested that sustainability evaluations prioritize the functional integrity of grazing ruminants and their surrounding environments than resource sufficiency. For example, the contribution of ruminant livestock as dowry is completely disregarded in most sustainability evaluation methods despite the tremendous contribution of livestock in this regard. The important benefits of ruminant livestock in the smallholder sector can only be achieved when alternative production strategies that use the best combination of resources are identified. Matching the benefits to sustainability requires a generic sustainability evaluation approach which is developed around the strengths of available approaches. This presents the importance of developing an appropriate approach that evaluates and incorporates these multiple roles of ruminant livestock into the main sustainability evaluations.

The role of ruminant livestock towards fulfilling the multiple producer goals is important. However, social issues are complex and conditions that define social sustainability are not clearly understood (Boogaard et al., 2011). Critical elements of the social dimension of sustainability are also not well established, they can vary from good health, access to adequate safe and healthy food, good governance among other elements (Dapaah et al. 2001; Marandure et al., 2017). Overall, the diversity of challenges require more than a single mitigation strategy. In this regard, Marandure et al. (2017) advocated for more holistic and transdisciplinary interventions, that consider the socio-economic and ecological capacity of the low-input ruminants production systems. Holistic interventions are also important to direct efforts towards more efficient use of resources (Marandure et al., 2017). It is therefore, necessary to analyse available approaches and create a conceptual foundation for a generic approach in the context of low-input ruminant production systems.

5. Sustainability evaluations of low-input ruminant production systems

The numerous available sustainability evaluation approaches for agricultural production systems differ in a number of aspects (Christian et al., 2009). Variations exist in scope (geographical and sectorial), general aims and objectives and target group (e.g. producers or policy makers) (Binder et al., 2010; Lebacq et al., 2013; Schader et al., 2014). Other variations exist in protocol for selection and aggregation of indicators as well as the time required for execution (Binder et al., 2010). Evaluation objectives also vary widely including purely scientific research, for monitoring or certification purposes, landscape planning tools (Goswami et al., 2017). Other sustainability evaluation objectives include environmental impact assessments, farm decision making purposes, strengths and weaknesses of production systems, benchmarks for management improvement and for policy advice (Goswami et al., 2017).

The diversity of evaluation procedures dictates that using a single blueprint for sustainability evaluation for different purposes is not feasible. Consequently, diverse evaluation approaches are linked to mixed results and interpretations making sustainability cross comparisons between farms, communities, landscapes, production systems, countries or regions more complex (Lopez-Ridaura, 2005; Munda, 2005; Zingore et al., 2009). Instead, Rigby et al. (2001) expressed that the mixed results, interpretations and conclusions drawn from studies differing in perspectives, agendas and priorities can provide a window to genuine insights. Furthermore, Thornton et al. (2014) predicted that the diversity will likely identify new research direction and new support tools to aid decision and policy making at multiple scales for further development of livestock production.

Overall, sustainability evaluation approaches have been categorised into numerous broad classes. Binder et al. (2010) recognised three classes namely; top-down farm assessments, top-down regional assessments with some stakeholder participation, and bottom-up integrated participatory or transdisciplinary approaches. Ness et al. (2007) categorized sustainability approaches into indicator-based, product-related, and integrated assessment approaches. Other approaches were categorised as farm-level assessment frameworks, participatory tools, scenario analysis tools, multi-criteria analysis tools, physical analysis tools, cost-benefit and cost-effectiveness analysis tools (De Ridder et al., 2007). Gasparatos (2010) mentioned biophysical, monetary, or indicator-based classes. Three broad categories reported by Lebacq et al. (2013) include; method-based approaches, objective-driven approaches and data-driven approaches. Categories given by Lopez-Ridaura (2005) included evaluations through indicators, composite indices and methodological frameworks. Most approaches, however, were designed for cropping systems with only a few dedicated to specialised livestock production systems (Ness et al., 2007). A multidimensional, transdisciplinary framework should, therefore, be formulated to underpin sustainability evaluations of ruminant production in low-input systems. Preceding the development of the framework is extensive literature search of available sustainability evaluation methodologies with particular reference to their applicability to low-input ruminant systems. In as much as sustainability evaluation of a system can be done through models or life cycle analysis (LCA), indicator-based approaches at farm levels will be considered for detailed analysis. Evaluations that use models alone are rare while, using the LCA is criticised for being biased towards the environmental impacts of production with little emphasis on the economic and ecological dimensions of sustainability.

