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Multifunctionality and diversity of livestock grazing systems for sustainable food systems throughout the world: Are there learning opportunities for Europe?

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Abstract

Throughout the world, livestock grazing systems (LGS) include, and provide livelihoods for, many rural populations. These LGS are represented in a wide variety of agroecological contexts and offer a huge variety of system organization. They contribute to sustainable food systems by providing multiple products including low-cost edible proteins and energy, draft power, outputs (carbon and soil nutrient regulation, landscape and biodiversity maintenance), roles (local development support in harsh environments, contribution to the circular economy) and benefits to populations (revenue, employment, and cultural assets). These multiple functions can be described through a multifunctional conceptual model specified for LGS. Applied to cases in Africa, Asia, Latin America and Europe, the framework enables the assessment of these systems in a holistic manner that includes four dimensions: production, social, environmental and local development. These dimensions and associated local indicators demonstrate the potential important contribution that LGS may deliver to sustainable food systems. Management of interactions and trade-offs between these functions may be improved using such a model in a multi-stakeholder approach. Some of the functions and balance between them might have been overlooked in the consideration of European food systems.

KEYWORDS

diversity, livestock grazing systems, multifunctionality, sustainable food systems

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1 | INTRODUCTION

Livestock grazing systems (LGS) are systems in which 90% of ruminant diets are composed of forage grazed from natural or cultivated grasslands, according to FAO and ILRI (Robinson et al., 2011). LGS play a significant role in livestock production accounting for 39% of global domestic ruminant numbers, and 30% of animal derived proteins (Mottet et al., 2017; Mottet et al., 2018). One and a half billion hectares of land usually unsuitable for cropping due to poor rainfall, soil fertility and topography are utilized by LGS as is 54% of the total terrestrial landscape. Much of this (28 M km^2) is in desert or marginal xeric shrublands areas (ILRI et al., 2021). Many of these systems are dependent on both the mobility of livestock and people (socio-ecological systems) as they take advantage of the spatial and temporal variability in forage production throughout the year. These mobile systems rely on natural resources and processes, for exmaple, existing forage, water source, manure from livestock and associated high human capital input. The large land footprint of LGS and its associated management of livestock result in impacts on the ecosystem dynamics that result in a diversity of functions for both the environment and human well-being at different scales and dimensions (production, economics, cultural, environmental, local development etc.). These functions are not always considered when assessing the impact of LGS although attempts to take a whole-of-system approach have been undertaken using the "Ecosystem Services" framework focused at the ecosystem scale (Huang et al., 2015). The prolific debates that occurred during the 2021 UN Food Systems Summit have led to several so-called "Coalitions" that have to be implemented by states and civil society, many of them dealing with livestock issues. They have confirmed that Food Systems are now a global issue and that industrialized countries cannot represent a model for the rest of the world but they also have a lot to learn from the Global South and its diversity of farming systems, particularly about herbivore breeding. In this paper we consider LGS, tackled here in a larger definition than that of the FAO, within the context of a Multifunctionality framework that makes transparent the many functions derived from LGS and we document the results of its application through global case studies. The hypothesis is that the multiple functions of LGS, demonstrated in a diversity of global contexts, will inform the description and identify pathways for sustainable food system development potentially overlooked in past agriculture simplification within Europe.

2 | WHY APPLY MULTIFUNCTIONALITY CONCEPT TO LIVESTOCK GRAZING SYSTEMS?

Current methods of assessing the different functions of LGS oversimplify and underestimate the impact and are limited in their abilities to consider simultaneously interwoven dimensions and the ways they interact. We hypothesise that the use of the concept of "Multifunctionality of agriculture" which was developed during the 1990s (Caron et al., 2008; Hervieu, 2002a, 2002b; Huang et al., 2015; UNCED, 1992) is a better way for developing a more exhaustive assessment of the different functions of LGS and allowing to express trade-off between functions reinforcing abilities for stakeholders involved to envision desirable futures for the activity. Through this Multifunctionality (MF) methodological approach, we seek to show that LGS have an important role to play in Sustainable Food System development worldwide. The MF considers the diversity of functions needed to assess impacts of agriculture at local, regional and international levels including production outputs, economic (employment, infrastructure and services development, financial fluxes, etc.), environmental (landscape management, GHG emissions, soil fertility, biodiversity and nutrient fluxes, etc.). Due to their large terrestrial footprint from local to global scale, LGS have significant impacts on ecosystem dynamics (biodiversity, nutrient cycling, land degradation, etc.) and climate change (GHG emissions, carbon sequestration) (Steinfeld et al., 2006). LGS also support massive amounts of social groups and populations throughout the world (ILRI et al., 2021), providing revenues, livelihoods, and social and cultural assets. In this regard, the MF framework has been adopted by Action Network 2 "Restoring value to grassland" within the Global Agenda for Sustainable Livestock (GASL), a global multi-stakeholder platform (www.livestockdialogue.org), as the relevant approach to use with multiple stakeholders to describe, evaluate, discuss and promote the different functions provided by LGS. This MF framework fits well with the global framework on Sustainable Development Goals (SDG) proposed by the UN 2030 programme, as the multiple functions of LGS relate to at least 8 SDGs out of the existing 17 (1: no poverty, 2: zero hunger, 5: gender equality, 6: clean water, 8: decent work and economic growth, 12: responsible consumption and production, 13: climate action, 15: life on land). Finally, considering the contribution of LGS to the emergent concern of sustainable food systems (SFS) debated during the September 2021 UN conference, the MF framework will allow the identification of crucial functions that might inform the main principles supporting SFS: environmentally friendly, easy access, availability, food security, food quality.

