ruminants

MDPI

*Article*

# Representing Cattle Farming around the World: A Conceptual and Holistic Framework for Environmental and Economic Impact Assessment

**Lucie Perin [1,*], Patrice Dumas [2] and Mathieu Vigne [3,4]**

[1] CIRAD, UMR Centre International de Recherche sur l'Environnement et le Développement, Université Paris-Saclay, AgroParisTech, CNRS, EHESS, Ponts-ParisTech, 94130 Nogent-sur-Marne, France
[2] CIRAD, UMR Centre International de Recherche sur l'Environnement et le Développement, 34398 Montpellier, France
[3] CIRAD, UMR Systèmes d'Elevage Méditerranéens et Tropicaux, Antsirabe 110, Madagascar
[4] UMR Systèmes d'Elevage Méditerranéens et Tropicaux, CIRAD, INRAE, Institut Agro, Université de Montpellier, 34398 Montpellier, France
* Correspondence: lucie.perin@agroparistech.fr

**Abstract:** Around the world, cattle farming systems are diverse and lead to diverse environmental and socio-economic consequences. To assess these consequences, the diversity of cattle farming needs to be represented. A conceptual framework based on three inter-linked concepts (management types, animal profiles and lineage groups) is proposed resulting in two typologies, and tested on cattle systems in Kenya. The management type typology provides an understanding of the cattle farming practices across the world. Animal profiles, defined by the animal's age and sex, and used together with management types, serve as a convenient unit for the analysis of feed use, environmental impacts, animal functions, and costs. Lineage groups bring together cattle and their progeny, making it possible to account for movements across management types and for all co-productions in impact assessments. The illustration on Kenya showed the completeness of the framework, the availability of management-type characteristics, and also the lack of precise data on shares of lineage groups and management types. The conceptual framework developed here should render it possible to capture and compare the multiple characteristics and functions of cattle farming around the world, including their environmental impact, which currently is a major issue for the global livestock sector.

**Keywords:** cattle farming systems; environment; typology; conceptual framework; environmental impact assessment; Kenyan cattle systems

check for updates

**Citation:** Perin, L.; Dumas, P.; Vigne, M. Representing Cattle Farming around the World: A Conceptual and Holistic Framework for Environmental and Economic Impact Assessment. *Ruminants* **2022**, *2*, 360–381. https://doi.org/10.3390/ruminants2040025

Academic Editor: Brian J. Leury

Received: 1 August 2022
Accepted: 20 September 2022
Published: 23 September 2022



## 1. Introduction

Cattle farming is a ubiquitous activity worldwide, characterized by strong heterogeneity in production methods and practices, with contrasting bio-physical characteristics and diverse production objectives [1]. Moreover, cattle movements within and between systems are common. They involve seasonal and nomadic movements and/or geographical movements during the lives of animals; for example, dairy system grass-based weaned calves being sent to a grain-based meat production system to be fattened [2,3]. Such movements determine births, adult reproduction, and replacement of culled animals, as cattle production requires breeding, even when milk is the main product.

Cattle farming systems comprise multiple activities, produce diverse products, such as meat and milk, and generate diverse economic impacts depending on their use of land and inputs, farming intensity and fertility management [4]. In addition to direct financial income from the sale of products, some systems provide many co-benefits such as draught power, walking financial capital, and fertility transfer depending on farming practices and the availability of resources [5–8]. For instance, in many low to middle-income countries, cattle are kept as financial walking financial capital and insurance for smallholder breeders [9]. While fulfilling diverse economic functions, cattle farming also produces various environmental services and disservices, locally and globally.

Cattle farming is associated with the extensive use of natural resources, mainly land, water, and nutrients [10]. In addition, cattle farming, and more globally ruminant farming, is criticized for contributing to greenhouse gas (GHG) emissions, which play a role in climate change. Ruminant supply chains are responsible for 80% of GHG emissions in the livestock sector, accounting for 5.7 GTeqCO2/year [11], and livestock farming is responsible for 14% of GHG emissions associated with human activities in the world [2,10]; emission intensity differing according to species and product specification (milk or meat production) [2]. Alongside enteric fermentation, which accounts for 46% and 43% of the total emissions in the dairy and beef supply chains respectively, the efficiency by which feed is converted into product is a major driver of GHG emissions, and is determined by the availability and quality of feed and animal productivity [2]. GHG emissions thus depend on local climatic conditions, farming systems, and the associated feed diet [2].

Inadequate manure management in cattle farming, which leads to water pollution and especially eutrophication, is largely determined by variations in animal feed nitrogen richness, pasture management, and herd mobility and management [6,12]. However, in mixed crop-livestock systems, large ruminants often contribute to crop productivity, as manure is used to fertilize the soil and the integration of livestock and crops can enable efficient nutrient recycling [2].

Biodiversity can be impacted through the use of resources for feed rations, the intensity of management, and the integration of livestock with other agricultural components. Livestock farming practices such as overgrazing, clearing, and ploughing can lead to soil compaction and ecosystem fragmentation [10]. However, most effects on biodiversity are indirect, such as deforestation, GHG emissions, water pollution, and increase of international trade. Positive impacts on biodiversity, such as maintenance of local grassland biodiversity, as well as maintenance of semi-natural vegetation agro-ecological infrastructures, can happen when cattle are not managed too intensively [13].

As cattle production systems have a significant environmental impact at both local and global levels, it would be interesting to be able to compare these systems. Given the difficulty of modeling the complexity of cattle production systems at a global scale, the most viable option would be to describe and classify them based on their production methods and practices. Furthermore, cattle production systems are not isolated, and interactions exist between them. Cattle frequently move across systems [14], for instance calves are born in dairy grass-based systems and are then fattened in feedlots. These movements, combined with the specific characteristics and constraints of animal production and co-production, pose challenges for environmental impact assessments, especially concerning GHG emissions. To assess these impacts, grouping activities related to cattle and their progeny as in [15], where cow-calf ranching and beef feedlot finishing are represented together, appears to be a relevant approach. The task is therefore to find the right boundaries, through lineage groups, while avoiding a level of complexity that makes modeling and assessment difficult. Environmental impacts targeted are GHG emissions, nitrogen pollution (N balance), and potentially biodiversity while economic impacts are returns, meaning the difference between costs and production.

Making sense of the complexity of relations between cattle systems across the world in order to set the stage for further studies comparing their overall benefits or downsides (economic, environmental, social) at a large scale is a major undertaking. It requires the diversity and complexity of cattle systems to be described, with a clear delimitation of these systems, while grouping and simplifying them [10,16,17]. To achieve this aim, typologies resulting from a holistic approach based on three main levels of analysis are developed in this paper and tested on cattle systems in Kenya. The framework is based on three linked concepts:

- Management type (MT), defined as a set of production methods and farming practices. The associated typology is partly based on existing typologies [18–21] used to describe and classify the diversity of cattle production systems based on farming practices; animal profiles, which divide an animal's life into phases based on age and sex, to obtain homogeneous feed use and animal characteristics to simplify environmental impacts analysis and computation; information on location and climate is needed for the analyses performed on animal profiles;
- Lineage group (LG), which groups the different phases of an animal from birth to death and makes it possible to address breeding and herd renewal constraints as well as animals' transition between MTs. Lineage group is the functional unit used for the final assessment of economic returns and environmental impacts, which should be determined by aggregating values computed at the animal profiles.

## 2. Materials and Methods

### *2.1. Conceptual Framework*

Highlighting the importance of the choice of farming practices and methods is at the core of this work. We therefore decided to introduce the notion of management type, which is characterized by specific criteria, including farming outcome, farming objective, general feed diet, herd management and mobility, pasture management intensity, crops and other agricultural component integration, and manure management (see Figure 1). These practices both influence GHG emissions and nitrogen use and impact landscapes, livelihoods, and costs. An animal could spend its entire life in the same MT, or could experience different MTs as it passes from one phase to another. The MT of reproductive cattle influences breeding choices, such as natural breeding or insemination. Finally, some animals are only present in particular MTs, such as oxen which are not produced in MTs specialized in dairy or meat production.