5.1 Indicator based sustainability approaches

Indicator-based approaches depend on selection of a set of measurable ecological, economic and social aspects of production used to quantify the sustainability of the system. The approaches demonstrate greater potential to capture the complexity and interconnectedness within production systems (Roy & Chan, 2012). The strength of such approaches is flexibility of handling a large number of criteria, their respective weighting, and a single score for overall evaluation of the system (Schader et al., 2014). At the core of sustainability evaluation approaches is indicator selection and aggregation techniques (Lopez-Ridaura, 2005). The two stages determine the strength of sustainability evaluation approaches. An indicator quantifies and simplifies complex realities into manageable amount of information (Roy & Chan, 2012). According to Binder et al. (2010), selecting few indicators might results in some critical aspects of sustainability and certain trade-offs escaping the analysis. Alternatively, using too many indicators complicates data collection, validation and proper monitoring of some relationships within a system.

Ideally, selection of indicators is not a prerogative of researchers but should be a collective exercise of all local stakeholders in the production system including farmers (Dumanski et al., 1998). This is contrary to top-down approaches that are criticised for often missing locally important measures (Fraser et al., 2006). Without consultations of all local stakeholders, sustainability evaluations merely reflect researchers' perspectives based on the research objectives (Dumanski et al., 1998). In bottom-up approaches, the role of researchers is to facilitate the process guided by their prior expertise (Dumanski et al., 1998). Such stakeholder involvement or public participation facilitates smooth adoption of the sustainability assessment results (Wagner, 2013). Otherwise, end users might ignore the whole process and its outcome if they are completely left out of the process (Marchand et al., 2014). The downside of active consultation in indicator development processes can be time and resource intensive (Wagner, 2013). In addition, it carries a risk of creating non-standardized data that complicates comparisons between regions (Boogaard et al., 2011), as sustainability indicators are not universal system, site and time specific (Ayantunde et al., 2011).

In as much as standardised sustainability evaluation tools are important for cross comparisons of ruminant production systems, the diversity of the systems should be adequately and accurately addressed by system-specific indicators. Studies that do cross comparison of different livestock production systems using a similar set of indicators tend to ignore the dynamic operational differences and production goals of the systems (Schader et al., 2014). For example, Atanga et al. (2013) used a similar set of indicators to assess sustainability of pastoral, agro-pastoral and landless intensive livestock production systems in Ethiopia. The conclusions drawn from such studies do not reflect the differences in livestock assets, goals, operational procedures or standards within the systems. However, some indicators are universal and can be applied at multiscale levels. For example, the input self-sufficiency indicator used to compare locally sourced to externally sourced inputs would be a relevant universal multiscale economic indicator. Otherwise, economic indicators used by the same authors, namely; gross farm income, savings and investments may contribute to misinterpretation of low-input ruminant system sustainability.

There is no set of indicators, no matter how comprehensive, that can precisely describe a system over a period of time (Walters et al., 2016). Research, therefore, remains constrained by lack of quantifiable and verifiable standardized sustainability indicators that can be used for comparisons of different locations or across production systems overtime (Ayantunde et al., 2011). This is equally true for methods used to aggregate indicators. Aggregation methods can involve the use of complicated mathematical equations (Grenz et al., 2009), models (Schindler et al., 2015), radial diagrams (Ran et al., 2015) or composite indicators (Olde et al., 2016).

Composite indices reduce the complexities of observing the value of individual indicators relative to their optimum level in sustainability evaluations (Christian et al., 2009). The indices integrate information from a set of sustainability indicators into a compound value to allow for a more rapid comparison of policy options and providing one big sustainability picture of the systems (Olde et al., 2016). Composite indices are, however, criticised for hiding sustainability challenges of some indicators or dimensions in a compound value (Olde et al., 2016). It is possible for indicators with high sustainability values to compensate for those with low values in a composite index, thereby, presenting a serious lack of transparency for problems resulting in misinterpretations (Meul et al., 2008). Furthermore, discrepancies arise from the scientific philosophy used to decide on the criterion for allocation of weights to each indicator (Franco et al., 2012). A practical tool based on composite indices provide a measure of long-term sustainability in low-input ruminant production systems in developing countries. The following sub-sections give a summary selected indicator-based sustainability evaluation approaches that do not pool the different dimensions into a single index.

5.1.1 ‘Indicateurs de Durabilité des Exploitations Agricoles’ (IDEA) method

The IDEA method is an acronym which when translated from French means Farm Sustainability Indicators. The method was designed by a multidisciplinary team of 30 French experts as a self-assessment framework for farmers (Zahm et al., 2007). The framework of the IDEA method involves 41 predetermined indicators which evaluates three major sustainability scales namely, the agro-ecological scale, the socio-territorial scale and the economic scale (Table 1; Zahm et al., 2007). Each indicator is allocated a numerical score and weight according to discretions suggested by the team of experts. A score for each scale is computed as cumulative weighted aggregate of each individual component and the sustainability scale with the lowest score taken as the overall sustainability score of the whole system (Zahm et al., 2007).