3 | BUILDING A MULTIFUNCTIONALITY CONCEPTUAL MODEL TO SUPPORT LOCAL LIVESTOCK GRAZING SYSTEMS DYNAMICS

A multi-stakeholder participative modelling approach was developed to ensure a broad diversity of contexts and world views informed a common framework applicable to the diversity of LGS global contexts. Participants included researchers from a range of disciplines related to LGS from seven different countries (Argentina, Brazil, France, Mongolia, Senegal, New-Zealand, Vietnam), and agribusiness, farmers and policy makers. An iterative approach was applied to ensure the robustness of the framework consisting of: (i) a literature review that created the base platform for conceptual model construction at the first workshop (May 2016); (ii) this was followed by interviews with 10 French farmers, and later with local stakeholders in sites of five of the different countries (iii); two further workshops (July 2016,

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December 2017) with several rangeland experts focused on clarifying definitions, discussions on the structure of the conceptual model and testing its robustness with respect to a set of indicators defined to assess the impact of livestock from a variety of perspectives. The resulting Multifunctionality of LGS conceptual model (CM) consists of four dimensions (productive, social, local development and environmental) within which entities (farmers, livestock, pastures, products, atmosphere, water, infrastructures, organizations, etc.) and processes (trading, feeding, producing, consuming, building, earning, etc.) operate within, and are described using UML language with their associated indicators (Figure 1 and the indicators described in the Case studies and Table 1). The construction of the CM allows for the exploration of not only the behaviour within in each of the individual dimensions but also the interactions between the dimensions and functions. Therefore, those working with the model can explore how changes in the behaviour of any of the entities influences the behaviour within and between the dimensions and functions. For example, the "Livestock" entity (see Figure 1) contributes to all four dimensions but is responsible for distinct functions: milk production, GHG emission, generate revenue, provide cultural assets. When a change to livestock management is made, functions linked to livestock are all altered and this process allows the analyses of interactions between the functions across the dimensions. The same process can be described for entities like "Farmer." This then enables the user of the CM to identify the differing outputs and to then make transparent the resulting trade-offs that may need to be explored. From 2017 onwards, the CM has been applied to a variety of case studies (Wedderburn et al., 2021), documented below. Application of the CM in the field has informed improvement of the model.

4 | STUDY CASES FROM SOUTH AMERICA, ASIA, AFRICA AND EUROPE

The cases documented below illustrate how the multifunctionality framework has been applied with different tools and methodologies to a diversity of contexts and issues regarding sustainable development of LGS throughout the world.

4.1 | Multidisciplinary team for improving holistic comprehension of multifunctional goods and services provided by pastoral ecosystems. Puna de Jujuy, Argentina

Context. The Puna (3500 m a.s.l.) is a high plateau located in a dry area (100–300 mm/year rainfall), very windy with high daily and annual temperature fluctuations. The vegetation is sparse, mainly shrubby steppes and archipelagos of very productive but sparsely distributed wetlands. In these hard environments there are limited possibilities for agriculture (Quiroga Mendiola & Cladera, 2018). The aim of this work is to promote the values of this high altitude pastoral system, as it is a producer of multiple goods and services. We organized the case into the four dimensions of the MF framework (productive, social, local development and environmental) through a multidisciplinary team approach to facilitate a holistic analysis of the whole system.

Material and methods. In order to analyse multifunctional goods and services of pastoralist agroecosystems, we formed a multidisciplinary researcher team. A Domestic Unit (DU) analysis scale was chosen as it is the first economic step of natural grasslands management

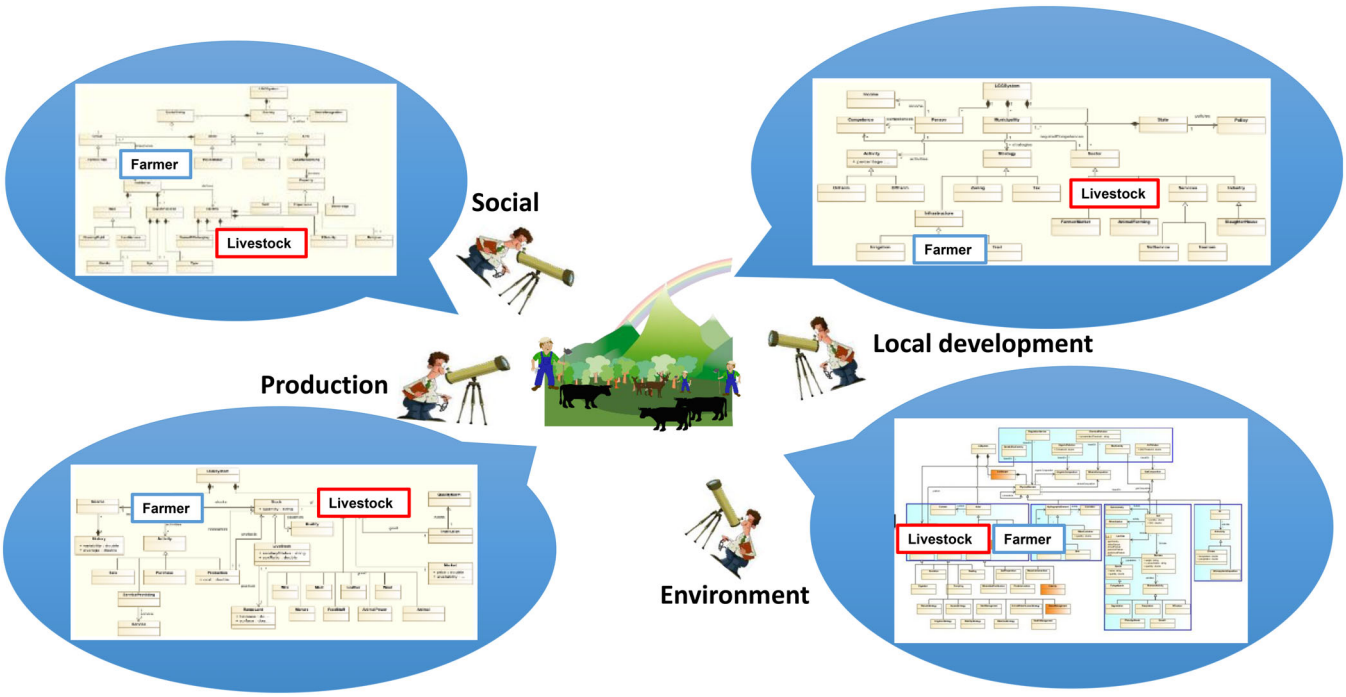

FIGURE 1 Building a multifunctionality conceptual model for livestock grazing systems organized with four dimensions including entities, processes and indicators