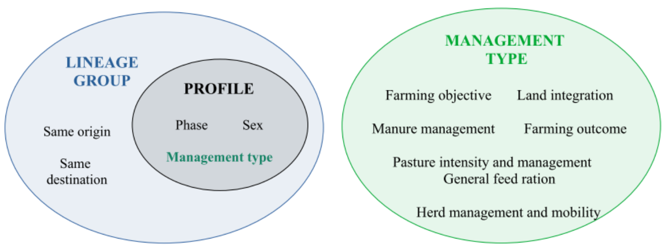


**Figure 1.** Description of MTs, LGs, and animal's profiles.

MT is used here instead of systems to avoid using a word with multiple definitions. A livestock system, as described by [22], is defined by elements in interaction, including animal species, resources, techniques, and practices implemented by a community or by a breeder, to meet needs by developing natural resources through animals. Other authors use a typological approach to define systems based on their similarities [18]. Systems, in that case, are defined as groups of farms with similar structures and functions that are expected to fulfil similar production functions.

To further simplify the assessment of resource use and environmental impacts within and across MTs, the life of an animal is subdivided into various profiles. Each animal profile is defined as a specific phase and sex (see Figure 1). An animal's life is therefore divided into phases depending on its age and reproductive status, distinguishing pre-weaning calves and young bovines after weaning, followed by young bulls and heifers having reached sexual maturity, and cows and bulls reared for reproduction and oxen, when relevant. Each MT is therefore composed of several animal profiles that are homogeneous in terms of practices, but concern different phases and sexes. In particular, a cattle's profile combined with its MT determines the diverse functions that it will fulfil, such as reproduction, milk or meat production, herd renewing, fattening purpose or draught power, as well as feed rations. This makes it possible to divide the life of an animal into homogeneous units and account for the environmental impacts at each stage of life, in particular through modeling. The location of an animal profile and the associated climate, although it does not directly enters the MTs description, should be taken into account in the modelling of animal profiles.

The animal profile is the unit at which the impacts are conveniently modeled and assessed, and MTs are considered as major drivers of impacts. However, to assign impacts, all cattle profiles and their co-produced animals (animals from the same origin) are also regrouped in a lineage group (LG), which is defined by a set of cattle profiles coming from the same mother and going through the same MTs. An LG is often seen as a linear relationship oriented from parents to children. In this case, an LG is a set of animal profiles of parents and children in a stationary state that are consistent with rates of offspring production and replacement of adults.

Notions of MTs, animal profiles, and LGs differ from notions of herds and farms. Herds are groups of animals kept together that can be composed of diverse animal profiles, and can even group together animals of different species. A farm is an entity used for cultivation and livestock production. A farm can be composed of one or several herd(s). In general, farms are characterized by a homogenous MT, but this is not necessarily the case. It is possible, for example, to have both an intensive dairy MT, using high levels of concentrates, and a grass-based extensive MT for young bovines on the same farm and for the same herd but involving different animal profiles. It is also possible, though probably rare, to have different MTs for a given animal profile within a farm. It should always be possible to decompose a farm or a herd into animal profiles, each associated with a MT. LGs can spread over multiple farms, as is the case in the grass-based with finishing feedlot LGs in the USA and Europe. An LG also can be entirely contained within a single farm, as is usual in ranches specialized in meat based solely on grass, which are common in South America.

The division of the life of an animal into profiles allows one to better trace the movement of cattle between MTs. As an example, a calf born and first raised on a pastoral dairy farm can then be transferred to a fattening feedlot to finish its life. A change of MT can potentially imply a change in geographical location. LGs are considered as units at which impacts evaluated at the animal profile level should be aggregated, as it regroups co-produced animals from the same origin. In the framework we propose, the analysis and computation unit, the animal profile, is therefore distinguished from the final assessment functional unit, which is the lineage group.

We have introduced in this framework three levels of analysis: MTs, animal profiles, and LGs. To analyze these levels, we organize each of them into typologies. A typology of cattle farming captures its complexity by organizing farms into quite homogeneous groups to generate a simplified representation of its diversity [23]. Cattle farming MTs may be classified according to multiple criteria and many possible combinations of criteria can be used [21,24]. Although typologies never capture the complete image of reality, they are regarded as a crucial factor in the description and analysis of various cattle farming systems, revealing productivity and future potential for growth [21] and intensification. Most of the time, typologies focus on the MT scale in addition to climatic conditions, but only treat the lineage group scale implicitly at large scales [16–18].

*2.2. Methods for Management Type Typology*

Criteria used in the MTs typology can be regrouped into seven main categories. Two of them do not appear explicitly in the decision tree (see Figure 2) as they are implied by other criteria:

1. Breed. MTs are characterized by specialized or multi-functional breeds. The later includes breeds used for meat and milk production (without any type of specialization in one of these products), fertility transfer, drought power, etc. Cross-breeds (*bos indicus*X*bos taurus*) would also add value to production having higher outputs and lower impacts on resources use under certain conditions (e.g., cross-breeds in semi-arid areas have higher output than local or exotic breeds);

2. Farming objective. We differentiate MTs with a multi-functional objective (e.g., meat/milk production, draught power, fertility transfer, generation of revenues, etc.,) and those with a production and revenue generation objectives. These objectives depend in particular on the availability of resources (water, feed, financial capital) and influence the age at which cattle are slaughtered;
3. Feed. Diet is an important criterion to take into account as it impacts animal production and is linked with pasture management, on-farm crop production, external feed purchases, and the use of waste and residues. Waste and residues use, as well as the use of the sides of roads and fields, are part of the typology as using these sources of feed renders it possible to spare natural resources. Feed rations depend on the animal profile and the MT. Diet impacts GHG emissions through digestibility, but also through crop feed production emissions and other environmental impacts and land use.
4. Relation to land:
    - Intensity of pasture management, described as intensive (i) or extensive (e) in Figure 3. Pasture management covers fertilization, grazing practices (rotational, seasonal), and stocking rates. Grass resource management is closely linked with herd mobility and nomadism. Some MTs are either extensive or intensive by definition, others are subdivided into extensive and intensive pasture management corresponding to high stocking rate, fertilization and a lower mobility for the latter;
    - Integration/relation to crops or other agricultural components (e.g., forests, pastures). This criterion has an impact on manure management and nutrient cycles, but also herd mobility and health, and diet composition. In the case of a multi-functional objective combined with crop integration, oxen may be present for draught power.
5. Herd management. Herd health and reproduction practices such as artificial and natural insemination are included in herd management. Cattle breeds are important to take into account due to their different impacts on farming objectives and production, as well as their environmental impacts. We consider herd management to be implicit to the breed, farming objectives and pasture management intensity considered, and therefore does not appear in the decision tree of Figure 2.
6. Herd mobility. Herd mobility varies according to the MT considered, grazing management, resources availability (grasslands, forests), and carrying capacity, and differentiates mainly between nomad and sedentary MTs, the latter reflecting a management based on grazing pastoralism along with a confinement of animals in barns when the weather dictates. It impacts grassland biodiversity, soil compaction, manure management, and nutrient and nitrogen cycles. Herd mobility also includes seasonal movement of animals such as nomadic pastoralism.
7. Manure management. Nutrient and nitrogen cycles are closely linked to herd mobility as well as pasture management. Manure management ranges from direct and uncontrolled deposition on pastures by animals to manure collection and storage in various forms: solid, liquid or slurry. This criterion does not appear in the decision tree (see Figure 2) as it is considered to be implicit to herd management and mobility.

