Matière
à débattre & décider

Livestock grazing systems and sustainable development in the Mediterranean and Tropical areas

Recent knowledge on their strenghts and weaknesses

Alexandre Ickowicz and Charles-Henri Moulin, editors

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Considering the efficiency indicators already established, but also those to be established, the sub-chapter Multicriteria evaluation of efficiency to account for the multifunctionality of livestock grazing systems provides a review of the contribution of the concept of efficiency to better take into account the contribution of the livestock sector to the SDG. This chapter provides an analysis of how these global objectives defined by the United Nations can integrate the multifunctionality of livestock systems, but also the multiplicity of local and global issues, notably through the use of multi-criteria evaluation approaches and the construction of compromises that stakeholders must make.

Efficiency to account for the complexity of the contributions of livestock grazing systems to climate change

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For several decades, the "livestock/environment" debate has fuelled questions about the development of agriculture in the face of global change. This societal debate has largely focused on the negative impacts of livestock farming (Steinfeld *et al.*, 2006) and in particular its contribution to climate change. The livestock sector is responsible for 14.5% of anthropogenic GHG emissions (total for agriculture: 23%). They are mainly due to ruminants, with 65% attributed to dairy and beef bovines and 6.5% to small ruminants. However, ruminants grazing systems would "only" be responsible for 20% of total emissions from livestock (Gerber *et al.*, 2013).

Moreover, the Intergovernmental Panel on Climate Change (IPCC) special report of 2019 "on climate change and land" presents scenarios of evolution that are much more worrying than the previous ones on the impacts of climate change and the necessary adaptation, in particular with regard to desertification, degradation and sustainable land management as well as food safety. However, Livestock grazing systems is also one of the possible levers for reducing emissions. These elements demonstrate that measuring the weight of livestock grazing in global changes is a complex task. This complexity requires us to implement adapted evaluation methods to correctly establish GHG balances (carbon dioxide - CO_2 -, methane - CH_4 - and nitrous oxide - N_2O). These assessments are essential for the operational design, for each situation, of two main types of mitigation actions: (i) to reduce the level of GHG emissions and (ii) to promote the transfer and storage of carbon (C) from the atmosphere to terrestrial compartments in stabilized form.

In this section, we provide a practical illustration of this methodological process, with research programmes implemented in various tropical regions, where very different livestock grazing systems are used. We recommend indicators based on the efficiency concept to better reflect the specific contributions of these systems to global issues, notably those related to climate. These indicators improve the often stereotypical view of the impacts of the livestock sector in general, and of livestock grazing systems in particular (Blanfort *et al.*, 2015b). However, it is not a question of denying these proven impacts, but of specifying their limits and conditions, through integrated methods targeting the processes and their consequences. These methods combine in an integrated manner (i) metrics adapted to the context, (ii) consideration of the levels of organisation and their interrelationship (animal, herd, plot, territory) as well as (iii) the characteristics of the stakeholders involved at each level (farmers, technical support, territory manager).

Are enteric methane emissions at the animal and herd level higher in livestock grazing systems in the South?

Even if ruminants are endowed with this capacity to convert cellulose into quality proteins, the processes of biochemical degradation and forage digestion produce residue. This includes the production of methane gas (CH_4), a consequence of the degradation of membrane walls composed of cellulose, hemicellulose and lignin in the rumen.

Livestock grazing systems (LGS) in tropical and Mediterranean areas are particularly challenged in the debate on methane emissions from cattle: the animal production/methane emission ratio is highly unfavourable compared to more intensive livestock systems in industrialised countries. According to the FAO (Gerber *et al.*, 2013), the global mean GHG emission from bovine animals is 46.2 kg CO_2-eq/kg carcass[12] for meat and 2.8 kg CO_2-eq/kg for milk. These figures are different if we only consider sub-Saharan Africa, Latin America and South Asia: 70 kg CO_2 eq are emitted for the production of one kilogramme of carcass and from 2 to 12 kg CO_2 eq for one kg of milk depending on the productivity of the cows (which is highly variable). These figures are primarily related to enteric methane emissions. Based on ratios per animal or per kilogram of product, they mainly reflect the lower digestibility of feed and the lower productivity of animals in most livestock systems in developing countries, in particular in warm regions. The stakes for mitigation are all the more obvious.

In the North, and in particular in mainland France, the research and support institutions for livestock farming have largely adopted these figures. The mitigation potential could reach 30% of current emission levels. But in the South, the possible alternatives are much less documented. The difficulties in implementing livestock farming techniques that would reduce enteric methane emissions have led many experts to conclude that only reducing the number of animals and setting up intensive farms are effective in reducing sectoral emissions (Thorpe, 2009 in Blanfort *et al.*, 2011).

From a methodological point of view, precautions are required when interpreting these figures, which are the result of a simple transfer of methods designed in the North to the real situation in the South. In addition to the multiple functions of raising livestock

12. The "kg CO_2-equivalent" (CO_2 eq) is a unit created by the IPCC to compare the impacts of the various GHGs on global warming and to be able to aggregate their emissions.

that go beyond the production of meat and milk, the agroecosystems and management methods are also very different. However, the techniques available to estimate the quantities of enteric methane from ruminants on tropical rangelands are limited (Rosenstock *et al.,* 2016), and are not adapted to certain contexts. This is the case for livestok grazing systems in West Africa, where in-vivo rangeland measurements are proving difficult. In regions with a semi-arid climate, the quantities of methane produced per animal depend mainly on the quantity and quality of forage ingested, which fluctuates widely depending on the season.