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TABLE 1 A summary of the indicators used in the case studies and the results of the application of the multifunctional (MF) approach

Case	Social indicators	Environmental indicators	Production indicators	Local development indicators	Results
Argentina/The Puna high altitude, dry pastoralism	Household members Number of local organizations in supply chain	Biodiversity Plant cover Dry matter production	Kg meat sold Diversity of livestock Drought strategies	Annual income Number and diversity of marketing channels	Strategies for resilience based on social networks and diversity of livestock species related to the local supply chain and household participants linked to local wealth generation. The grazing system maintains vegetation condition and diversity with cover regulating soil temperature and water.
Brazil/Maranhao Silvo-pastoral systems	Employment Profit	Biodiversity Animal welfare Carbon balance	Kg meat/ha/year	Number of businesses	Greater profit achieved compared with monoculture, with potential for further gain with payments for additional ecosystem services provided that is, increased biodiversity of flora and fauna, and enhanced soil conservation. Animal welfare was enhanced.
Senegal/Ferlo Rangeland based dairy milk platform	Social inclusion Collaboration between forage producers	Biomass production GHG emissions	Biomass flows Efficiency of milk collection Litres of milk/day	Networks of biomass supply Milk income Milk value chain development	Exploration of three scenarios of dairy intensification identified the trade-offs between outputs and inputs and social and environmental consequences and assisted in sector strategy development.
Mongolia/Bulgan forest steppes conservation coexisting with livestock systems	Household income Participating families Diverse employment	Increased numbers of existing species Reintroduction of species	Livestock production	New business opportunities	The positive uptake by herder households of conservation related employment alleviated poverty and improved environmental outcomes while not diminishing existing livestock systems.
Vietnam/Dien Bien mountain beef systems development	Household income Social networks Insurance Cultural activities Employment	Soil organic matter and fertility	Percentage of beef supplied Inputs	Profit going to actors in the value chain	Results showed the contribution that extensive beef production brings to the household, community, and local development in comparison to other livestock systems and cropping activities.
China/Qinghai plateau conservation with livestock systems	Tibetan Buddhism cultural relationship with nature	Landscape heterogeneity indices Bird biodiversity	Yak grazing intensity		The landscape mosaic created by yak grazing had a positive impact on bird species richness. Extensive pastoralism and related culture

(Continues)

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TABLE 1 (Continued)

Case	Social indicators	Environmental indicators	Production indicators	Local development indicators	Results
					coexist with improved environmental outcomes.
France/PACA agro pastoral systems in Mediterranean mountain area	Still to be defined, using the simulation model, in interacting loops between local stakeholders	Same	Same	Same	Identifying relevant actors and activities LGS have to interact with to foster sustainability of socio ecological system; identify processes and properties of LGS putted into questions and identification of levers of public actions to be settled

and knowledge transmission, and because relevant indicators and measures already existed at this scale for use in the approach. Four dimensions were addressed. 1. *Productive Dimension*: the main local product is meat (llama, sheep or goat) sold in the local market (formal and informal) Indicators: (a) $/kg of meat produced/year; (b) kg meat sold/year; (c) livestock diversity: number of animal species/flock; and (d) number of strategies against drought. 2. *Social Dimension*: we assessed (a) the number of family members living and working in the household (productive unit persistence and knowledge transmission); and (b) number of local organizations in which the DU participates. 3. *Local development dimension*: (a) annual income (US$ meat) and the number and diversity of marketing channels for the meat produced. 4. *Environmental Dimension*: kg DM/ha/year (carbon capture and forage provision), vegetation cover (water and temperature regulation), plant diversity and richness (biodiversity maintenance).

Results 1. *Productive dimension*: (a) and (b) Meat production ranged from 487 to 2272 kg meat/year/D.U., 50% for self-consumption and 50% for sale (Echenique et al., 2015; Paz et al., 2011). (c) Flocks with two animal species and, (d) 3–5 diverse strategies to face drought (changing grazing sites; changing flock composition; reducing flock size; buying fodder from outside the area and finding new ways of agreement between herder's families) (Quiroga Mendiola, 2015a). This demonstrates the family's capacity to produce meat for self-consumption and for other consumers, and also the different knowledge and strategies for various animal species per flock and diverse landscape management. 2. *Social dimension*: the stability or fragility of the family was demonstrated as they are made up of 1–5 members that remain in the production unit and are linked to 1–4 local market organizations. These networks provide diverse and flexible opportunities such as negotiation capacities, improving selling prices, information access, etc. (Alcoba et al., 2018). 3. *Local development dimension*: annual income of US$1194 to US$6289 (local and country wealth generation) and diverse marketing channels: actions of the cooperative to sell the meat outside the territory; selling most of the meat for Christmas, Easter or social events; selling some animals to an intermediary or local trader who buys meat; and finally, the sale or exchange of meat with neighbouring families or other members of the community, showing the generation of wealth and family and community resilience (Alcoba et al., 2018). 4. *Environmental dimension*: shows a forage production of 300 kg DM/ha/year; 65%–73% vegetation cover and genetic richness and plant diversity conservation in a sustainable way (Molina, 2011; Quiroga Mendiola et al., 2010, 2015b).

Conclusions. The multifunctional goods and services that the pastoralist agroecosystem provide, were acknowledged and analysed and were better captured by a multidisciplinary team, to provide a more comprehensive understanding of the system complexity. The application of the MF approach allowed us to measure and integrate several indicators in the four different dimensions, analyse diverse herder strategies to cope with this kind of environment and be more resilient to shocks, and to make transparent and place a value on the systems multifunctionality.