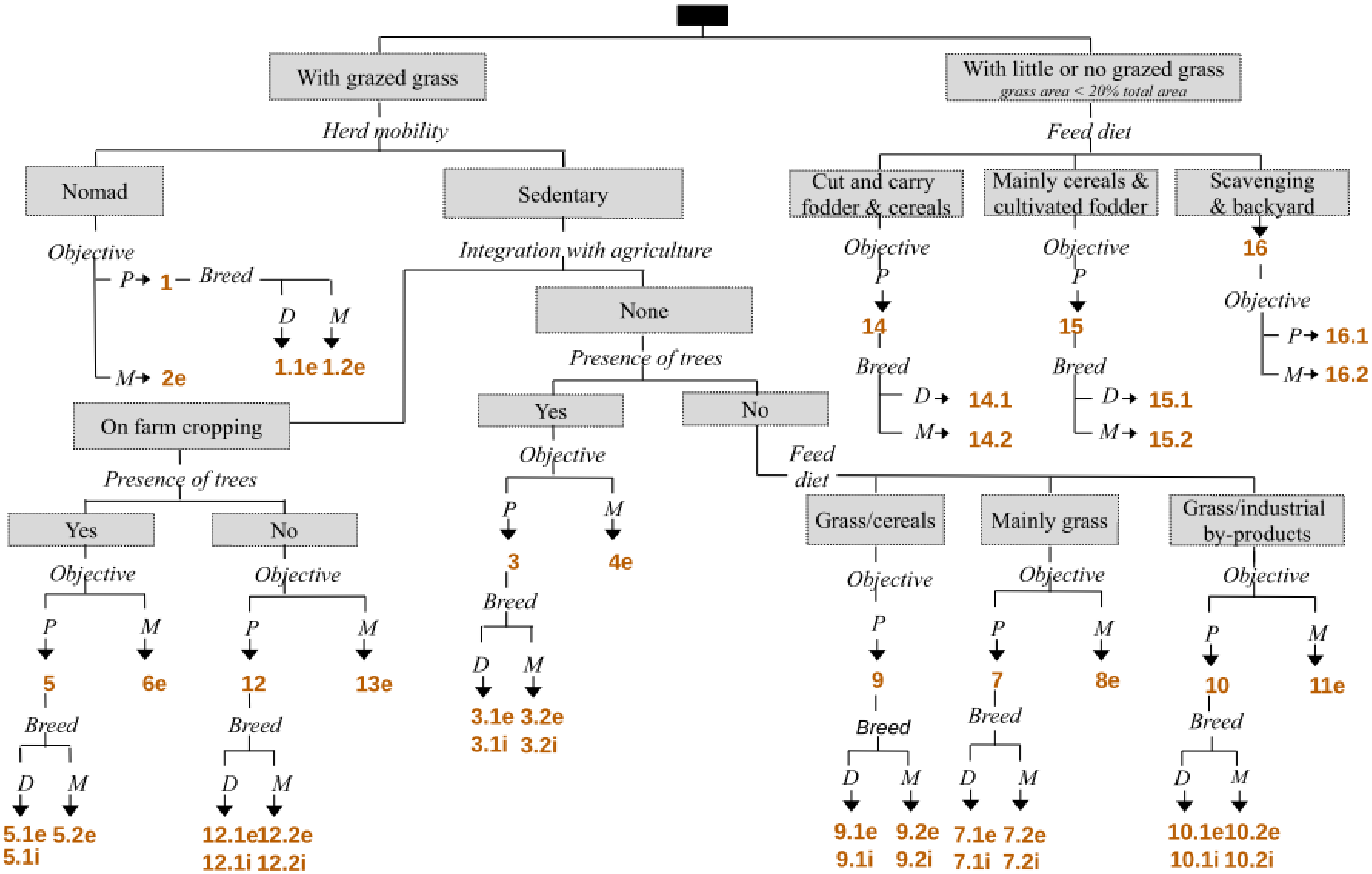


**Figure 2.** Decision tree for the construction of cattle MTs typology based on criteria (D: dairy breed, M: meat breed, P: production, M: multi-function, i: intensive pasture management, e: extensive pasture management).

Geographical location and climate are considered as external factors, in contrast with other typologies based on the FAO ago-ecological zones (arid, humid, temperate) [25] which include climate as a criterion. Climate and location are taken into account in the framework, however, as they should be used for animal profiles modelling. Climate is important because it influences the performance of each MT, in particular through net primary production (NPP) and on farm feed yields. All MTs could potentially and theoretically be based all over the world. In practice, environmental (temperature, NPP) and socio-economic (access to markets and credits) contexts favor one MT over another. Climate certainly influences the MT adopted and has consequences on some of the practices used through grass quality and yield, herd mobility and management (e.g., time spent indoors and outdoors), and pasture management (e.g., herd mobility through grazing patterns). It could even be that some MTs cannot exist in certain regions of the world because of climatic constraints.

### *2.3. Methods for Lineage Group Typology*

LGs regroup all co-produced animals, meaning all animals from the same origin, and going through the same MTs. They allow one to characterize the trajectory of an animal over its life, including transitions between MTs and geographical location. Understanding connections between animal profiles and the progression of animals from one MT to another are therefore needed to describe LGs. Relations between profiles are similar for all LGs as they have similar breeding constraints for calf production and replacement constraints for adults. A generic herd structure can therefore be used to link animal profiles together (see Figure 3).

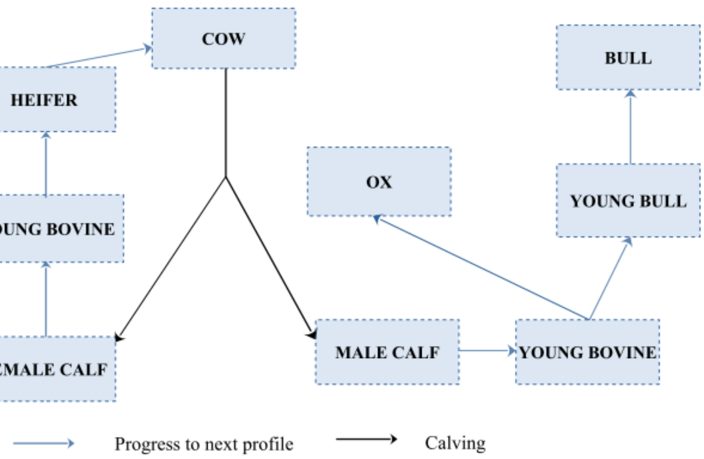


**Figure 3.** Cattle herd structure [26].

LGs are classified using movements between MTs. While evolving towards another profile (see Figure 4), cattle can progress towards another MT or stay in their MT of origin. When progressing toward other MTs, possibilities are restricted by considering that cattle that are not destined for reproduction preferentially move toward MTs with more digestible feeds for fattening. Therefore, non-reproductive cattle born in feedlots and similar MTs with a diet based on cereals and cultivated fodder stay in feedlots, while non-reproductive cattle originating from grass-based MTs can move to specialized fattening feedlots or veal calf farming. In some cases, reproductive female cattle can also progress to other MTs before returning to their origin, as it is common in New Zealand for example, where heifers from intensive dairy MT are reared in less productive areas before returning to their MT of origin [27].