According to Marie et al. (2011) the IDEA method was designed in the context of French and European conditions and references. Major modifications would be required before it can be applied to low-input ruminant systems in developing countries (Zahm et al., 2007). For example, Marie et al. (2011) showed that different indicators or scaling of indicators have previously been done to adapt the method for assessment of dairy production in Algeria and Egypt. The method was restricted by its inflexibility in indicator selection as well its reliance on rigid objectives. There are no provisions to include other non-economic roles of ruminant livestock in the sustainability evaluations using the IDEA method. The IDEA method has also been considered weak when applied to sustainability measurements of other specialised production practices (Zahm et al., 2007). The top-down approach employed by the method on goal setting, indicator selection and aggregation procedure is the most prominent weakness of the method (Olde et al., 2016).

5.1.2 Monitoring Tool for Integrated Farm Sustainability (MOTIFS)

The MOTIFS method was developed by researchers to specifically evaluate individual Flemish farms. According to Meul et al. (2008) the method is based on 47 weighted indicators grouped in 10 themes: use of inputs, quality of natural resources, biodiversity (ecological), productivity and efficiency, profitability, risk (economic), internal social sustainability, external social sustainability, disposable income, entrepreneurship (social), with three levels of aggregation. The indicators are allocated scores between 0 (undesirable levels or non-sustainability) and 100 (ideal sustainable levels).

Indicators relevant to the developed themes are obtained from literature, except when no indicators from literature do not match some themes, then stakeholders and experts are consulted in developing appropriate indicators (Meul et al., 2008). Otherwise, stakeholders consultations are also considered for other stages of evaluation (Meul et al., 2008). Under the MOTIFS method, the economic, ecological and social sustainability dimensions are considered equal and this principle of equality is inherently built into the system (Meul et al., 2008). In cases where all the matching indicators exist in literature, the method resembles a top-down approach. The fact that reference values for each indicator are determined by researchers (Meul et al., 2008) is a further reflection of the top-down approach phenomenon. Quantification of indicators relies on data that is readily available on-farm, thereby, making it inappropriate for application in low-input ruminant meat production systems where data records are not readily available. The MOTIFS method is dominated by performance-based indicators. It has been suggested that practice-based indicators could be more appropriate for low-input ruminant systems in developing countries (Marie et al., 2011).

Some tools such as, the MOTIFS (Monitoring Tool for Integrated Farm Sustainability) combine the use of available literature with limited key expert consultations during indicator development (Meul et al., 2008). In principle, most indicators are derived from literature and key experts consultations are done in cases where literature fail to provide some indicators (Marie et al., 2011). The application of the tool in low-input ruminant production systems is associated with challenges related to predetermined themes and indicators which may not be relevant in the context of the systems in developing countries (Grenz et al., 2009). The lack of substantive stakeholder consultations is also a drawback of the tool. The tool is also restricted by its dependence on available farm data which might not be readily. In addition, MOTIFS is dominated by the use of performance-based indicators whereas, practice-based indicators are considered more appropriate for low-input ruminant systems in developing countries (Marie et al., 2011).

Practice-based indicators could be more desirable in low-input ruminant systems where production or management records are not available than the production-based indicators used in most evaluation approaches (Gayatri et al., 2016a). Ecological practice-based indicators should assess inputs self-sufficiency, biodiversity, biomass flow, land degradation, stocking rates, proportion of invasive species and levels of chemical use and soil organic matter among others. Economic practice-based indicators should include diversity of income sources, total value of livestock, value of other multiple non-monetary roles of livestock and direct costs associated with ruminant production. Social indicators could include intergenerational inheritance, involvement of producer in livestock based organisations, household food adequacy and gender access to livestock resources. The method used for aggregation of the indicators is important as it determines the effectiveness of the sustainability evaluation approach.

Most approaches are measurement-based, where the sustainability concept is decoded into a quantifiable set of indicators used to construct metrics which define the sustainability of the system. Thus, management-based approaches treat indicators as isolated variables during analysis whilst, ignoring the dynamic inter-relationships between them (Sala et al., 2015). For simplicity, the third step of a system-specific evaluation should consider a topical aggregation of indicators using the measurement-based approach at local stakeholders' level to produce preliminary or tentative sustainability results.