4.2 | Improving grassland system multifunctionality by natural regeneration of native trees for the implementation of a silvopastoral system for beef production in Brazil

Context. Traditionally, in Latin America, extensive systems are the most common management for cattle ranching based on monoculture forages and low stocking rates (Chara et al., 2017). Deforestation is part of the process to implement monoculture pastures in large areas and different biomes of tropical countries, including Brazil. This practice improves the profits in the short-term, but after many years the soil fertility, biodiversity and stocking rate capacity are reduced, and consequently also the farmers' income. Pasture degradation has taken place throughout Brazil affecting approximately 100 million hectares. The silvopastoral systems that incorporate trees and shrubs into pastures increase the amount of biomass per unit of area and provide other ecosystem services. Silvopastoral systems aim to promote sustainable intensification of land, while increasing vegetation and animal biodiversity, water use efficiency and biomass production, while

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respecting animal welfare compared to traditional monoculture forages (Mauricio et al., 2019). The objective of this study is to demonstrate that natural regeneration of native trees and bushes associated with grass forages is one sustainable option to implement multifunctional silvopastoral system (SPS) in Brazil.

Material and methods Several seminars were organized where a demonstration farm (1000 ha in Maranhao State, Brazil) was used to illustrate and discuss the SPS practices (natural regeneration) with farmers, ONG (Brazilian Center for sustainable livestock - CBPS), local extension services, researchers and students under the coordination of the Federal University of Sao Joao Del-Rei Brazil. The four dimensions of the MF approach were applied to the SPS which deliver a range of functions including high production (meat per hectare/year), social improvements (jobs and financial stability), environment (biodiversity, animal welfare) and the importance of SPS for local development (livestock business and sustainable practices).

Results. It was demonstrated that the profit from the SPS has steadily increased in comparison with traditional monoculture systems based exclusively on Brachiaria. In addition, high biodiversity, fauna and flora from silvopastoral practices has positively changed the farm landscape, which has enhanced through soil conservation, forage biomass and animal welfare (Mauricio et al., 2019). The seminars fostered the discussions and clarified several technical points among stakeholders (farmers, technicians and students) that facilitated the practical changes towards implementation of the SPS.

Conclusions. The multifunctionality and multi-stakeholder approach used in this case study (farmers, researchers, extension services and students) increased the adoption of the system by other farmers (1000 visitors per year) and consequently improved the sustainability of livestock production in the region. It is expected that the economic, social and environmental benefits of silvopastoral system could be used for further policies and payment for ecosystem services (PES).

4.3 | Multifunctionality of the Tibetan grassland system

Context. Known as the "Water Tower of Asia", the Qinghai-Tibetan Plateau is an irreplaceable source of water for billions of people in the area downstream of the plateau. The plateau is a vast plain raised over 4000 m above sea level and surrounded by mountain ranges. The plateau's unique geological history and high-elevation environment makes it the centre of origin for a rich number of plants and animals. The world's largest grazing system, that is, *Kobresia* grasslands, covers an extensive 450 thousand km^2 of the plateau and is formed by pastoralism over the past 8000 years (Miehe et al., 2019). The dominant plant species, *Kobresia pygmaea*, is a sedge less than 4 cm high, adapting well to the grazing of livestock (Miehe et al., 2019). Having both a thick turf layer and a dense root mat, the *Kobresia* grasslands are resistant to yak trampling and have high water retention capacity. There was a steady population growth and application of production-orientated agricultural policies during the people's commune period, with a substantial increase of livestock numbers from the 1950s to 1980s. Although overgrazing posed threats to the provisioning of ecosystem services of the *Kobresia* grasslands, the total number of livestock declined continuously following a series of grassland protection and restoration policies launched during the past two decades. In *Kobresia* grasslands of Qinghai, the stocking rate from 2003 to 2012 was 15.41 million sheep units, showing a drop of 21.3% compared to the 19.58 million sheep units of 1988–2002 (Zhang et al., 2014). Further decline of livestock numbers is projected to take place in response to intensifying urbanization and subsidized land-use extensification. Previous studies on Tibetan avian assemblages (Li et al., 2018) have found that small-farming pastoralism can keep the grassland landscape, slow down the encroachment of shrubs, for example, *Potentilla fruticosa*, and create habitats for open-grassland specialists. In the regional development planning of Qinghai Province (Quighai Provincial Government, 2021), the main function of *Kobresia* grasslands is water and biodiversity conservation. However, nowadays more than 80% of the population in this region are still subsistence pastoralists (National Development and Reform Commission, 2013). For local pastoral communities, the provisioning service of the grasslands remains to be prominent. Prioritizing *Kobresia* grasslands' environmental functions in the national policies often leads to the question: what are conditions under which the grasslands' environmental and economic functions can be realized in synergy?

Material and methods. Using the MF framework, we examined the impact of yak grazing on biodiversity and landscape structure in Nyanpo Yutse of the eastern Qinghai-Tibetan Plateau. Using Unmanned Aerial Vehicles, we obtained high-resolution (15 cm level) landscape imageries of 45 km^2 and calculated landscape heterogeneity indices (Fritz et al., 2018). We conducted two breeding-season bird surveys in 140 sample plots. To measure yak grazing intensity, we first conducted participatory mapping of the pasture boundaries, and then counted herd size grazed on each of the 140 sample plots. Finally, we developed statistical models to test the threshold of grazing intensity that can best sustain the multifunctionality of the livestock grazing system.

Results. Our study found no significant correlation between livestock grazing intensity with bird diversity while the landscape mosaic created by yak grazing had a positive impact on bird species richness. In particular, we found that human built structures, including Tibetan prayer flags, increased the vertical complexity of the landscape, and formed a keystone structure (Tews et al., 2004) to sustain high-diversity bird assemblages. Among pastures where livestock grazing intensity is lower than one sheep unit/ha, there was pronounced species replacement among sample sites, indicating that species having varied habitat requirements could coexist in the landscape where extensive pastoralism was practised.

Conclusion. Our study demonstrated that extensive pastoralism will benefit the plateau's biodiversity conservation through maintaining the heterogenous structure of the landscape. The multifunctionality of the Tibetan grassland system should be acknowledged and supported. The *Kobresia* grasslands are not only a wilderness region that matters for biodiversity and water conservation, but also a

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precious cultural landscape where tangible and intangible values of nature and society intertwine.