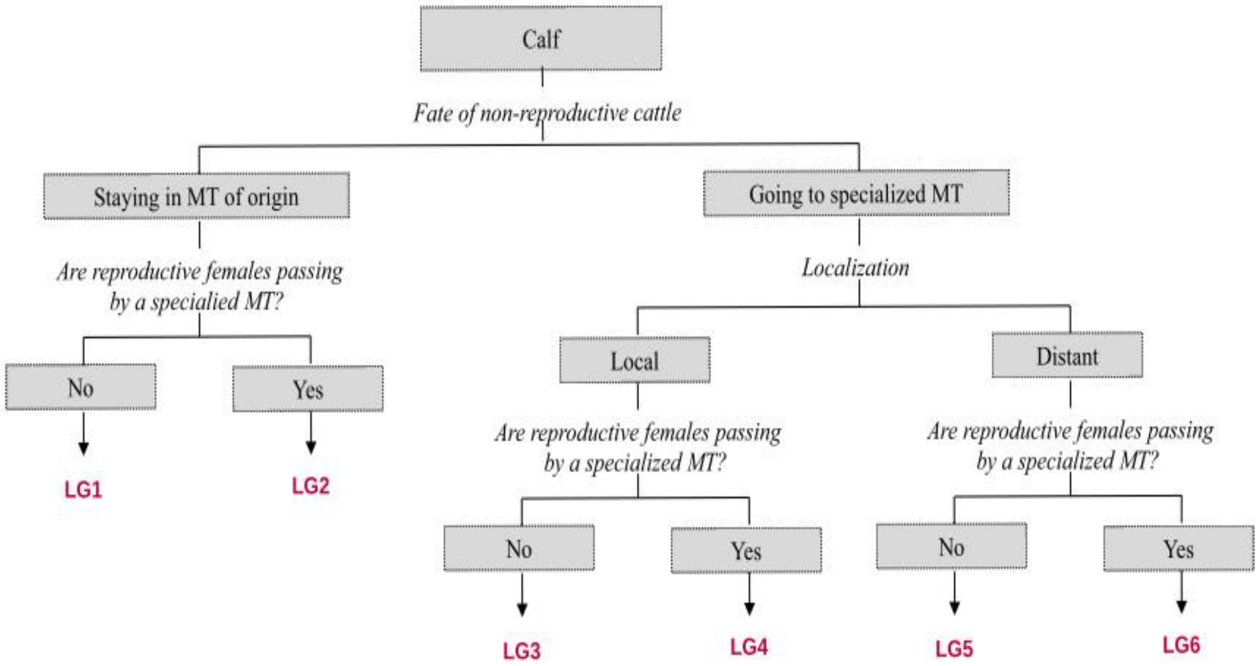


**Figure 4.** Decision tree for the construction of the LG typology.

Based on herd constraints and farming choices, six LGs were identified (see Figure 4) using criteria described below:

- The fate of non-reproductive cattle. This fate (culled or fattened) discriminates between lineage groups based on whether or not non-reproductive cattle (cattle that are not destined for reproduction) stay in their MT of origin.
- Location. For non-reproductive cattle progressing away from the MT of origin, there is a distinction between local and distant location from the MT of origin. A local MT is located at a close distance from the MT of origin while a distant MT is located at a long distance from the MT of origin. Local or distant location affects time and costs of cattle transport, contributing to environmental and economic impacts.
- In addition, each reproductive female cattle can pass through a specialized MT as heifers before returning to their MT of origin and participate in herd renewal/milk production as cows.

## 3. Results

### *3.1. Management Type Typology*

The typology presented is based on existing cattle farming systems from all over the world. Based on the decision tree in Figure 2, the 16 MTs identified are presented below and are described in more detail in Table A1 in Appendix A:

- 1.1.e/1.2e—Traditional pastoral dairy/beef MT with a production objective;
- 2e—Traditional pastoral MT with a multi-functional objective;
- 3.1.e & 3.1.i/3.2.e & 3.2.i—Sylvo-pastoral dairy/beef MT with a production objective;
- 4e—Sylvo-pastoral MT with a multi-functional objective;
- 5.1.e & 5.1.i/5.2.e & 5.2.i—Agro-sylvo-pastoral dairy/beef MT with a production objective;
- 6e—Agro-sylvo-pastoral MT with a multi-functional objective;
- 7.1.e & 7.1.i/7.2.e & 7.2.i—Grass-fed dairy/beef MT with a production objective;
- 8e—Grass-fed MT with a multi-functional objective;
- 9.1.e & 9.1.i/9.2.e & 9.2.i—Externally complemented grass-fed dairy/beef MT with production objective;
- 10.1.e & 10.1.i/1.2.e & 10.2.i—Grass-fed dairy/beef MT, using industry by-products with a production objective;

- 11e—Grass-fed MT, using industry by-products with a multi-functional objective;
- 12.1.e & 12.1.i/12.2.e & 12.2.i—Internally complemented grass-fed dairy/beef MT with a production objective;
- 13e—Internally complemented grass-fed MT with a multi-functional objective;
- 14.1/14.2—Zero-grazing dairy/beef MT with grass, with a production objective;
- 15.1/15.2—Zero grazing dairy/beef MT without grass, with a production objective;
- 16.1/16.2—Scavenging & backyard MT with a production/multi-functional objective.

### *3.2. Animal Profiles*

Male and female calves first belong to the milk-fed pre-weaning phase. Cattle are born and raised with the mother until weaning, or separated from the mother and fed with milk powder in intensive management types. This phase is followed by a post-weaning phase called the young bovine phase. Female cattle leave that phase to become heifers as soon as they are ready to reproduce to then become a cow (after the first calving). Males able to reproduce become young bulls and then bulls if they are dedicated to breeding, or an ox if they are castrated. The age at which an animal belongs to a particular phase depends on the MT, in particular on the farming objective (specialized or multi-functional) as well as the specific diet, which influence animals' growth rates and sexual precocity. The animal profile together with the MT determines an animal's feed ration and function, and is a convenient unit for the analysis of feed use, environmental impacts, and costs. Typical ages for the different phases depending on the corresponding MT are shown in Table A2 in Appendix A.

### *3.3. Lineage Group Typology*

From the LG decision tree (see Figure 4), we identified six lineage group categories:

- LG1—All cattle staying in their MT of origin

All reproductive and non-reproductive cattle are born and fully reared in their MT of origin.

- LG2—Cattle staying in their MT of origin with reproductive females going through another MT

Non-reproductive cattle stay in their MT of origin while reproductive female cattle go through another MT before returning to their management type of origin.

- LG3—Non-reproductive cattle progressing to a local MT

Non-reproductive cattle are born in one MT before progressing to a local MT to be reared until slaughter. Reproductive cattle stay in the MT of origin.

- LG4—Non-reproductive cattle progressing to a local MT with reproductive females going through a specific MT

Non-reproductive cattle progress to a local MT for fattening, while reproductive female cattle go through another MT, typically less intensive, before returning to the local MT.

- LG5—Non-reproductive cattle progressing to a distant MT

Non-reproductive cattle are born in one MT before progressing to a distant MT to be reared until slaughter. Reproductive cattle stay in the MT of origin.

- LG6—Non-reproductive cattle progressing to a distant MT with reproductive females going through a fattening MT

Non-reproductive cattle progress to a distant MT and reproductive female cattle go through another MT before returning to a local MT.

## 4. Contextualization and Comparison with Existing Typologies: Case Study of Kenya

Livestock production in Kenya contributes about 13.4 percent (USD 3.1 billion) to agricultural value added with cattle being the most important contributor [28]. Farmers raise cattle, both beef and dairy animals, in different production systems [29]. Dairy animals represent around 25% of all cattle population with an estimated population of 4.5 million cows in 2018 while beef animals represent around 75% of all cattle population with an estimated population of 14 million animals [29]. The herd structures in these different systems are not well described in publications, in particular the age of cattle in the different systems is not described.

### 4.1. Dairy Production Systems in Kenya

Kenyan dairy production systems are characterized either as sedentary or pastoralist [30]. They are divided into three general categories: grazing systems (GS), zero grazing systems (ZGS), and semi-zero grazing systems (SZGS), corresponding to different levels of external input uses by [30] (see Table 1) while [29] divide dairy production systems in intensive, semi-intensive and extensive systems. Even though both typologies are certainly similar to each other, they sometimes differ in inputting systems to categories. For example, systems classified as extensive "controlled" by [28], with cattle supplemented with high quality fodder and commercial concentrate correspond better to the semi-intensive category in [30].

The three categories described by [30] are subdivided into mixed and solely livestock systems, as well as medium-to-large-scale (more than four cows) and small-scale systems (four or less cows) [31–33]. Low intensity middle-to-large scale mixed systems and solely livestock systems are described as grazing based, and are in the same regions. The difference between those systems seems to correspond to the level of specialization only, and not to differences in livestock management nor in integration with crops [30]. Similarly, low intensity small scale systems are based on grazing only and not easily differentiated.