To assess the magnitude of these variations and identify the appropriate adjustments, in the absence of available in vivo measurements on grazing ruminants, in vitro fermentation experiments of their diet can be conducted. These experiments conducted "in defined and controlled conditions", do not accurately reflect daily enteric methane emissions, because they involve the artificial reconstitution of the rumen. However, in the absence of other adaptive techniques in the Sahelian grazing areas, this method has been used to study the effects of vegetation dynamics on enteric methane produced by bovines in northern Senegal (Doreau *et al.,* 2016). In this region, transhumant farmers are entirely dependent on natural forage, the quantity and quality of which decreases during the dry season. In the rainy season, the diet consists of young grasses that are more digestible and richer in protein than dried grasses and woody plants (trees and shrubs) in the dry season. The study suggests that the ingestion of dry season forages leads to increased methane formation in-vitro. However, since ingested amounts decrease by more than half during this period (Assouma, 2016), daily methane production per animal is not necessarily higher. A study comparing the quantitative and qualitative effects of seasonal changes in feed would be required to complete these initial elements. This is especially true since, while lower feed intake does indeed reduce daily methane emissions (g CH_4/animal/day), it also increases methane yield (g CH_4/kg DM ingested) (Goopy *et al*., 2020).

Accordingly, in regions with persistent and seasonal forage deficits, the development of forage supplies and low-conversion forage and feed supply chains could offset the increase in methane yields due to the food deficit. Care should be taken to ensure that these changes in practices are not associated with indirect increases in GHG emissions (transportation, land use, etc.). The selection of lower-emitting plants may also be an option for mitigation. Specifically, legumes and ligneous plants contain varying degrees of secondary compounds (tannins, saponins), which are reputed to inhibit methane production by modifying the activity of rumen microbes (Archimède *et al*., 2018). In the Sahel, bovines naturally consume a significant amount of ligneous material with these properties (Assouma, 2016). However, it would be necessary to determine the effects of these practices on methane emissions (Figure 3.1).

These observations from the field reveal that ruminant diets and their effects on methane production are complex and variable, primarily in view of the diversity of feeds throughout the annual forage season. The various elements can therefore have

Figure 3.1. Faeces bag on young zebu cattle to measure excretion and predict ingestion, in northern Senegal (Assouma, 2016).

antagonistic or, on the contrary, synergistic effects. However, while forages consumed with a low conversion factor (percentage of ingested energy converted into methane) are levers that can be used to reduce emissions, reasoning solely on the basis of methane yield or feed conversion factor is restrictive. This is because GHG emission mitigation must not be obtained at the expense of the performance and well-being of the animal or the environment. Moreover, the parameters relating to methane emissions (emission factor, methane yield, conversion factor) of tropical forages are still insufficiently described, justifying the implementation of studies on local forage resources that take these multiple factors into account.

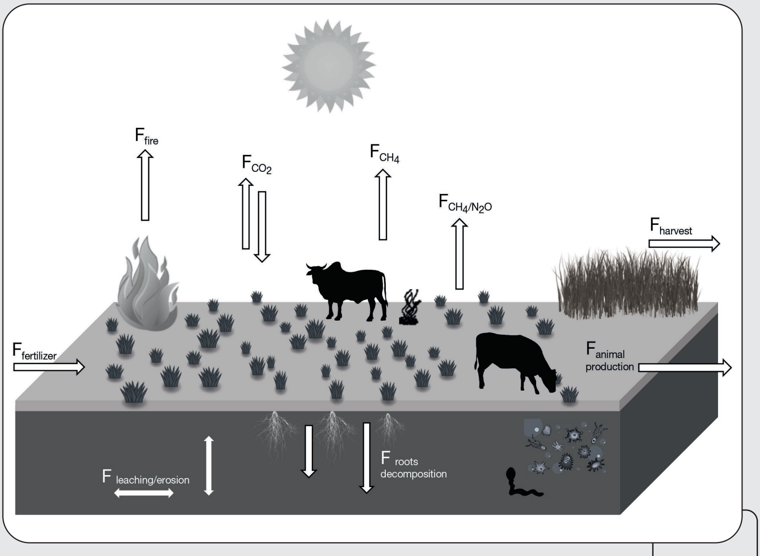
Increasing carbon storage in grasslands and rangelands

Livestock grazing systems have a specific potential to offset some of their emissions through carbon (C) sequestration in the soil and vegetation of grasslands and rangelands. Forage plants capture carbon from the atmosphere by photosynthesis, and accumulate it in the soil through root decomposition (Box 3.1).

These grazing land occupy 30% of the land surface (or 70% of the world's agricultural land), they contain 30% of the world's soil carbon stock. However, this sequestration potential proves to be highly variable (from 0 to 4 tC/ha/yr) depending on the ecological zone, soil characteristics, climatic conditions and agricultural practices (Soussana *et al.*, 2010). As a result, soil management appears to be a key point in controlling these carbon fluxes in the climate change fight. According to Gerber *et al.* (2013), it represents the greatest potential for emission reductions within the agricultural sector.

Box 3.1. Carbon cycle dynamics in grazed ecosystems.

Figure 3.2. Diagram of carbon cycle dynamics in grazed ecosystems (from Soussana *et al.*, 2010).



F = Flux.