4.4 | Community-based conservation provides a platform for maintaining multifunctional use of Mongolian mountain-forest steppe ecosystems

Context. Mongolian rangelands account for 73% of the country's territory that directly supports the livelihood of over 300,000 pastoralists, around 10% of the population (NSO, 2020). Half of Mongolians benefit from the economic activity generated from pastoralism. The most common livestock types include sheep, cows, yaks, goats and horses. Mongolia's rangelands encompass three major ecological zones: the mountain-forest-steppe, steppe, and desert-steppe (Hilbig, 1995). The Khoid Mogoin Gol Teel Local Protected Area (KMG-T LPA) in Bulgan soum (district), Arkhangai aimag (province), occupies 137,000 ha of mountain forest-steppe. One-third of the LPA is covered by forests (44,830 ha) that host rich biodiversity including globally endangered species such as musk deer, saker falcon, steppe eagle, red deer, and Mongolian marmot (Marshall-Stochmal et al., 2020). As of 2020, the LPA provided forage to over 34,000 livestock reared by over 200 herder households residing within KMG-T. Due to its proximity to the Arkhangai centre and the central road going to the western region, the KMG-T LPA has been affected by illegal logging, poaching, forest fires and overgrazing. Therefore, the Bulgan Soum Government took KMG-T under local protection in 2017, and the Zoological Society of London (ZSL) facilitated the management of the LPA from 2018.

Methods and methods. Multiple stakeholders, including the Bulgan Soum Government, the Union of Conservation Communities (UCC) uniting 15 herder organizations, Aimag Environment & Tourism Department (ETD), Aimag Forestry Unit (FU), Aimag Ecological Police (EP), and ZSL have been co-managing the KMG-T LPA. Their differing roles in the use of rangelands and partnerships for maintaining ecosystems were analysed using the multifunctionality framework and associated indicators.

Results. These are summarized across the four dimensions as follows. *Social*: over 270 herders (162 households) joined UCC with increased participation in natural resource management, and positive attitudes towards nature engaging in conservation activities. Poverty rates decreased (0.115–0.084) with increased access to financial services through Village Saving and Loan Associations (VSLAs) and a rise in the average household income (553,837 MNT to 963,224) (IRIM, 2021). *Environment*: Thanks to 17 Volunteer rangers conducting SMART patrolling in their areas, KMG-T became a zero-poaching area with a substantial reduction in illegal logging. UCC reintroduced marmots, whose population increased by 36% over 3 years, while the populations of musk deer and red deer remained stable (IRIM, 2021). UCC members fenced 8.3 ha of forest area supporting natural regeneration and reforested 3 ha areas. *Local development*: UCC's conservation inspired other communities in Bulgan Soum and the Government leading to the establishment of five more herder groups (ZSL, 2021). Most of the tree planting and waste cleaning activities in Bulgan are being handled by UCC members. Environment and Forestry units collaborated with UCC herders to clean forests in over 30 ha and firewood was supplied to the Aimag residents raising around 60 million MNT over 3 years (ZSL, 2021). *Production*: With increased income, livestock production in KMG-T was slightly increased (8%), including cattle (20%), horses (7%), sheep (2%), and goats (3%) (IRIM, 2021). Besides livestock production, UCC members diversified their incomes by introducing new businesses such as tourism, haymaking, vegetable growing and briquette making (ZSL, 2021).

Conclusion. The case confirmed the applicability of selected indicators across four dimensions of the multifunctionality framework in the complex Mongolian livestock system (LS). Specifics to Mongolia included additional new indicators proposed by herders that reflect their perspectives shaped by the nature of extensive LS and pastoral cultures. Social and environmental dimensions were a more pronounced feature for Mongolian LS compared to local development and production dimensions. The government partners and CBOs found the multifunctionality concept and the indicators useful for M&E and Planning for rangeland management specifically measuring progress towards SDG 1, 3, 5, 6, 8, 13, 15 and 17.

4.5 | Dairy oriented agropastoral system in Northern Senegal: Thinking multifunctionality of milk production in a semi-arid environment

Context. Milk production in Senegal is mainly based on pastoral systems (Corniaux et al., 2012). However, this production is too seasonal and dispersed to provide a significant supply to the dairy industries. It is therefore very poorly collected by local industries, most of which prefer to use imported milk powder, mainly because of lack of competitiveness of local milk, which is still very expensive as a raw material. In northern Senegal, the department of Dagana is experiencing a dynamic in the local milk sector due to the development, since 2007, of an industrial dairy that uses local milk (Bourguoin et al., 2018). This company is faced with seasonal hazards and strong variability in production from year to year. The Dagana milk innovation platform (PIL), created at the end of 2014, brings together all the stakeholders involved in the local milk value chain (breeders, farmers, collectors, processors, NGOs, public institutions) to work on scenarios for the sector's development. Since 2018, a reflection has been carried out on the means to intensify milk production ecologically by relying on local agricultural and natural resources. The objective of this work is to better understand the local milk production potential by adopting a perspective on the multifunctionality of this sector in the Sahelian pastoral system.

Material and methods. Starting from the MF conceptual model, this work consisted of co-constructing a computer simulator with PIL stakeholders that is capable of modelling zootechnical, ecological, agricultural, socioeconomic and geographical parameters (Delay et al., 2021). This model reproduces the production conditions of livestock farmers in the Sahelian strip living in the vicinity (50–60 km

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radius) of a river that irrigates intensive agriculture on its banks. Workshops enabled the stakeholders to put forward various hypotheses on the organization of the sector and to discuss the constraints of each type of stakeholder. A first workshop for the general public focused on the role of biomass flows in the sustainability of pastoral dairy systems. A second workshop focused on the organization of the milk collection system with local stakeholders in order to achieve greater efficiency and social inclusion.