Small-scale dairy farmers, also called smallholders farmers, are dominant in Kenya, owning over 80 percent of the dairy cattle national herd, and undertaking more than half of the country's milk production [30,34,35]. Large dairy farms represent the remaining 20 percent of the dairy cattle national herd, often from indigenous origin [34,36]. With the additional distinctions introduced by [30], mixed/solely livestock and small-scale/large-scale, the dairy farming system typology is more precise but is, however, lacking quantified shares for these distinctive systems.

In zero-grazing units, cattle are stall-milked and stall-fed [31], using cut- and carry fodder [34] as well as concentrates and alternative supplements [33]. Cattle are not grazing. ZGS are often associated with improved breeds for their higher yields, with high external input levels [30] and high level of management [28]. Small-scale zero-grazing units represent 34.5% of the dairy cattle population in Kenya whereas large-scale zero-grazing units represent 6.7% [28]. ZGS practices correspond to MTs 14.1, 15.1, and 16.1 in the typology, depending on their association with agriculture and on the scale (see Table 1). Scavenging and backyard MT with a production objective (16.1) is mainly present in urban and peri-urban areas, close to large consumption centers, where animal breeding is not mixed with cropping mostly due to land unavailability. Zero grazing with grass dairy MT with a production objective (14.1) corresponds to ZGS mixed with fodder production, including cut and carry grass to stall-feed cattle. Zero grazing dairy systems without grass (15.1) are not common in Kenya and should correspond to large-scale dairy farms only. Cattle are kept indoors in those MTs.

In semi-zero grazing systems, cattle are partly confined, mixing grazing during the day and confinement at night with feed supplementation [28]. They represent 47.6% of the dairy cattle population in Kenya [28]. SZGS corresponds to various MTs of the typology depending on the scale and on the association with crops. Mixed SZGS correspond to internally complemented grass-fed dairy MTs with a production objective (12.1.e & 12.1.i) for medium-to-large scale farms and with a multifunctional objective (13e) for small-scale farms. Solely livestock SZGS correspond to externally complemented grass-fed dairy MT with a production objective (9.1.e & 9.1.i), a sedentary MT without integration with agriculture or trees where grazed or cut grass is the main feed for cattle. Other feed is produced off-farm. Share of extensive pasture management (e) and intensive pasture management (i) practices are difficult to characterize here as it depends on each farmer's own management decisions (grazing in paddocks, natural or managed pastures, fertilization, etc.). To our knowledge, the grazing intensities are not reported in any document, and the link between more detailed drivers of pasture management than the MTs is not described either.

**Table 1.** Description of dairy production systems in Kenya [28,30,31,34,36], G = grazing; SZG = semi-zero-grazing, ZG = zero-grazing.

| | | **Small-Scale—Solely Livestock** | **Small-Scale—Mixed** | **Medium- to Large-Scale—Solely Livestock** | **Medium- to Large-Scale—Mixed** |
|---|---|---|---|---|---|
| G | *Corresponding MT* | 2.e | / | 7.1 or 8 | 12.1.e or 7.1 or 8 |
| | *Controlled or uncontrolled (FAO typology)* | Uncontrolled | / | Both controlled and uncontrolled | Controlled |
| | *Farming objective* | Multiobjective (dairy, meat, blood, manure, draft power, walking financial capital) | / | Multiobjective (self-consumption, manure, walking financial capital) and also market oriented, generation of income | |
| | *Feed* | Grass (natural) | / | Grass (natural) | Grass + crop residues, fodder, small amount concentrates [27] |
| | *Average herd size* | Less than 10 cows | | Up to 50 cows (in controlled grazing systems [27]) | |
| | *Breed* | Local—Zebu purebred or crossbred | | | |
| | *Average milk production* | Between 2 and 11 L/cow/day | | | |
| | *Market access* | Poor market access, mainly for self-consumption or milk sells directly to consumers | | | |
| | *Land availability* | High | | | |
| | *Intensification level* | Low (extensive feed, mostly local breeds, no AI, large pieces of land) | | | |
| | *Location* | Pastoralist areas | / | North Rift, South Rift | Rift Valley |
| SZG | *Corresponding MT* | / | 13.e | 9.1.e & 9.1.i | 12.1.e/i |
| | *Farming objective* | / | Multiobjective | Market oriented, generation of income | |
| | *Feed* | / | Grass (natural and improved pastures) + fodder/sillage + post-harvest grazing (on-farm) | Grass (natural and improved pastures) + supplements (off-farm) | Grass (natural and improved pastures) + supplements (on-farm) |
| | *Average herd size* | / | 1–3 cows | More than 3–20 cows | |
| | *Breed* | / | Exotic—Fressian crossbred or Ayshire crossbred | | |
| | *Average milk production* | / | Between 2 and 10 L/cow/day | | |
| | *Market access* | / | Medium market access, milk sold directly to consumers or cooperatives | | |
| | *Land availability* | / | Medium | | |
| | *Intensification level* | / | Medium (stall-fed and stall-milked, cross-breeds, little use of AI, medium pieces of land) | | |
| | *Location* | / | Central Rift, Western Region, Eastern Region | Central Rift | Central Rift, South Rift |
| ZG | *Corresponding MT* | 16.1 | 14.1 | 16.1 | 15.1 or 14.1 |
| | *Farming objective* | Market oriented, generation of income | | | |
| | *Feed* | High quality residues + concentrates | Cut and carry fodder, including grass + cereals + little concentrates | High quality residues + concentrates | Fodder + concentrates + cereals |
| | *Average herd size* | 1–3 cows (rural) and 7–8 cows (urban) | | More than 15 cows | |
| | *Breed* | Exotic—Fressian or Ayshire mainly | | | |
| | *Average milk production* | 15–30 L/cow/day | | | |
| | *Market access* | Market oriented, milk sells to traders or dairy cooperatives | | | |
| | *Land availability* | Scarce | | | |
| | *Intensification level* | High (intensive feed, small pieces of land, exotic breeds, AI) | | | |
| | *Location* | (Peri)-urban | Central Region, Central Rift | (Peri)-urban | Central Region, Central Rift, South Rift |

Grazing systems are divided in two types in the FAO typology [28]:

- "Uncontrolled" GS, where local breeds are roaming on communal lands (e.g., Maasai lands in South Rift Valley), with unimproved pastures and limited supplementation. They represent 5.2% of the dairy cattle population in Kenya. This category corresponds to the grazing pasture based systems with low external input levels [30];
- "Controlled" GS on private lands, fenced and sometimes divided in paddocks, with improved or crossed breeds, use of artificial insemination (AI), improved grazing practices supplemented with high quality fodder and commercial concentrates. They represent 5.9% of the dairy cattle population in Kenya. This category corresponds better to medium input level systems in [30];

GS also correspond to various MTs of the typology depending on the scale, the external input used, and on the association with crops. Mixed controlled GS as described in the FAO typology correspond to internally complemented grass-fed dairy MTs with a production objective (12.1.e) for medium-to-large scale farms. It is therefore difficult to differentiate mixed GS with mixed SZGS in the MTs typology as the farming objective is the same and feed diet is similar. The main difference being that cattle are stall-fed and stall-milked at night in SZGS while cattle are kept outdoors constantly grazing in GS. Stall-feeding might help farmers to feed specific ration to each cattle, to meet the specific animal needs to reach optimum milk production. Solely livestock GS correspond to traditional pastoral dairy MT with a production objective (1.1.e) or grass-fed dairy MT with a production objective (7.1) or a multi-functional objective (8) depending on the scale and the mobility type. The first one corresponds to "uncontrolled" GS, as they are nomad MTs with high cattle mobility in search for feed resources, whereas the two latter can correspond to either "controlled" or "uncontrolled" GS as the distinction is not clear.