In the case of livestock grazing systems, based on grazing or harvesting grasslands, or rangeland, the processes involved in exchanges with the atmosphere are complex and intertwined. CO2 net emissions are derived more precisely:

- for the inputs: from photosynthesis and root decomposition in the form of organic matter, fertilization and animal manure;

- for the outputs: from the respiration of above-ground parts of plants and of the soil-root complex and from the respiration of animals (Figure 3.2).

The balance of these inputs and outputs can lead to carbon storage/removal. As such, grasslands are potential carbon sinks. A distinction is made between carbon storage, which constitutes a net balance of carbon accumulation in the ecosystem (taking into account emissions), and the sequestration process, which only involves carbon inputs.

Given these uncertainties, the scientific references available in the tropical areas on these issues are insufficient. The standard metrics and methodologies used may be inappropriate for a correct assessment of grazing ecosystems in these regions, where the overall storage potential is high in relation to the areas concerned. The research presented in this section contributes to establishing references on carbon sequestration processes at the plot scale in two tropical terrains in the Amazon and in an island environment of the Indian Ocean. With regard to the semi-arid zone of West Africa, the related work integrates the territory scale and is therefore discussed in the last part of this sub-chapter.

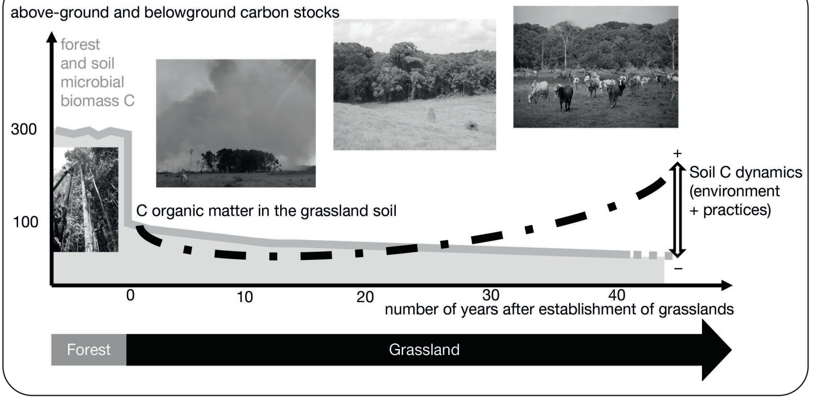
The Amazon is an emblematic region for sustainability issues related livestock grazing systems. Efforts to combat deforestation continue to be a priority for preserving carbon stocks and other ecosystem services provided by forests such as biodiversity and the maintenance of rainfall regimes. However, this core principle must also be combined with sustainable management of areas converted to grazing land to establish climate change mitigation strategies.

In the French Amazon (Guyana), measurement and observation devices on carbon fluxes and stocks have been established in deforestation-derived grassland systems (Blanfort and Stahl, 2013; Blanfort *et al.*, 2015a). Cattle farming systems are extensive (~ 1 LSU/ha); feed is provided solely by cultivated grasslands (mainly Brachiaria humidicola grass), with low input use. This “ranching” type of management is widespread throughout the Amazon region.

The research setup consists of an innovative combination of two approaches. Measurements of net gas exchanges of CO_2 between the atmosphere and the grazing ecosystem are carried out in 2 grassland plots equipped with flow towers (turbulent correlation method). Quantification of the rate of carbon fixation/emission by the grasslands leads to net annual carbon profiles integrating all ecosystem biological processes and the impact of management practices (such as rest periods and stocking rate). In addition, grassland carbon storage is estimated by measuring soil carbon stocks over a chronosequence (4 control forests and 24 grasslands aged from 6 months to 36 years). Samples are taken at 1 meter depth of, in order to capture deeper soil horizons than the usual standard.

The results demonstrate that deforestation-derived grasslands in Guyana function as carbon-storing ecosystems (Figure 3.3), provided they are sustained over several decades (Stahl et al., 2017). After around twenty years, storage potentially amounts to 1.27 ± 0.37 tC/ha/yr, while the neighbouring native forest stores 3.23 ± 0.65 tC/ha/yr (Guyaflux INRAE device). Carbon accumulation in stabilized form occurs in the lower horizons, between 0.3 and 1 m depth (Stahl et al., 2016). This storage level constitutes a very significant mitigating potential linked to the maintenance over time of a productive and non-degraded (dense, non-eroded) grassland cover developing on soil that retains good physico-chemical qualities. This includes encouraging the establishment

Figure 3.3. Reconstructing soil carbon stock dynamics after the conversion of Amazon rainforest to a grazing system.



of grassland with a mixture of grasses and legumes to permit nitrogen inputs into the soil. The implementation of a rotational grazing system and an adjusted stocking rate is also essential to maintain an active and covered biomass throughout the year. The maintenance of vegetation by slashing is clearly preferable to clearing by fire, which leads to nitrogen losses and a modification of biological activity. It is also noted that conditions favourable to the accumulation of carbon in the organic matter of soils grazed also promote the production of a good quality forage resource.

If the strategy of sequestering carbon in the soil is a proven mitigation potential for livestock grazing systems, it also has limitations.

Soil stocks are extremely fragile and can be altered in a number of ways: by a change in land use, temperature rise, or by various fertilization or other tillage practices. In order to produce references in the tropics, research projects on the island of Reunion are specifying the modalities and potential for carbon sequestration of permanent grasslands on volcanic and sandy soils.