Results. The milk potential of the Richard-Toll dairy basin was estimated at between 2000 and 10,000 litres/day according to different seasons and three levels of productivity: pure pastoral, intensified pastoral and intensified pastoral with stabling (Cesaro et al., 2020). During the workshop discussions, the stakeholders considered that these estimated potentials were credible because they were sufficiently close to the reality on the ground (collection varying between 3500 and 9500 litres/day between 2018 and 2021), accounting for local fodder resources. To this end, the objective of efficiently and sustainably exploiting the milk potential requires cooperation between actors in several sectors (rice, sugarcane and milk). Nevertheless, rules of access to agricultural by-products by livestock farmers must be discussed between the actors to allow the circulation of biomass on a territorial scale. Maximum scenario estimates the material flow at 4000 tonnes of dry fodder (rice and sugar cane) and 2000 tonnes of agriculture by-products (rice bran). Moreover, dairy intensification may also induce equity in the allocation of natural and economic resources between groups of herders and have social (concentration of resources) and environmental (concentration of herds) consequences. Intensified pastoral farms produce between 3 and 4 times more milk than a traditional pastoral system but need eight times more inputs. Cattle prolificity is also three times higher in intensified pastoral farms than in traditional ones. This new distribution may increase the differentiation between herders living near agricultural areas and those living in sylvo-pastoral areas.

Conclusions. The use of the concept of multifunctionality (Ickowicz et al., 2018) during the simulation workshops allowed the stakeholders to see what levels of interdependence should be considered to achieve sustainable dairy intensification scenarios and to better comprehend and understand the points of view of the other stakeholders in the territory and the compromises to be sought.

4.6 | Grazing livestock system in the mountainous Northwest Vietnam as a sustainable option for local development

Context. In the mountains of north-western Vietnam, smallholder livestock farms rely heavily on natural pastures for animal feed (cattle, buffalo). However, livestock grazing systems are considered insufficiently intensive to meet the national increased meat consumption and reduce import dependency, and to provide sufficient income to value chain stakeholders to contribute in poverty reduction. Livestock farming is in competition for space and resources with other economic activities (fruit and forestry plantations), or environmental protection (forest protection). These systems therefore remain weakly supported by local government, and are not considered in the livestock development strategies. Reconsidering the multiple functions of mountainous grazing systems at landscape level might change the assessment of their role in local development strategies.

Material and methods. This study has quantified the multiple contributions of the grazing systems to the sustainable development of farms and territories using the example of livestock farms in Quai Nua commune in Dien Bien Province. In this mountainous commune, extensive grazing systems coexist with livestock systems in the process of intensification with trough feeding, forage production and fattening systems. The approach was to identify indicators from the multifunctionality framework on the four dimensions covering the herd, the farm, the community and the landscape and the services and value chain scales. The indicators were used in discussions on the contribution of livestock grazing systems to the sustainable development with a diversity of local stakeholders (livestock farmers, agricultural extension staff, representatives of the livestock cooperative, stakeholders of the beef value chain).

Results. This study produced references on the contribution of livestock grazing systems to the sustainable development in the study Quai Nua Commune. Concerning the *production dimension*, livestock grazing systems produce about 49% of the beef production and about 48% of the meat integrated into the beef value chain (fresh meat, meal and dried meat typical of this region). For the *environmental dimension*, livestock grazing systems support soil organic fertility and production of the cropping systems through about 18% of the manure produced at communal level. The remainder is provided by permanent stalling of livestock. The contribution of these systems to landscape management has not been assessed. The livestock grazing systems contribute to *local development* with 11% of the profits of actors in the beef value chain (collector, slaughter man, restaurant and processor). Other profits come from more intensive livestock systems and monogastric livestock, and 66% of farm workers are directly linked to these systems. However, although consumers show a preference for meat from grazing systems, the products from these systems have not been differentially marketed. Using the MF framework allowed the identification of different points of view. Livestock farmers attach importance to income and low input production. *Social dimension*. They also emphasize the importance of the social links that exist between farmers who graze (sharing the time to supervise the animals at pasture). Finally, in addition to the function of bank savings (accident, planned events), these herds also provide for needs during social events (weddings, funerals, etc.). Agricultural extension officers explain that livestock grazing systems contribute to the livelihoods and standard of living of the population, providing an opportunity for work in a region that lacks it. Although these systems contribute clearly to poverty alleviation, the other actors of the beef value chain still focus on the functions of meat production and quality products.

Conclusion. These discussions highlight the full complementarities of the contributions of livestock grazing systems to production and economy, but also to the social dimension and to local development in the province. Grasslands, essential for animal feed, contribute

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significantly to meat production, job creation, income and profits along the beef value chain. It seems necessary to ensure a visible, logical and sustainable approach to the management of grasslands to support animal production and the sustainable development of territories where livestock grazing systems are part.

4.7 | What is at stake about assessment of multifunctionality of grazing systems in French Mediterranean mountains?

Context. Landscapes of most of the mountain regions of the Mediterranean area in Europe have been strongly shaped by pastoral farming, while this activity also contributes to the cultural identity of these areas. Livestock farming in these regions relies on grazing and coexists with the dynamics of livestock farming that relies on intensification and the associated increasing contribution of industrial feed. These regions also face deep socio-economical changes in the move from rural to residential and the tourism economy (Garde et al., 2014). As a consequence, public lands, a main component of grazed areas in the Mediterranean, support multiple uses that livestock farmers have to deal with. Meanwhile, environmental management of so called "semi-natural areas" and the contribution of grazing to biodiversity has become of concern while these constitute a reservoir for endangered species like wolves. The Agri-environmental scheme promoted by the European Common Agricultural Policy has amplified this concern and put emphasis on grazing practices. Concern related to the future of livestock grazing goes beyond the environmental dimension alone. It also addresses considerations for contributing to cultural identity, maintaining landscape (two dimensions strongly related to tourism activity) as well as delivering food products rooted in the local economy. Social concerns include how to enhance the interaction between resident and the promotion of inclusiveness. These dynamics indicate the complexity of the social-ecological system and to explore the future of the livestock grazing system within this dynamic requires dialogue with all stakeholders involved across scale from the sector to the territory (Zahm et al., 2008).