Few elements are available in the literature concerning movements of cattle. In Kiambu county, dairy farms are described as « flying herds » because of sourcing replacement heifers from the Rift Valley where infrastructure is better developed [30]. This situation corresponds to LG2 or LG4, with reproductive females going through a specific MT. Dairy calves can move to intensive production systems to be fattened for meat production, but without specific mention of their MTs of origin [28]. It is not clear if beef cattle in other meat production oriented beef systems could come from dairy systems or not.

### *4.2. Beef Cattle Production Systems in Kenya*

The beef industry is the largest contributor to agricultural GDP in Kenya, at around 35 percent. Beef industry is especially valuable (income and employment) in the arid and semi-arid lands, where beef production from pasture is the main economic activity [28].

Beef production systems in Kenya are classified as [28] (see Table 2):

- **Extensive grazing systems** (both pastoralism and ranching) representing 56.4% and 5.3% of beef cattle population in Kenya respectively where cattle are born and reared in the same MT (LG1) or progressing to a local MT (LG3);
- **Semi-intensive grazing systems** (agropastoralism) representing 37.9% of beef cattle population where cattle are born and reared in the same MT (LG1) or progressing to a local MT (LG3);
- **Intensive systems** (feedlot) representing 0.3% of beef cattle population where cattle are either born and reared in the same MT (LG1) specialized in beef breed or often coming from another MT to be fattened for a few months before slaughter, either in a local MT (LG3) or a distant one (LG5).

**Table 2.** Description of beef production systems in Kenya [28].

| | | | |
|---|---|---|---|
| **Extensive** | Pastoralism | *Corresponding MT* | 1.2e |
| | | *Production objective* | Income generation (meat or live animals) + manure |
| | | *Feed* | Grass (natural) |
| | | *Average herd size* | 50 heads |
| | | *Breed* | Indigenous—Zebu |
| | | *Average meat production* | 125 kg/head |
| | | *Market access* | Meat sold directly to consumers or live animals in markets |
| | | *Land availability* | High |
| | Ranching | *Corresponding MT* | 7.2.e & 7.2.i |
| | | *Production objective* | Income generation |
| | | *Feed* | Grass (natural and cultivated) + little supplements |
| | | *Average herd size* | 150 heads |
| | | *Breed* | Crossbreeds |
| | | *Average meat production* | 240 kg/head |
| | | *Market access* | Local niche market and international market (export) |
| | | *Land availability* | High |
| **Semi-intensive** | | *Corresponding MT* | 6e |
| | | *Production objective* | Income generation (+ manure) |
| | | *Feed* | Grass + crop residues and by-products (on-farm) |
| | | *Average herd size* | 10–12 heads |
| | | *Breed* | Mainly crossbreeds and pure exotic breeds |
| | | *Average meat production* | 240 kg/head |
| | | *Market access* | Medium—animals sold to middle-men in local markets |
| | | *Land availability* | Medium |
| **Intensive** | | *Corresponding MT* | 15.2 |
| | | *Production objective* | Income generation |
| | | *Feed* | Highly nutritious fattening diet |
| | | *Average herd size* | Few dozen for dairy breed and several hundred for beef breeds |
| | | *Breed* | Crossbreeds or exotic beef breeds |
| | | *Average meat production* | / |
| | | *Market access* | High—prime beef markets (urban areas or export) |
| | | *Land availability* | High |

Pastoralism extensive systems are subsistence systems with low inputs level. Pastoralism systems are nomadic, where cattle are moving in search for feed and water, often leading to conflicts over resources [28]. Pastoralism systems correspond to traditional pastoral beef MT with a production objective (1.2.e) in the typology. Ranching extensive systems are mainly turned toward commercialization and export markets [28]. Ranching systems correspond to grass-fed beef MT with a production objective (7.2.e & 7.2.i) where cattle are mainly grazing without association with agriculture, with potential partial confinement overnight or during some period of the year.

Semi-intensive systems are mixed systems with low inputs level and subsistence oriented, keeping livestock, and growing crops. Crop residues and by-products are used to feed cattle while animals produce manure and draught power. Cattle often graze on communal lands or in paddocks for agropastoralists with large pieces of land [28]. These systems correspond to agro-sylvo-pastoral beef MT with a multi-functional objective (6e) in the typology, where cattle are associated with rain-fed agriculture, including production of fodder.

In intensive systems, cattle are kept for a short period of time (3 months). Capital and labor intensive, some intensive systems focus on fattening dairy culls and dairy bull calves while others focus on fattening beef breeds [28]. Intensive beef systems correspond to feedlot fattening MT with a production objective (14.2) where cattle are fed with highly nutritious feed for fattening purpose and can be kept outdoors or indoors in dry climate.

### *4.3. Relevance of the Typology in the Context of Kenya*

This contextualization to Kenya reveals that all cattle systems found in the country can be linked to a MT from the typology. Although local systems are more specific than the developed typology in this paper in a specific dimension, stall-fed and stall-milked at night in versus outdoors constantly, the typology enables to encompass a large diversity of local systems, in line with detailed previously proposed typologies in Kenya [28–30]. However, by taking the FAO typology [28,29], large-scale GS with concentrated feed complement and SZGS are mixed in MT 12.1 (see Figure 5) [29]. Distinguishing them appears difficult based on grazing and feeding characteristics. This difficulty could have potential impacts on economic assessment but not much on the environmental assessment as the feeding practices appear to be similar. Low intensity systems in [30] are also difficult to segregate, same as in the typology developed in this paper.

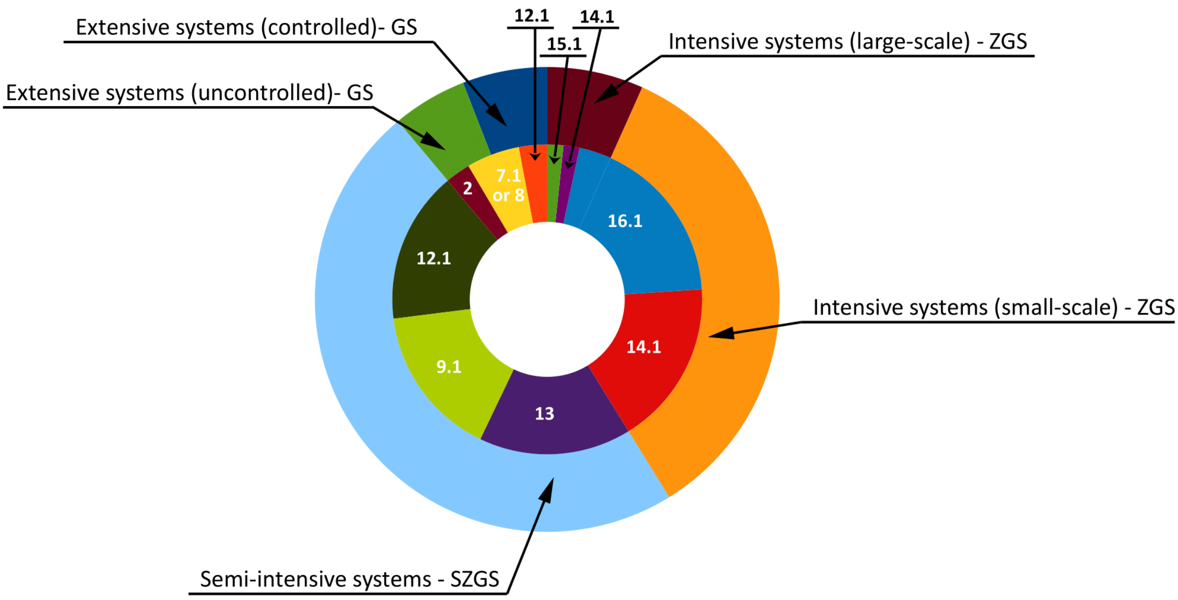


**Figure 5.** Share of dairy production systems. Outer circle: dairy systems according to literature [29,30]. Inner circle: dairy systems according to the typology.