5.1.3 The Driver-Pressure-State-Impact-Response (DPSIR) framework

The framework was directly derived from the Driver-State-Response (DSR) framework which was developed in 1993 by the Organisation for Economic Cooperation and Development (OECD) (Hong, 1994). The DPSIR framework illustrates the cause-effect relation of agricultural practices on the environment (Ran et al., 2015a). Specific to this study, livestock production activities are the 'driving force' disturbing the environment by exerting a 'pressure' (Ran et al., 2015a). As a result the environment assumes a particular 'state', which, in turn can 'impact' the wellbeing of the ecosystem, the economy or society (Mondelaers et al., 2009). Finally, undesired levels of drivers, pressures, states or impacts might trigger a 'response' from society (Mondelaers et al., 2009). Indicators that are relevant for assessment of each stage are defined at every level.

The greatest limitation of the DPSIR framework is its strong inclination towards environmental issues without adequately addressing the economic and social dimensions of sustainability

(Goswami et al., 2017). Some indicators cannot be classified under one category of the framework, for example, carbon dioxide (CO_2). Emission of CO_2 exerts a pressure to the environment; CO_2 concentration is a state; increase atmospheric CO_2 concentration has an impact of rising temperature, whereas, the CO_2 related tax is a response (Goswami et al., 2017). Furthermore, the conceptualization of complex and dynamic interrelationships among the components is too simplistic (Goswami et al., 2017). Pressure, state, and response are connected by complex and dynamic relationships and cannot be captured by linear frameworks such as PSR and DPSIR (Goswami et al., 2017). The framework is also criticised for lacking focus on policy (Goswami et al., 2017) .

5.1.4 Response Inducing Sustainability Evaluation (RISE) method

The RISE method was developed at the Swiss College of Agriculture, as a holistic approach to facilitate communication and coordination processes from all stakeholders from farm to policy levels (Grenz et al., 2009). The method is designed to assess sustainability at a single farm level over a period of a year (Häni et al., 2003). Data is collected through farmer interviews using questionnaires and collected data is subjected to a computer model that integrates 57 sustainability parameters into twelve indicators (Grenz et al., 2009). The twelve indicators include energy, water, soil, biodiversity, emission potential, plant protection, waste and residues, cash flow, farm income, investments, local economy and social situation (Häni et al., 2003). The process of indicator development involves extensive literature review, stakeholder participation and consultations with key experts (Grenz et al., 2009). Each indicator is evaluated based on a “State” (S) which is the current condition of the specific indicator and a “Driving force” (D) which indicates a measure of the estimated pressure the farming system places on the specific indicator (Grenz et al. 2009). The “Ds” are determined from direct parameter measurements. The standardized scale for the “S” and “D” of each indicator ranges from 0 to 100 where higher values are more desirable for the “S” (S=100) while lower values are desirable for the D (D=0) (Grenz et al. 2009). The aggregate value of each indicator (DS) is given by “DS”= “S” – “D” with values ranging from -100 to +100 (Grenz et al. 2009). The overall results are summarized and displayed in a sustainability polygon. The benchmark values used for each indicator are derived and/or adapted from literature (Häni et al., 2003).

The challenges of the RISE method are related to its predetermined themes and indicators which may not be relevant in the context of the low-input ruminant production systems in developing countries. The complexity of data analysis technique in the RISE method excludes other stakeholders including farmers and this may affect dissemination and adoption of recommendations made from the analysis. The reliance on conventional economic principles such as, cash flow analysis, labour or capital profitability and other economic parameters renders the method unsuitable for low-input ruminant meat production systems in developing countries. According to Häni et al. (2003) a highly-trained analyst is required for an in-depth assessment that gives the “S” and “D” values. In addition, the RISE method has greater application in evaluating sustainability at individual farm level but may be compromised when applied to low-input production systems (Häni et al., 2003).

5.1.5 Sustainability Assessment of Food and Agricultural systems (SAFA)

The SAFA framework identifies good governance, environmental integrity, economic resilience and social well-being as the four dimensions that guide or characterise global food and agricultural systems (FAO, 2013). The SAFA framework then describes the essential sustainability principles for each of the four dimensions based on international and conventions reference documents (FAO, 2013). The framework is based on 21 broad themes defined by 58 sub-themes measured by 116 indicators developed through expert consultations (FAO, 2013).

Most sustainability indicators of the SAFA framework are performance rather than practice-based. Nevertheless, the framework can be adapted to the low-input ruminant systems by excluding irrelevant themes and replacing performance-based indicators with practice-based ones in assessments (Gayatri et al., 2016).

The SAFA framework is considered to be multi-scale, multi-sectorial and adaptable to individual conditions of evaluated entities. Similar to the RISE method, application of the SAFA framework to low-input ruminant systems is weakened by its use of predetermined themes and sub-theme indicators. Analysis of data for the SAFA framework is through a specialised SAFA software and this might exclude most low-input ruminant producers from the process leading to low adoption of research recommendations.