The diachronic device extends over a period of nearly 15 years (2004 to 2019), based on an intensive organic and mineral fertilisation trial on 4 m^2 microplots in permanent grasslands used for mowing. It was conducted on 3 sites:

- one site on sandy soil in a coastal zone in a tropical climate (arenosol) initially very low in carbon (20 tC/ha on the 0-15 cm horizon),
- and two sites at altitude (900-1,500 m) on volcanic soils (andosol) initially very rich in carbon (80-100 tC/ha).

Fertilisation rates were up to 70 m^3/ha of liquid manure and 12 t/ha of compost per harvest.

The results indicate that the ratio between the increase in soil carbon and the carbon provided by fertilization is greater for compost than for slurry: from 16% to 28% for compost and from 2% to 8% for slurry. This difference is due to the nature of the carbon provided. Compost carbon is less likely to volatilize, the volatile part being partly lost during the composting process. Globally, a significant and substantial increase in soil carbon stock is measured each year in response to organic matter inputs in the form of manure and compost, ranging from 0.32 and 2.85 tC/ha/yr. Carbon sequestration was found to be greater on sandy soils that were initially poorer in organic matter and therefore in carbon. However, the increase observed on andosols is still significant, with an accumulation of several tons of carbon over the entire period, whereas these andosols, which are by nature rich in carbon, are considered to be "saturated" in carbon (Zieger *et al.*, 2018).

From reference acquisition to the development of energy and carbon balance at the farm scale

In contexts based on closed and clearly delimited management spaces, the "farm" is a relevant scale for actions aimed at climate change mitigation and adaptation. It integrates the "plot" and "herd" scales, which in turn integrate the biological, ecological and physiological processes taking place at smaller scales, in the plants, the soil and the animal. The farm is the management unit where decisions related to practices are made by clearly identified decision-makers: the farmers, their families and their employees. It is therefore a functional level, relevant for drawing up assessments that will guide strategic choices and the practices implemented.

The diagnostic tools that characterise the levels of energy consumption and GHG emissions at this level of organisation of the "farm" come in different types: calculators, protocols, user guides and models (Box 3.2). Construction and mobilisation procedures for these tools were conducted in two French tropical overseas territories: an island situation on Reunion and one in the French Amazon in French Guiana.

T**he carbon calculator tool "PLANETE" designed in mainland France and validated by the European Energy Agency (The AgriClimateChange Tool ACCT)**, was first adapted to the context of the island of Reunion to assess energy consumption and GHG emissions on livestock farms in this department (Thévenot *et al.*, 2011). The high human density, combined with significant effluent and fodder production, renders the environmental assessment of farms in relation to climate change crucial.

Based on this tool, renamed Planète Mascareignes, 235 energy assessments have been carried out on the island of Reunion on all animal production on the island (Vigne, 2007; 2009a; 2009b; Vayssières *et al.*, 2010; 2011b). These results can be used to calculate the environmental cost of insularity, defined as the additional energy consumption and GHG emissions induced by the overall transport costs imposed by the island's isolation and the decision to develop livestock production systems on the island of Reunion that require high levels of imported inputs. On the whole, this cost is high because it is equal to or greater than 20%, both in terms of energy consumption and GHG emissions. In addition, these efficiency and inefficiency indicators provide a comparison of local livestock production (Table 3.1).

Table 3.1. Techno-environmental performance of the various animal productions on the island of Reunion in 2007 assessed at the farm level including resource consumption and indirect GHG emissions related to input consumption (Vayssières *et al.*, 2010).

Animal production	Feed conversion efficiency	Energy efficiency	Share of animal feed-related NRE consumption	Global GHG Emissions	Coefficient of variation of variation Coefficient of variation	Share of enteric emissions in total GHG emissions
	(kg concentrate feed consumed/kg product)	(kg gross energy produced/ kg NRE consumed)	(%)	(kg CO_2 eq animal protein produced)	(%)	(% CH_4)
Milk (dairy farm)	0.79	0.37	55.3	87.3	24.5	26.2
Meat (cattle breeder farm)	4.00	0.19	31.9	239.7	66.5	65.5
Meat (cattle fattening farm)	5.48	0.42	53.3	104.7	27.3	40.1
Meat (pork)	3.23	0.62	77.0	35.9	18.7	6.1
Meat (poultry)	2.19	0.36	75.3	25.9	15.6	1.8
Meat (rabbit)	3.99	0.15	58.8	83.2	28.8	2.3

NRE: Non renewable energy.
GHG: Greenhouse gas.

The production of 1 kg of beef protein has the higher impact in terms of GHG emissions, followed by cow's milk, while chicken and pork production have the lowest impacts. Regardless of the type of protein produced, animal feed is the main source of fossil energy consumption (>30%). The differences are primarily explained by three factors: feed conversion efficiency, reproduction and mortality rates, and methane conversion rates between ruminants and monogastrics.

On the face of it, these findings would encourage the substitution of red meat by white meat, in accordance with other studies (De Vries and de Boer, 2021) and which is now widely relayed in human nutrition recommendations for environmental reasons, in addition to the nutritional arguments produced by the medical world. However, other elements must take account of food choices, notably the "feed-food" competition. Compared to ruminants, monogastric animal rations contain a higher proportion of products that can compete with human food (Mottet *et al.*, 2017), such as cereals, and that humans could consume directly and more efficiently. This is not the case for forage grasses, for which only ruminants are efficient. In addition, the development of beef cattle farms on the island of Reunion has been accomplished through the establishment of grass breeding systems in vast areas of the territory which, during the 1970s and 80s, were in the process of being depopulated with a risk of closure by wasteland and the invasion of exogenous invasive plants. This has resulted in a revival of economic activities in these rural areas of altitude that would not be valorized by other activities than livestock.