It is worth noting that the typologies made for Kenya did not take agro-ecological zones as an important criterion, which is in line with the MTs typology developed in the article. However, this is not a generalization. In larger countries, such as Brazil, or in countries where the diversity of agro-climatic zones is the main constraint on practices, for example in Senegal, agro-ecological zones would have been part of the classifications. Farming practices would still have been present in the classification, sometimes confounded with the agro-ecological zone (e.g., the Ferlo sahelian zone being associated with nomadic extensive MTs only) or sometimes co-existing in a given agro-ecological zone (in the South of Brazil, for instance).

The proposed typology is the result of a search for exhaustiveness on cattle systems on a global scale. Certainly not all MTs are intended to be present on smaller scales (national or regional scales). In Kenya for example, some MTs are not present or hardly present. Sylvo-pastoral MTs (MTs 3 and 4) refer to the exclusive use of land for forest products and animal production (either grazing or fodder production). These MTs are often planted forests (bocage form in Europe or orchards with trees used for fruit/nuts production and/or timber) with agroforestry practices or pastoralism in open shrub and tree savannah (e.g., Ferlo region in Senegal). From field observations, sylvo-pastoralism could have high potential interest in Kenya, particularly to reduce climate vulnerabilities of farmers and to restore degraded systems by deforestation [37].

Grass-fed MTs using industry by-products (MTs 10 and 11) refer to the association with the food industry whose waste is used for animal feed (e.g., sugarcane production, brewery waste, vegetable cakes, etc.,) in addition to grazing. Feeding from industrial wastes or by-products might be present in Kenya. For example, MTs based on spent grain in Western Kenya, a by-product of beer making process [38], or dairy MTs in peri-urban areas in the Kiambu county [30], very localized and occasional, therefore not considered as a MT on its own. This feeding practice could allow smallholder farmers to access more easily intensive cattle systems, especially in arid and semi-arid areas, as wastes could be available at a lower price than off-farm commercial feed. Alongside valorizing industrial by-products and wastes, this feeding practice could allow the use of croplands for growing food instead of feed, especially in the context of growing population.

Environmental impacts assessment of the livestock sector is effective when it takes into account the multiple dimensions of livestock farming, including monetary and non-monetary benefits, such as income, food, draft power, manure, and insurance [28] as well as other sectors such as feeding practices including origin, nature and quality, but also grazing practices, breeds, etc. The MTs typology developed in this paper appears to possess many dimensions necessary to assess environmental impacts [30] even if quantification of shares of MTs at the country level is unknown; some shares are given by [29] but for a typology that is less specific than [30]. General characteristics of systems—feeding system, grazing management, breeds, production objectives—are given by [28–30] based on expert knowledge and fieldwork observations. But some grazing practices are still difficult to take into account as they appear to be related to the farmer's own choice rather than MTs practices common to all units belonging to that MTs. Nonetheless, the typology described here is relevant and can be operationalized to model detailed MT as in [30] even if absolute quantification appears difficult because of a lack of information on quantified shares of those systems.

There is a general lack of information on animal movements in the literature on Kenya livestock systems, although movements of calves exist from dairy systems to meat production systems [28], and within dairy systems across regions [30]. It could imply that these movements are not precisely taken into account in environmental analysis leading to a risk of incorrect allocation of environmental consequences of livestock rearing, such as greenhouse gas emissions. This is particularly problematic when determining emissions per unit of production. For example, the emissions associated with gestation and first years of calves rearing would be associated with dairy systems, even if the calves end up in the feedlots system. A negative bias would be introduced in the evaluation of emissions per unit of meat, if the movements across systems are not taken into account, as in [29] (although emissions per unit of product are not shown in this document).

## 5. Discussion

### *5.1. Framework's Use for Various Studies*

This conceptual framework is intended to serve as a basis for economic studies along with assessments of the environmental impacts of cattle farming practices. The first level of analysis, MTs, enables a global understanding of cattle farming practices and methods across the world. Owing to the division of the life of cattle into profiles, environmental impacts and economic costs can be assessed and attributed at all life stages of the animal. Moreover, each animal is included in an LG, allowing one to take into account movements, from one profile to another and from one type of management to another, when relevant. In the framework, the analysis and computation unit, the animal profile, is distinguished from the final assessment functional unit, the LG. Such distinctions allow one to better attribute impacts and services to all phases of LGs and between MTs. Targeting phases to which impacts can be attributed could help to find efficient solutions to decrease environmental impacts of the livestock sector. This framework and the system boundary used is similar to approaches used in life cycle assessment (LCA) studies [39]. Through LGs, products, costs, and impacts of an animal's ancestry can be assessed upstream and downstream. This allows one to account for all co-productions (animals and co-products included) in environmental impact assessments.

Along with environmental impact and economic studies at the country level [40] and at the global level [16,17], the typologies presented above could be used in any approach requiring clear specification and discrimination of the management farming practices and LGs. This framework also could be used for social and cultural studies. However, some relevant criteria, such as herd size, professionalization, rights equality, number of workers per animal centered on livestock farm structures and herder characteristics, are not present in this framework. Some criteria could still be linked with social, religious or cultural elements, such as intensity of resource use.

As the MTs typology provides many details on practices, such classification can be useful when formulating new policy to support livelihoods of herders. Indeed, policymakers can focus on the specific needs and challenges faced by herders as the classification informs them in details. The MTs typology is somewhat exhaustive and detailed; such a level of detail may not be suitable for some studies and policy analysis. It is also possible to group together some MTs, as some criteria described in the Section 2.2 could be irrelevant. For example, if the policy issue is about livestock and landscapes, criteria "Farming objective" and "Feed" could be disregarded and the corresponding MTs aggregated. Similarly, if the issue is about economic incentives for specialization, criteria "Presence of trees" and "Feed" could be less relevant and corresponding MTs aggregated.

Animal profiles and MTs are relevant units to determine costs, although other elements could be added, for instance geographic elements on distance to markets or input transport costs, with effects of scale based on herd sizes. The split in LGs may not be the best solution for assessment of costs and profitability at the farm level, as farms are constituted around herds, and the price of animals bought or sold to other MTs is generally considered as exogenous and known at that level. At higher scales, it is more relevant to split by activity (or representative farms) than by farm; the split in lineage groups and in phases within lineage groups thus is relevant to determine prices and costs that are different for animals moving across MTs.

### *5.2. Limits of Previous Methods and Typologies*

Production management is at the core of the MT typology. Several typologies [18,19,21,26] use agro-ecological zones as criteria, meaning that production systems are determined by, among other elements, climatic conditions. Contrary to these studies, agro-ecological zones (arid, semi-arid, sub-humid, humid, highland) are not integrated in the MT typology developed in this paper. This choice makes it possible to distinguish MTs solely on farming practices and methods and not on their geographical location, as MTs could theoretically be established anywhere in the world. In the setup of the proposed framework, climate and agro-ecological zoning are nevertheless taken into account, as they should be integrated in the modeling of animal profiles. Climate influences the performance of each MT through, for instance, NPP and on-farm crop yields.

Many typologies are also defined by the link with crops, such as [20], distinguishing between grazing, mixed, and industrial systems [21], criteria also used in the MT typology. However, when the link with crops is the sole entry point for management practices, various practices of farming are mixed, rendering it difficult to distinguish intensification levels. In particular, some pastoral systems can correspond to very intensive ranching (e.g., New Zealand), while others correspond to nomadic transhumance systems (e.g., Sahel). Likewise, mixed systems cover both intensive European systems and significantly less-intensive systems, such as some systems in Asia where crop residues are mostly used, leaving animals to roam the fields after harvest. Some studies [18,21] adopt a classification system based on several criteria, such as integration with crops, relation to land, irrigation, and agro-ecological zone. In these typologies, it may be easier to distinguish practices when they are closely tied to agro-ecological zones, but again, different practices and management intensities will still be confounded. The integration with crops (livestock only or mixed farming) is borrowed from those typologies, as well as the relation to land (landless or grassland-based). The application on Kenya shows that our typology is in line with detailed local typologies, which are based on intensification level, scale of farms, and integration with crops, and in that specific case, matches better with our approach centered on practices compared to other typologies based on agro-ecological zones. We think that, in other contexts, agro-ecological zoning could be used in existing typologies. In that case, practices should still be described, so that the MTs typology can be used, and agro-ecological zones can be taken into account in the modelling of animal profiles.