5.1.6 Marco para la Evaluación de Sistemas de Manejo de Recursos Naturales mediante Indicadores de Sustentabilidad (MESMIS)

MESMIS is an acronym which when translated from Spanish means ‘Indicator-based Sustainability Assessment Framework’. The framework, specifically designed for multi-scale (farm, municipal, sub-regional and regional) sustainability evaluation of natural resources management, was developed by a group of Mexican researchers and developmental workers (Astier et al. 2012). The MESMIS has been adapted to some low-input agricultural systems in South America, Europe and Asia (Ran et al., 2015a). The framework is based on five general attributes related to sustainability namely: (1) productivity (capability of the system to provide sufficient goods); (2) stability (reaching and keeping a stable and dynamic balance); (3) adaptability (finding new balance in changing environmental conditions); (4) equity (fair intra- and inter-generational distribution of costs and benefits) and (5) autonomy (or self-management).

The sustainability evaluation process involves active participation of stakeholders following six steps shown in Figure 1 and represented as: (1) characterization of the system; (2) identification of the crucial points which enhance or constraint its attributes; (3) identification of a set of diagnostic criteria, then selection of strategic indicators; (4) measurement of indicators; (5) synthesis and integration of results; and (6) conclusions and recommendations (Astier et al., 2012). Finally, case studies are done in different geographical locations to validate and give feedback to the framework.

The MESMIS framework lacks strategies for integration and analysis of the dynamic behaviour of low-input ruminant systems in the context of developing countries in Africa. The flexibility of the framework is also limited by the themes or sustainability attributes that are pre-set. In that regard, deriving indicators for some themes such as, stability and resilience is difficult (Astier and García-Barrios, 2012). The other weakness which is also common to other methods is the assumption that all stakeholders have prior knowledge of the sustainability concept, therefore, can contribute positively towards evaluation thereof. In most communities in the developing countries, the sustainability concept is hardly understood by most ruminant producers (Ayantunde et al., 2011). Moreover, the low literacy levels of most producers limits the strength of indicators developed. Marandure et al. (2017) demonstrated the scientific naivety of sustainability indicators developed solely by low-input livestock producers. Nevertheless, despite the weaknesses of the highlighted sustainability evaluation methods, they remain essential in disclosing the operational viability of production systems (Herrero et al., 2013). The fact that local sustainability concerns arise from lack of awareness of the concept in most developing countries further reinforces the importance of developing a unique system-specific approach, especially for low-input ruminant systems.

6. Towards a system-specific approach for sustainability evaluation of low-input ruminant production systems

The available sustainability evaluation approaches demonstrate individual limitations when applied to low-input ruminant systems. This is not surprising given that the approaches were designed in light of evaluating livestock production systems in different contexts (Gayatri et al., 2016; Latruffe et al., 2016; Lebacq et al., 2013). However, the huge variations between ruminant systems in developed and developing countries precludes the judicial application of these approaches in both systems. For example, relevant production information is widely accessible in the developed countries but rarely available in most developing countries. Differences also exist in the level of technology, literacy level of producers, production goals as well as support services available. Despite the differences, there are rare isolated reports of modified versions of the approaches used to assess sustainability in low-input ruminant systems. In light of the challenges highlighted, a baseline blueprint for a system-specific evaluation approach for low-input ruminant systems in developing countries is therefore proposed.

The proposed system specific framework should incorporate a component of sustainability awareness. This component should ascertain prior knowledge of the sustainability concept and spread awareness of the principles of sustainable livestock production to all stakeholders. Perceptions of local ruminant producers on sustainable production should also be established to inform on broad based social, ecological and economic issues that will help to develop sustainability evaluation themes. This can be done through individual interviews of different stakeholders. If there are any institutions or organisations that promote sustainable livestock production in the respective areas, they can also be identified at this stage for possible collaboration.

The new framework, as presented in Figure 2, should provide an interactive platform where ruminant producers and other stakeholders highlight the challenges and opportunities of the local ruminant production system. Ruminant producers should particularly state their production goals and outline their current and desired production status. The current and desired multiple functions of ruminant livestock in the respective communities should also be identified and recorded. If the identified multiple functions of ruminant livestock are considered as multiple products of the system, they can be allocated an economic value and incorporated into the economic dimension of sustainability. Functions, such as, provision of meat and milk already have direct market values whereas, provision of draft power and manure can be derived indirectly. However, other social functions of ruminants such as, a sign of wealth are difficult to allocate economic values. In this regard, producers and other stakeholders can be asked to allocate social values relative to the function's importance to their livelihoods. To accomplish this, producers must be allowed to do a free listing of all the functions of ruminant livestock in their production system. The multiple functions can then be categorised into; those with a direct economic value, those whose values can be derived and those whose values need to be determined by stakeholders. Alternatively, all functions can be allocated weights by stakeholders relative to their importance to their livelihoods. The weights can then be transformed into scores for incorporation into sustainability evaluations. Similarly, credence values of the low-input ruminants systems can be free listed, allocated weights by stakeholders before being transformed into scores and incorporated into the proposed approach.