In all sectors combined however, there is considerable room for improvement, for example by favouring sources of supply closer to the island of Reunion. It is also necessary to reduce the distribution of concentrated feed for ruminants. This can be achieved mainly by improving the quality of the fodder supplied (by replacing part of the concentrates) and by improved monitoring of reproduction (reduction of the calving-to-calving interval).

In French Guiana, the planned transition of Guyanese agriculture requires contextualized assessment tools. The objective is to establish energy and GHG emission diagnoses with the aim of identifying action levers adapted to the farms in this territory.

The objective is to identify more efficient and environmentally effective farming systems in a territory that is emblematic of global change. The "French Amazon" is indeed an emblematic situation. French Guiana is the only French department that has seen an increase in the utilized agricultural area (UAA) and the number of farms. However, despite its continental and non-insular location, this territory remains very dependent on food imports; the coverage rates are almost zero for milk and 17% for beef. The expected doubling of the population in French Guiana by 2030 will lead Guyanese decision-makers to make decisive choices as regards territorial development. A strong endogenous growth of certain agricultural sectors such as livestock is intended. This implies the implementation of a development plan for the ruminant sector consistent with forest preservation (95% of the territory, 50% of the carbon of French forests) and with the framework of European climate commitments. The development of already deforested areas (sometimes not exploited) and the implementation of grassland systems with a higher stocking rate are mentioned. Moreover, unlike other more industrialised regions of Europe, the agricultural sector is much more important in the carbon balance of this department (23% of annual changes in forest land use).

In order to have local references, an Energy/Carbon balance tool was adapted in a study conducted in 33 farms that were subject to an Energy/Carbon diagnosis including 15 beef farmers (Dallaporta, 2016). The results indicate that energy efficiency and GHG emissions vary according to the types of livestock systems and their degree of development (Figure 3.4).

We refer to a typology of the Livestock Institute (2014):

• "cattle farmers" correspond to small-scale structures where the farm manager is multi-active,
• "the large land owners" are catlle farms of over 200 ha that have completed their land acquisition phase,
• the farmers with land reserves constitute an increasing group to the type "large land owners".

The energy and GHG emission diagnostics established on these Guyanese grass-fed farms are also highly dependent on the calculation method chosen (Figure 3.4). Expressed per unit produced (tonne of meat), the efficiencies are twice as low as the means observed in mainland France (Table 3.2). This can be explained by the fact that livestock grazing systems in French Guiana are characterised by almost exclusive grass feeding, fodder species of lower value and with high seasonal variability, as well as low stocking rates. Conversely, the efficiency ratio calculated per unit area is highly favourable in French Guiana, with a greater number of hectares available per animal, which can store more carbon in the soil, without significant consumption of non-renewable energy (only solar energy is used for the growth of grasses, combined with natural rainfall). Consequently, French Guiana illustrates very effectively the potential of livestock grazing systems in the humid tropics to produce quality meat (on grass), with environmental costs that are much lower than the more intensive systems common in temperate area.

Figure 3.4. GHG emissions according to the energy balance of grassland cattle systems in Guyana (2013). A: per ton of live weight sold; B: per hectare of utilized agricultural area (UAA).