Material and methods. Our hypothesis is that applying a multifunctionality approach of LGS will support discussions between stakeholders in their dialogue on a sustainable future for livestock farming activities in territories. We interviewed stakeholders involved in livestock activities in the Provence-Alpes-Côte-d'Azur region, e.g. livestock farmers and their representative, farm and pastoralism advisors, food chains operators, local elected persons, representative of nature protection associations, protected area managers, local development associations etc. These interviews included considerations on the diversity of livestock farming, the main recent changes, difficulties with ensuring the future of farm activities or interacting with other land users. We then organized three focus groups to deliberate on this future. Short videos of the interviews where the different points of view of stakeholders were captured, helped to organize the dialogue around the dimensions making it easier for participants to express their views.

Results. Among actors closely related to farming activities (farmers, pastoral advisers, meat sector operators and protected area managers) the main questions regarding multifunctionality dealt with the trade-off between the abilities to use the LGS system for the preservation of forage resources, as a marketing advantage for specific pastoral products and advocacy for the usefulness of pastoral systems to foster biodiversity of natural grazed areas (i.e., justifying strong public supports elaborated within the second pillar of European CAP). In a wider arena of discussion, involving actors of the local community, questions dealing with protection of remarkable or endangered species related to pastoral ecosystems were embedded within a wider spectrum of questions including the maintenance of local identity, high value tourism economic operations, as well as contributing in designing and reinforcing social interactions at local level. Reinforcing diversity of participation is required, especially the inclusion of citizen associations and consumers. It appears also that putting emphasis on short supply chains is a lever to reinforce the perception of livestock activities within the territory as it helps to maintain dialogues and interaction between local society and farmers while allowing farmers to keep control on maintaining consistencies for their systems and the meanings of their jobs (Lasseur & Dupré, 2017).

Conclusions. Using the multifunctionality approach enabled the reduction of misunderstanding between stakeholders about what could be the future of LGS. The MF approach also enabled the participation and dialogue that underlines the positive outcomes and interactions of embedding a large spectrum of stakeholders when dealing with reinforcement of territorial sustainability with the contribution of livestock farming activities.

5 | TRANSVERSAL ANALYSIS OF MULTIFUNCTIONALITY

The opportunity to apply the Multifunctionality common framework to a global range of contexts has demonstrated the power of the approach. Table 1 summarizes the cases, the specific set of indicators they used and the results of multifunctionality based local debates and analysis.

Creating a space and process for multi-stakeholders to hear, respond and decide. In all cases the MF framework provided a common language and forum to make transparent the world views of the participating stakeholders and through this for them to come to a common understanding of management, policy and adoption of management practice. This was aided by the defining of local indicators ascribed to each of the four dimensions of the framework to account for the context and the diverse world views of stakeholders. The choice of indicators and the inclusion of the stakeholders in the process ensured that the process was relevant for the context. To populate the diversity of indicators requires a range of qualitative and quantitative methods, to gain a baseline and then to test the impact of policy and management options. Gaining data is not always easy and requires the use of a range of expertise to populate and analyse the information.

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TABLE 2 A summary of the utility of the multifunctional (MF) approach by case

Case	Utility of multifunctional approach
Argentina/ Puna	The resilience and adaptive capacity of the Puna herders at the household and community level was able to be explored through the application of the four dimensions. Successful implementation of the approach required a multidisciplinary team which for this context was not the norm, thus building the capacity to tackle such complex socio-ecological issues.
Brazil/ Maranhao	Exposing a range of actors including students, farmers and agribusiness to the holistic analysis using the MF approach of the silvo-pastoral system has had a positive impact on adoption of practices by farmers. Students have gained a greater understanding of the complexity of the system and how it works.
Senegal/ Ferlo	Building and using a simulation model based on the MF approach contributed to a facilitated dialogue between stakeholders to find solutions to share resources and find synergies between actors and biomass fluxes.
Mongolia/ Bulgan	The development of local indicators was key in ensuring the MF approach was relevant. In this case, not all four dimensions were equal with greater emphasis being on the social and environmental. The approach was appreciated by planners to assist in development of policy.
Vietnam/ Dien Bien	The MF framework facilitated dialogue between actors based on common indicators showing the complementarity of different agricultural systems towards sustainable development of the territory and reaching the objective of food supply for the population
China/Tibet	The MF approach demonstrated that the Kobresia grasslands are a cultural landscape where nature and society interact to the benefit of the environment and the wellbeing of people.
France/Paca	The MF approach allows to identify main relevant dimensions of LGS putted into questions by local actors to contribute to the sustainability of local socio ecosystem and it promotes local device to settle dialogue and allow identification of levers to foster mid-term co-evolution

Multifunctionality LGS conceptual model applicable to a variety of contexts. The cases show (Table 2) that the MF framework is operational and relevant to a diversity of contexts and issues. Nevertheless, the processes and tools developed and designed may be as diverse as workshops, brainstorming, surveys, participatory films, action research processes, participatory simulation models to analyse and identify the four dimensions, their entities and processes and their indicators. The heuristic significance of our approach relies in maintaining a consistency between its relevance for each case study as well as its contribution to global debates on livestock farming facing climate change, biodiversity erosion, food security and poverty and inequities alleviation. In Europe where past development of livestock systems was mainly driven by economic and some main environmental concerns (pollution, climate change), rethinking livestock development through its contribution within territories to social interactions and solidarity, cultural life, biodiversity conservation, economic networks and infrastructures would be facilitated using this Multifunctionality framework. Following the monogastric model, many herbivores farming systems have been unplugged from the local resources using industrial livestock feed often supplied by components coming from abroad assessed by only economic efficiency. These livestock systems have thus lost their links with their social and ecological environment and are more and more criticized by their neighbours as well as environmental or animal activists. Such communities have lost the link with domestic animals, which is part of the Western culture, considering their environment as wild and forgetting that most of the European landscapes have been produced by centuries of livestock husbandry and cannot be maintained without it! Our purpose, by using the Multifunctionality framework, aims to formulate scientific evidence about the other dimensions linked to livestock grazing systems in the diverse faces of their environment. The diversity of cases above show how this Western story is at work in many other parts of the world, generating tensions between increasing the production, specializing the workers, changing the breed, seeking for markets and the traditional place animals have in the family or the community (like in Senegal or Vietnam). The Argentinian, Tibetan and Mongolian cases illustrate the importance of these links on which the social dimension is based and that only slight and cautious changes are introduced. On the other hands, when changes have already happened, like in Brazil and France, people are seeking new arrangements between livestock farming and their human and ecological environments. The Multifunctional framework allows in this way to understand the complexity of each situation and what makes it able to change, mobilizing the same levers but differently. It allows us to overcome the fact that each situation is different, yes, they are but following a common framework which represents the essence of livestock farming all over this world.