It is possible that the low literacy levels of most ruminant producers in low-input production systems (Ndhleve et al., 2012) and lack of production records might preclude the development of scientifically sound indicators (Marandure et al., 2017). In this regard, the qualitative and quantitative information derived from the discussions with stakeholders can facilitate setting up sustainability evaluation themes and selecting goal-oriented process-based indicators that are relevant to current production practices. In addition, relationships, drivers and hypothetical cause and effect, positive or negative feedback loops that define the production system can be established. Selected indicators can undergo indicator reinforcement using literature and some key experts in various fields. The indicator reinforcement process is not meant to change selected indicators but rather make them more pragmatic guided by the broad themes developed in consultation with stakeholders. As in many evaluation approaches, reference values for each indicator are determined by stakeholders and in some cases from literature and key experts.

Practice-based indicators could be more desirable in low-input ruminant systems where production or management records are not available than the production-based indicators used in most evaluation approaches (Gayatri et al., 2016). Ecological practice-based indicators should assess inputs self-sufficiency, biodiversity, biomass flow, land degradation, stocking rates, proportion of invasive species and levels of chemical use and soil organic matter among others. Economic practice-based indicators should include diversity of income sources, total value of livestock, value of other multiple non-monetary roles of livestock and direct costs associated with ruminant production. Social indicators could include intergenerational inheritance, involvement of producer in livestock based organisations, household food adequacy and gender access to livestock resources. The method used for aggregation of the indicators is important as it determines the effectiveness of the sustainability evaluation approach.

Most approaches are measurement-based, where the sustainability concept is decoded into a quantifiable set of indicators used to construct metrics which define the sustainability of the system. Thus, management-based approaches treat indicators as isolated variables during analysis whilst, ignoring the dynamic inter-relationships between them (Bell and Morse 2003). For simplicity, the third step of a system-specific evaluation should consider a topical aggregation of indicators using the measurement-based approach at local stakeholders’ level to produce preliminary or tentative sustainability results. In reality, however, all socio-ecological systems (SES) including ruminants production exhibit spatial and temporal complex dynamic behaviour such as positive and negative feedbacks, nonlinear responses, emergent properties, and unpredictable results (Astier and García-Barrios, 2012). The systems are characterised by short-term regulation and long-term adaptation to persistently changing biophysical and socio-economic conditions (Goswami et al., 2017). In step four, a complex-adaptive approach that employs systems dynamic modelling should be considered for a more realistic aggregation of indicators. This can be achieved by designing a simplified user friendly, systems dynamics simulation model using qualitative and quantitative data obtained from local stakeholders.

Low-input production systems including ruminant systems are known to exhibit various levels of vulnerability to different conditions. Various studies have demonstrated the vulnerability of the systems to certain biophysical conditions related to climate change (Nardone et al. 2010; Musemwa et al. 2012; Ghahramani & Moore 2016). Similarly, the systems may also be vulnerable to unsustainable indicators but there is no evidence in literature of indicators being interrogated further after recording weak sustainability scores. Thus, the effect of unsustainable indicators on the vulnerability of low-input ruminant systems has not been explored. In this regard, an additional component of the proposed evaluation approach should be to further interrogate indicators with poor sustainability scores. The vulnerability of the low-input ruminant system to these indicators should be assessed and the adaptive capacity of the system to such indicators established.

Conclusions

Sustainability evaluation methods in use currently are individually not sensitive to the realities of the low-input ruminant livestock production systems particularly in tropical and subtropical developing countries. The methods are inadequate to accurately incorporate the multifunctionality roles of ruminant livestock and credence value relevant to rangeland-based ruminant meat production in developing countries into the evaluations. It was suggested that a system-specific sustainability evaluation procedure should include a sustainability awareness component, an amalgamation of an ecological and the sustainable livelihoods components, and a component that assesses the vulnerability of the system. Use of practice-based indicators was proposed to be more appropriate in addressing realities of low-input ruminant systems than process-based indicators. The indicators can be integrated using systems dynamic modelling technique to take care of the complex non-linear relationships between indicators.