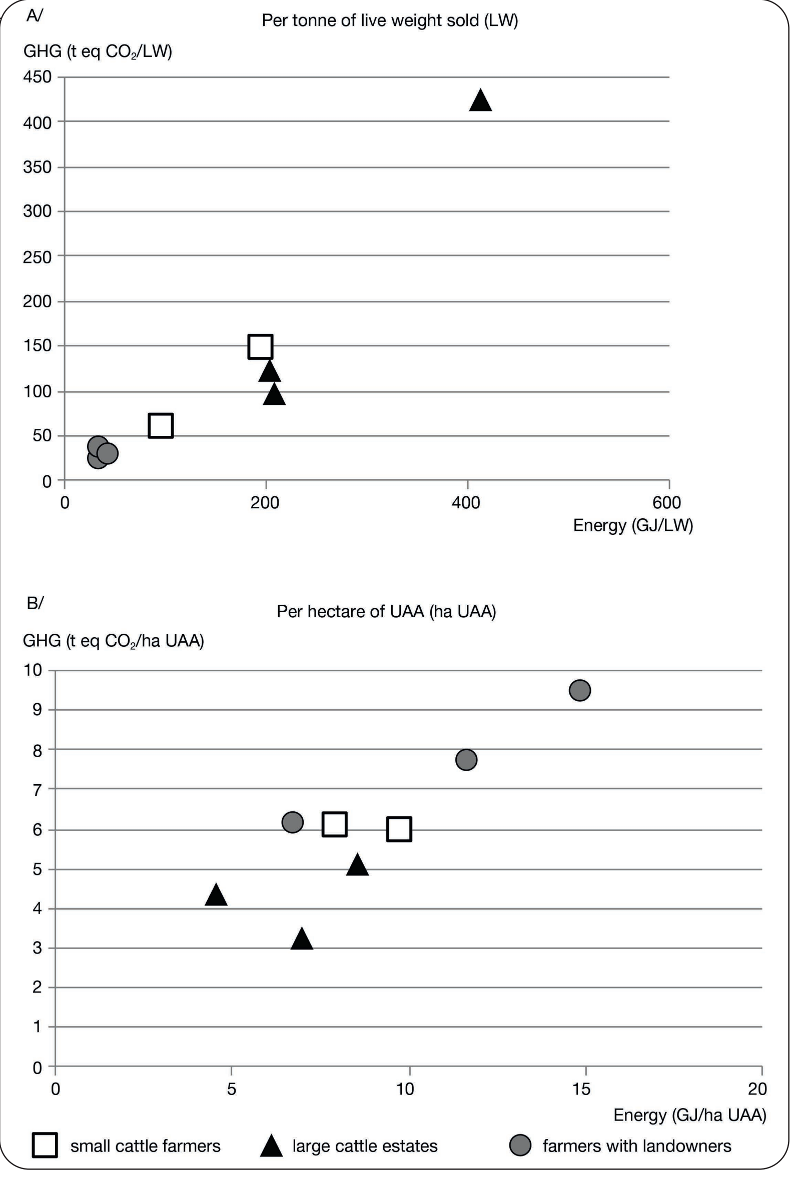


Table 3.2. Comparison of energy and GHG emission balances in French Guiana and metropolitan France (Bordet *et al.*, 2011; http://agribalyse.ademe.fr/).

Energy efficiency				GHG emission efficiencies				
Per unit produced		Per unit of area		Per unit produced			Per unit of area	
ACCT DOM®	Planete®	ACCT DOM®	Planete®	ACCT DOM®	Agribalyse®	Planete®	ACCT DOM®	Planete®
French Guiana	Mainland France	French Guiana	Mainland France	French Guiana	Mainland France	Mainland France	French Guiana	Mainland France
GJ/unit	GJ/unit	GJ/ha	GJ/ha	t eq CO2/unit	t eq CO2/unit	t eq CO2/unit	t eq CO2/ha	t eq CO2/ha
73	30	7	16.6	27.1	14.4	12.8	4.6	5.6

Box 3.2. AgriClimateChange Tool (ACCT), an energy and carbon balance tool adapted for the French overseas departments - example of its adaptation to French Guiana in collaboration with Solagro (http://www.solagro.org).

Vincent Blanfort

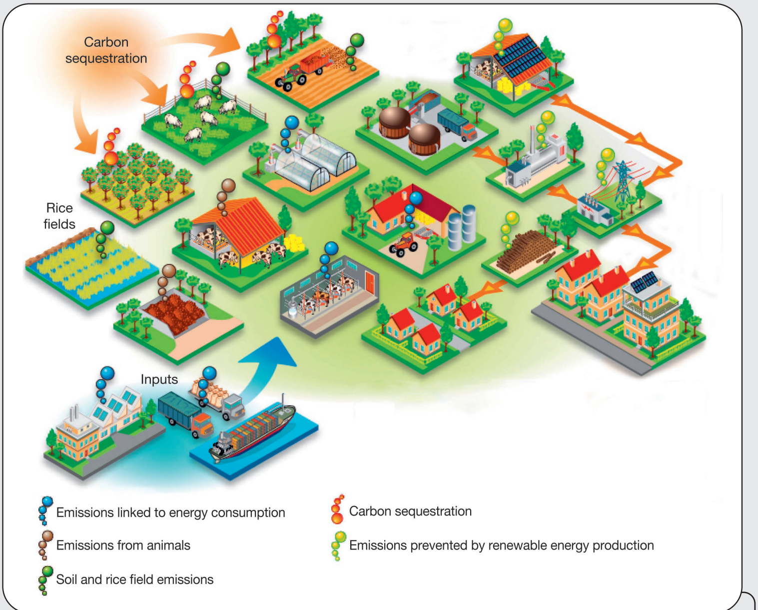
ACCT provides a "technical" quantified inventory of the situation, covering an overall analysis of:

- the Farm energy dependency: non-renewable energy consumption, production and consumption of renewable energy (indirect energy used for purchases of feed, fertilizer and equipment),
- greenhouse gas emissions: GHG emissions on the farm (total, per item and additional production/storage of carbon in the soil),
- nitrogen environmental indicators: water risks (overall balance on the "soil/UAA" level).

This is an analysis by production house to identify the most energy-consuming and GHG-emitting items.

Finally, this tool makes it possible to identify proposed improvement actions quantified in terms of energy, GHG and cost savings (Figure 3.5).

Figure 3.5. A schematic diagram of the GHG emission sources, carbon stock changes and GHG emissions prevented by renewable energy production taken into account in ACCT.



Source: https://solagro.org/travaux-et-productions/outils/acctool-acct-simplified-version-acct-dom.

ACCT is the result of a development process based on tools and reference systems that have mobilised various stakeholders since 1999 in conjunction with Solagro and CIRAD for the French overseas departments:

- Planète® (1999-2010), creation of references by farming system (RefPlanete 2010);

- Dia'terre® (2010), a national Ademe tool for farm energy and waste management diagnosis; (ADEME: French Energy Agency)

- ClimAgri® (2009), Ademe tool for energy and waste management diagnosis on a territorial scale (Solagro);

- Life+ AgriClimate Change programme - http://www.agriclimatechange.eu/, (2009-2013);

- ACCT-DOM® (since 2014), support for energy investment policies on farms in the French overseas departments (Antilles, Reunion);

- ACCT-DOM® in Amazonia in French Guiana (2017) and Brazil (2021) implemented by Cirad.