Supporting sustainability through different scales. The MF framework has also shown its robustness when applied to different scales, household (Puna), farm (Brazil), landscape (Tibet, France), local (Mongolia) and sector (Vietnam, Senegal) and different socio-ecological contexts ranging from communal, migratory, individual and sedentary systems. In the discussion processes among stakeholders, it appeared clearly that multiple scales must be managed and represented to build a holistic and collective understanding of system and territorial sustainability.

MF framework to articulate activities in territories. Our target was to build a strong common conceptual framework in order to overcome the singularities of each case study in order to demonstrate the role of LGS beyond the strict animal productions. It confirms that everywhere in such contrasted situations, LGS is not an isolated activity, as some other economic activity could be; LGS, due to its large landscape footprint is closely linked to a specific area, which provide its resources but which is also used by other stakeholders. Sustainable management of territories needs articulating and facilitating synergies between activities and sectors in order to collectively design the

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future for which the Multifunctionality framework helps to organize discussions on priorities, interactions and trade-offs.

Managing diverse points of views and trade-offs. The cases demonstrate the relationship between the dimensions and the dilemmas involved in attempting to deliver a balanced outcome across the different dimensions. What is very clear is the multiple functions LGS deliver and how this delivery is mediated through human intervention. No longer is it acceptable to focus only on productivity or environment alone when considering these systems, but to acknowledge, value and respect the interrelated multiple functions.

The multiple functions of LGS still present but fragile. The diversity of cases analysed show that in most of the contexts where traditional LGS are in place, the diversity of functions within the four dimensions are really operating (see list of indicators identified) and support the viability and sustainability of the socio-ecosystems. But it appears also that, faced with economic and policy dynamics, some of these functions might be endangered calling into question the sustainable future of an important part of the local society and even of the environment.

6 | CONCLUSION

The Multifunctionality framework applied to a diversity of livestock grazing systems has shown at the landscape level the existence of strong and operational interactions between production, social, environmental and local development impacts that support the sustainability of these socio-ecosystems. This interweaving of functions allows the opportunity to identify what policy and practice to prioritize to ensure all are achieved simultaneously and equitably. Central to the delivery of these functions are people and their wellbeing and associated institutions. As we address the issues related to food sovereignty and security, we can take a holistic approach as demonstrated in these cases to align land governance, resource access, cultural identity and rural livelihoods. This is a means to secure sustainable food systems (SFS), including livestock grazing systems, well rooted in territories through multi-sectorial synergies, delivering local goods and services but oriented towards larger value chains and trade. This brief round-the-world trip illustrates the diversity of LGS in different geographical, historical and political contexts and also its consistency as a human ancestral activity based on our societies' interactions with the natural world through the mediation of domestic animals. Considering herbivores, this has generated a diversity of breeds, each of them well adapted to the environment in which their breeders are living, allowing them through multiple interactions with their environment to adapt their practices to the resource availability, diversity and variability in space and time. However, in most of the industrialized countries – but not only – we notice a strong homogenizing dynamic, particularly in cattle and standardization of breeding conditions considering only how to optimize meat or milk production and forgetting the other livestock functions … which start to be contested by several social movements (consumers, environmentalists, animal welfare activists, etc.). Alternatives and new pathways are sought to overcome this industrialized vision of livestock farming, but in a context that has changed and could generate new conflicts as the French case illustrates. Application of our common framework across a diversity of global livestock systems has enabled us to develop, systemic and dynamic point of view. LGS is at the core of the links between human societies and the natural world, this is obvious in traditional situations like in Argentina, Tibet and Mongolia; it needs careful management when the process of change is ongoing, like in Senegal and Vietnam, and it has to be rebuilt when the transformation has been done, and is not considered as plenty satisfying, like in Brazil and France. The lessons that emerge from the use of the multifunctionality framework in the analysis of the LGS in our case studies may be summarized as (i) The four dimensions resonate with all livestock farmers and provide an inclusive approach for full participation. In the real-world livestock farmers do not separate production and profit from social and environmental outcomes, they seek to achieve all. The inclusive approach facilitates the growth of social networks resulting in building greater community resilience and sustainability of agricultural and food systems at territorial level (ii) The framework enables the exploration of the whole system and demonstrates the importance of promoting diversity (livestock species, livestock systems, flora and fauna, …). Making clear the complexity of the context and situations from the view point of many of those who participate in the system also helps to find sustainable pathways for food systems. (iii) Viewing LGS as part of nature and not separate, enables the integration of LGS into nature and biodiversity conservation schemes. This enhances the productive biodiversity and cultural functions while increasing the sustainability of LGS and food systems (iv) Innovative value chains including traditional and smallholders livestock systems is an option for Sustainable Food Systems (v) Sustainable Food Systems may need to build on the complementarity of different livestock systems whilst building on the synergies with other land use activities. Thus can we in Europe and elsewhere reverse this global standardization starting from this only Western model and take advantage of the lessons from the Global South, as illustrated in this paper, to reinvent and redesign multifunctional and sustainable LGS, well integrated and adapted to the diversity of territories?

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from All data from the authors. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from the author(s) with the permission of All data from the authors.

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