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Table 1: Summary of critical points of sustainability of smallholder ruminant livestock farming systems (adapted from: Bernués et al. 2011)

Type	Description
Technical and economic	Animal fertility. Reproductive performance of grazing animals in harsh environments is lower than in more favoured pastures or more intensive systems.
	Dependence on external inputs. Smallholder livestock production systems are considered low-input, but there is wide variation in terms of energy use and feed self-sufficiency.
	Animal productivity. Smallholder livestock production systems are low output, and are therefore considered inefficient; however, grazing resources do not have alternative uses and do not compete with human nutrition.
	Labour productivity. Labour productivity is key to measuring the economic sustainability of farms; in general, it has increased in the recent past in beef systems but not in meat-sheep systems.
	Dependence on social grants. Social grants constitute a huge portion of incomes for most households
Social	Access to resources. Availability of land, financial resources and support services (externtion) is critical for improved productivity
	Intergenerational succession. Lack of continuity due to lack of children or children not willing to continue in farming is a major limiting factor of farm reproducibility.
	Ageing farming population. Related to the previous point, the average age of farming continuity continues to increase.

	Opportunity cost of household labour. Off-farm labour, both the farmer and other members of the household, is increasing. Sometimes, this cannot be explained only with economic logic, but lifestyle and values.
	General living conditions in rural communities and access to education, health and leisure services are deficient in comparison to urban areas.
	Freedom of participation. Smallholder community members must freely participate in local organisations of their choice.
	Deficient training of farmers. Low implementation of advisory services and associative organisations.
Environmental	Contribution to total livestock GHG emissions. Smallholder livestock production systems are not linked to deforestation and the use of fossil fuel and other external inputs is not substantial. Manure handling and deposition is not a significant problem.
	Carbon sink and mitigation potential. Grassland soils and biomass store large amounts of carbon that, at least partially, offset the methane emission from rumen fermentation.
	Nutrient cycles and pollution. Nutrient cycles are more closed and in balance due to the low use of external inputs and better distribution in soils. Pollution of water courses is less probable in grazing systems.
	Conservation of biodiversity. Some endangered species in smallholder livestock production systems are directly linked to the presence of domestic animals.
	Landscape. Grazing livestock can be an effective tool to modulate vegetation dynamics and preserve traditional open mosaic landscapes.
	Climate change. Rising temperatures and lower precipitation, less water availability and extreme events (drought)