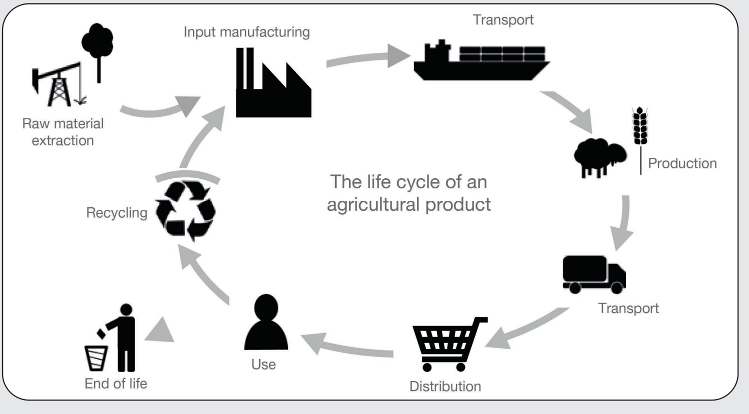
Box 3.3. Seeing beyond the herd or the farm through the "life cycle" approach.

Mathieu Vigne

For several years now, environmental assessments no longer focus solely on the direct impacts of livestock activities, i.e. the impacts that take place on the farm. They are based on the "life cycle" approach, which defines all the processes that take place upstream of the system, mainly to produce inputs, and downstream, to bring the system's product(s) to the consumer and to treat the waste generated by its consumption (Figure 3.6). This approach can be applied to measure the indirect environmental impacts linked to the production and consumption of the product. For livestock production, the "emblematic" indirect impact concerning greenhouse gas emissions is, for example, the impact on deforestation in South America linked to the consumption of soya cake by livestock systems in Europe.

This approach is all the more important as it enables the design of practices that jointly reduce impacts both locally (so-called "direct") and elsewhere (so-called "indirect"), and so avoid "false good ideas" such as relocating feed production and breeding (farmer cattle, fattening cattle), which can lead to higher transport-related impacts (see case study on livestock farming on the island of Reunion).

Figure 3.6. The life cycle of an agricultural product.



Applied to fossil energy consumption and greenhouse gas emissions, this approach has been implemented by UMR Selmet researchers, in particular on numerous dairy and beef cattle systems in a variety of contexts in South and Central America (Brazil, Costa Rica, Guyana), Africa (Burkina Faso, Burundi, Egypt, Mali, Democratic Republic of Congo, Zimbabwe) and the Indian Ocean (Reunion, India). This holistic approach also allows us to make accurate comparisons of very diverse systems in terms of the level of intensification and utilisation of grazing. Our work shows that the importance of "indirect" emissions is lower for tropical systems in developing countries largely dominated by low-input systems (Vigne *et al.*, 2015).

Towards carbon-neutral grazing livestock territories?

The farm-scale assessments described above relate to well-defined areas (the boundaries of the farm) and whose management is based on also well-defined (usually individual) decision-making systems. They are poorly adapted to systems open to input imports (Box 3.3) or to community-based resource management, which are also characterised by temporal variability (seasonality) and spatial heterogeneity of ecological processes of GHG emissions or carbon sequestration. This is the case for livestock farming in the Sahel, which is traditionally discussed in the debate on global warming, but whose impact has never been precisely assessed because pastoral ecosystems are complex, poorly conceptualised and not assessed from this point of view.

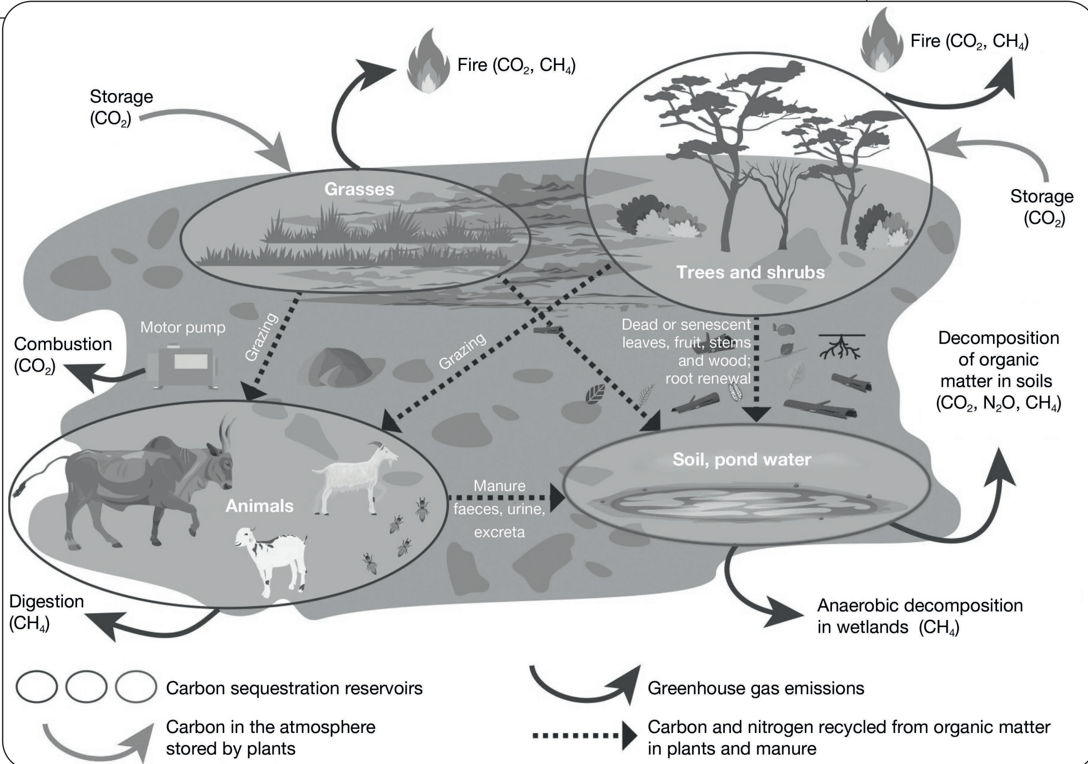
An original system adapted to these variabilities has made it possible to address these issues in a pastoral area of the Senegalese Ferlo (Assouma et al., 2019). It integrates the different compartments of the ecosystem (animals, soil, vegetation) and measures all components of the carbon balance at the landscape level (Figure 3.7). The catchment area of the Widou borehole (circle of 30 km diameter around the borehole, i.e. 706 km²) in the sylvopastoral region of the Ferlo Nord was chosen as the spatial unit of analysis.