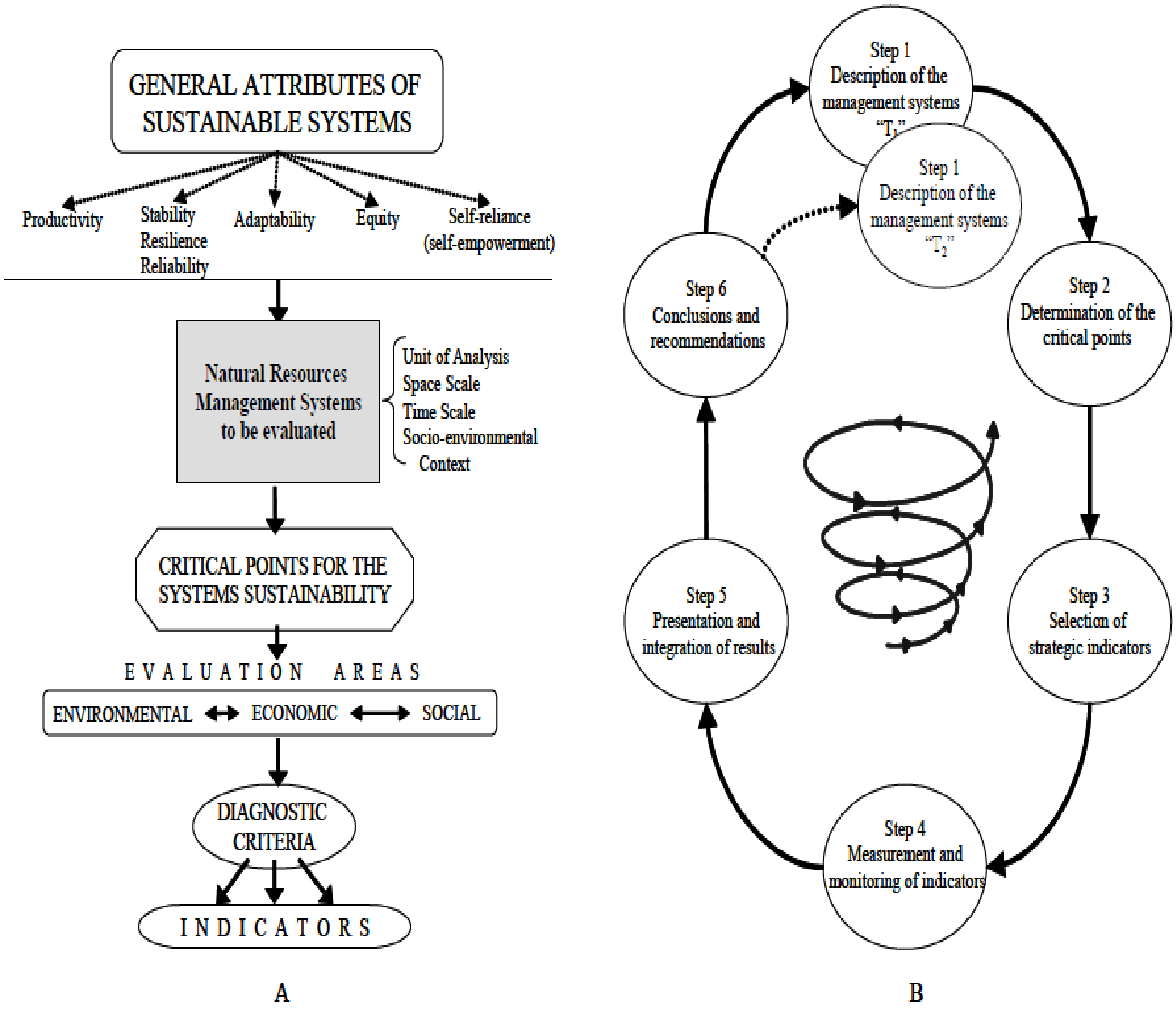

Figure 1: The MESMIS operational structure: (A) attributes to indicators and (B) Step-wise cyclical evaluation procedure (Source: Lopez-Ridaura, 2005)

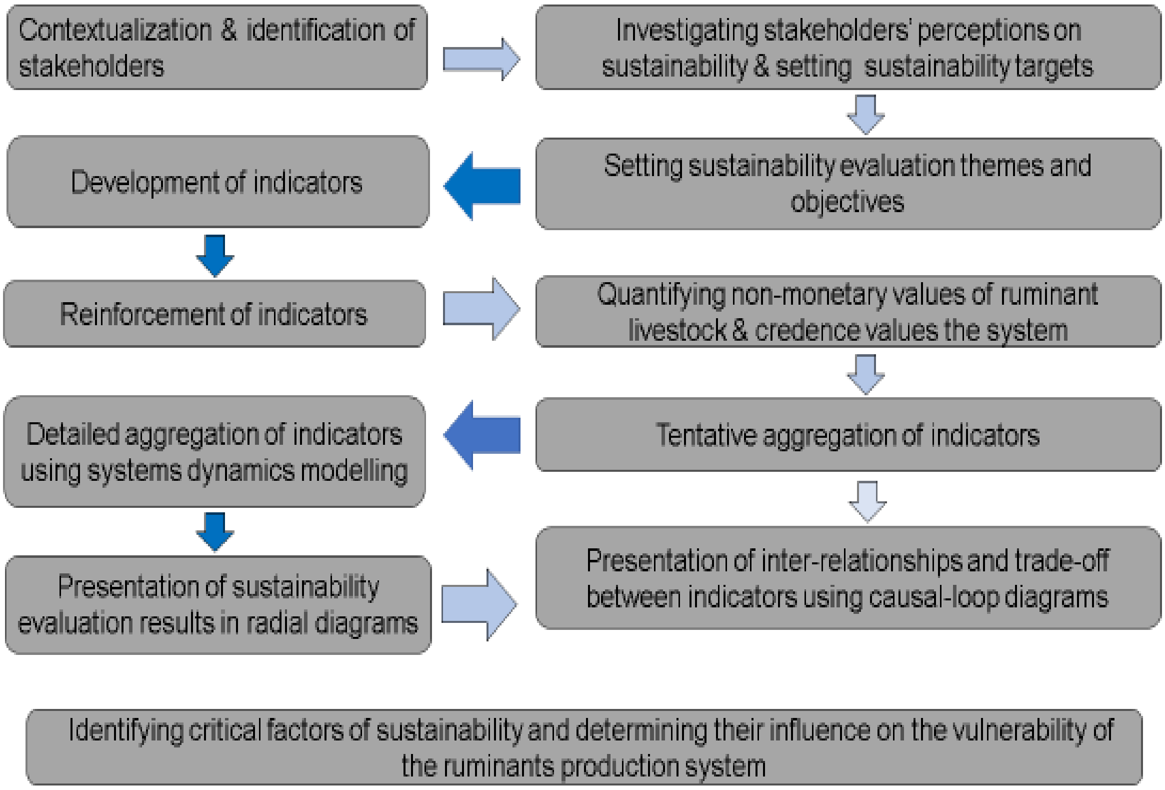

Figure 2: Proposed system-specific framework for low-input ruminant meat production system