The results indicated that the carbon footprint of the area is in balance, although it varies according to location and season. In this grazing ecosystem, one hectare emits 0.71 tonnes of carbon equivalent per year and sequesters 0.75 tonnes: it therefore stores the difference, i.e. 40 ±6 kilograms of carbon equivalent. The carbon balance is thereby neutral: carbon sequestration in the trees, shrubs and soils offsets the GHG emissions of the animals linked to their feed and the deposit of their droppings. At a more detailed level within this area, spatial variation can also be observed in relation to livestock farming practices. Grassland, shrubland and woodland, where animals move to graze, are locations where carbon sequestration prevails. Conversely, resting areas near campsites and the edges of water points, which are subject to a lot of dung and where vegetation is scarcer, are emitters because of the high GHG emissions at ground level during the rainy season. The seasonal variation of the carbon balance could also be measured. In the rainy season, the ecosystem emits much more GHG than it stores carbon - animals and ponds with their surroundings being the main sources of emissions. Conversely, in the dry season, the ecosystem stores - as dung and grasses are buried in the soil by trampling animals - and the large GHG fluxes to soils that occur in the rainy season decrease considerably as soil moisture levels fall.

By highlighting the spatial and temporal heterogeneity of emission processes and carbon sequestration, mitigation options can be proposed for the various landscape units:

- developing and maintaining water troughs near boreholes and ponds to avoid droppings being deposited directly into the water;
- making better use of the natural vegetation that grows each year in order to ensure a longer availability of fodder resources with the delimitation of temporary set-asides accompanied by a good firebreak system and the constitution of fodder stocks (straw/hay);

Figure 3.7. Simplified model of GHG emissions and carbon storage in a Sahelian pastoral territory (Assouma *et al.*, 2019).



The ecosystem approach to carbon balance is based on this model. A spatially explicit and monthly measurement protocol was implemented from May 2014 to October 2015 to estimate GHG emissions (enteric methane from livestock, nitrous oxide and methane from soil, ponds and termites, fuel consumed, fires) and carbon sequestration (above-ground and below-ground biomass from trees and shrubs, soil and animals).

• by better use of animal waste to produce organic manure for fertilising garden soils or fuel in biodigesters for the surrounding populations.

In view of the seasonality and interannual variability that condition the functioning of these ecosystems, as well as the livestock system mobility, this ecosystem-based approach to carbon balance still needs to be consolidated by measurements over several years and by diversifying the sites. The multiplication of measurements of GHG emissions and carbon sequestration potential would consolidate these results and enable integrating these references into the IPCC guidelines relating to pastoral and agropastoral systems, for which there is still insufficient data, in particular the offsetting of emissions by carbon sequestration potential. The approach could also help to compare different types of tropical landscapes or agricultural territories, more or less densely grazed, where livestock farming is integrated with protected areas, specialized agricultural areas, etc.

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This chapter has mobilised the results of several field research schemes on livestock grazing systems in tropical areas. The elements presented illustrate the relevance of the concept of environmental efficiency to address the issue of climate change, but also the difficulties it raises in tropical and Mediterranean regions.

To conclude, it is essential to stress the lack of sufficiently numerous and solid scientific references, such as those available in the North. Researchers have shown that the direct transposition to the South of reasoning, or even measurements carried out in the North, is unsuitable. In fact, biological and biochemical mechanisms do not follow the same rhythms, nor have the same intensity: photosynthesis, metabolisms, decomposition, among others, are very different in the tropics. Furthermore, livestock systems do not function according to the same logics, because of specific constraints and opportunities, such as land tenure or access to land, decision-making systems, access to services and inputs, etc. A first conclusion is therefore the importance of continuing this work on producing references, in order to improve evaluations and avoid the need to resort to transpositions of North-South reasoning.

Beyond the lack of scientific references that they highlight, these examples show the potential of tropical grassland systems to meet climate change challenges. Whether at the fine scale of plots and soil-plant relationships, at the intermediate scale of farms or at the broader scale of landscapes and territories, we highlight interesting mechanisms for soil carbon sequestration, reduction of methane emissions by cattle and energy consumption. These mechanisms depend on good practices at all levels, hence the interest in producing multi-criteria or even multi-level evaluation or simulation tools. It is important to note that these potentials concern both relatively extensive grassland systems such as in French Guiana, where grassland management makes it possible to constitute carbon sinks up to one metre deep, and more intensive systems such as those on the island of Reunion where organic matter inputs play a role not only in fertilising fodder plants, but also in sequestering them in the soil.