As the MTs typology provide many details on practices, such classification can be useful when formulating new policy to support livelihoods of herders. Indeed, policy-makers can focus on the specific needs and challenges faced by herders as the classification informs them in details.

### 5.3. Strengths and Weaknesses of the Framework

To better distinguish intensification levels, we propose additional criteria based on management practices, such as herd mobility and management, and pasture management. Furthermore, the distinction is made between a productive objective and a multi-functional objective that integrates milk/meat production, draught power, manure production, walking financial capital, and insurance possession, allowing many co-benefits of cattle farming to be considered in addition to meat and milk production. These additions allow different levels of intensification to be distinguished much more easily than any existing typology. Links with trees are ignored in existing typologies, although sylvopastoralism can be very different from pasture-based livestock farming [41]. We therefore added an explicit consideration of trees with sylvopastoralism to the integration with other agricultural practices. The contextualization of the MTs typology applied to Kenya showed that the conceptual framework developed in this paper can be well applied to cattle systems in that context, with a good match with the detailed typology of [30]. Examining existing typologies for Kenya through the lens of our typology showed differences among those typologies, which could lead to confusion when describing dairy production systems. A criteria locally important for systems differentiation in Kenya, the practice of stall feeding at night is not explicit in our typology, however, systems differ on other characteristics in most cases. In one particular case, in the FAO typology, two systems correspond to the same MT, as similar feeding practices correspond to different systems ("controlled" GS and SZGS). Overall, the MTs typology could describe systems with a relevant level of precision.

An advantage, but also a potential weakness of the typology is the level of detail. The MTs typology is already detailed, and the analysis and computations on animal profiles should add location and/or climate as distinctive drivers. We could not find a way to simplify the typology while still accounting for all the criteria relevant for environmental impact and economic returns evaluation. As explained before, however, it is possible to simplify the MTs typology by considering some criteria only and regrouping MTs. The Kenyan case shows, however, that this level of detail may be relevant, and that some groupings done in livestock systems typologies for Kenya may be problematic.

A lack of data, especially in some regions such as sub-Saharan Africa, remains a major issue for future work using the framework developed here. Indeed, data for each MT, especially in low to middle-income countries, might be currently difficult to gather. Having a detailed typology of MTs, however, should help to narrow down management parameters, such as herd management, pasture management and type of feed basket. Data on the share of each MT and LG may also be difficult to gather. In Kenya, the different MTs are well described, however the share of MTs is only available for the FAO typology, which is less precise than our typology. Quantified information on cattle movements across MTs, which could be used to determine shares of the LGs is also lacking. This issue, however, does not prevent the use of these typologies for only a specific country or region of the world where data are available. Added to an economic model, the data gap on MT shares could be overcome by making it possible to select MTs that perform better in specific contexts.

When lineage groups are not clearly taken into account and defined [6,16,26], the full complexity of cattle farming risks is not considered. For instance, the link between grass-based MTs for the pre-weaning and reproduction phases and feedlots for the finishing phases in the USA and Europe is ignored in studies at the global level. Even in Kenya studies, movements across MTs are not precisely described, nor considered in assessments. The conceptual framework presented therefore makes it possible to capture and compare the multiple characteristics and functions of ruminant farming around the world in a more consistent way.

## 6. Conclusions

The management type typology might fail to capture the entire and complex diversity of cattle farming at a global scale. Some elements, such as nomadism or seasonal nomadism, are in effect still difficult to precisely take into account due to their dependence on climatic and local conditions. One can also only imagine that some breeding practices adapted to very local and specific conditions, such as oasis farming or emerging ruminant farming, or practices adapted to climate change and changes in consumption habits, could be missing in this work. Despite this potential weakness, the conceptual framework designed and the three levels of analysis should permit an accurate assessment and attribution of the environmental impacts of most management choices. Testing the framework and typologies on the case of Kenya showed the relevance of the framework at country scale, but also the lack of data on systems shares.

**Author Contributions:** Conceptualization, L.P., P.D. and M.V.; methodology, L.P., P.D. and M.V.; validation, L.P., P.D. and M.V.; writing-original draft preparation, L.P.; writing-review and editing, L.P., P.D. and M.V.; supervision, P.D. All authors have read and agreed to the published version of the manuscript.

**Funding:** This work benefited from the French state aid managed by the ANR under the “Investissements d’avenir” programme with the reference ANR-16-CONV-0003.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Acknowledgments:** The authors would like to thanks Philippe Faverdin (INRAE) for his many comments on earlier drafts of the article and for all the discussions and ideas that were instrumental in the development of the conceptual framework.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

**Table A1.** MT typology classification (e: extensive pasture management, i: intensive pasture management).

| Management Type Name | Description | Examples |
|---|---|---|
| 1.1.e/1.2e—Traditional pastoral dairy/beef MT with a production objective | Main outputs are milk and/or meat sold for income generation. High mobility. In case of low temperatures may cattle also be confined in barns. Extensive (e) pasture management with local breeds or locally adapted breeds. Possible feed complements, mainly cereals when grass is less or not available. | Mountainous dairy MTs (e.g., Europe). |
| 2e—Traditional pastoral MT with a multi-functional objective | Main outputs are meat and milk for self-consumption, draught power, walking financial capital, and fertilizing. Based on the extensive movement of herds and flocks in search of forage, led by human family units with no permanent home base, sometimes following a cyclical grazing movement under the influence of rainfall [42]. Extensive (e) pasture management with local breeds or locally adapted breeds. | Traditional nomadic MTs from arid and semi-arid countries (e.g., the Sahel region, India). |
| 3.1.e & 3.1.i/3.2.e & 3.2.i—Sylvo-pastoral dairy/beef MT with a production objective | Refers to the exclusive use of land for forest products and animal production by browsing shrubs and trees and/or grazing co-existing forage crops [42]. Characterized by plantations of various tree species (e.g., walnut trees, cherry trees, oaks, etc.) associated with raising or leading the herd in a forest. Local, locally adapted or crossbreeds. | Bocage forms, pasture-orchards, meadows [36]; extensively managed pastures in dry climate (e.g., Ferlo region in Senegal); intensively managed pastures in humid climate (e.g., South America). |
| 4e. Sylvo-pastoral MT with a multi-functional objective | Idem as MTs 3 | |
| 5.1.e & 5.1.i/5.2.e & 5.2.i—Agro-sylvo-pastoral dairy/beef MT with a production objective | Similar to sylvo-pastoralism MTs but associated with rain-fed agriculture (cultivation of livestock feed on site) [19]. Agro-sylvo-pastoralism incorporates agricultural crops, potentially including forage crops for livestock production, where trees may produce timber, pulp, fruits, rubber, and syrup or be browsed for grazing animals [42]. Local, locally adapted or crossbreeds. | Not much represented in current practices |
| 6e. Agro-sylvo-pastoral MT with a multi-functional objective | Idem as MTs 5 | |
| 7.1.e & 7.1.i/7.2.e & 7.2.i—Grass-fed dairy/beef MT with a production objective | Pastoral dairy management types without association with agriculture. In semi-confinement, sometimes with only a few hours of grazing/day [43]. Animals are confined when weather conditions dictate. Local, locally adapted or crossbreeds. | Ranching MTs (e.g., New Zealand, USA, Brazil, Argentina, South Africa). |
| 8e. Grass-fed MT with a multi-functional objective | Pastoral management types without association with agriculture, with a multi-functional objective including the possession of walking financial capital. Local, locally adapted, or crossbreeds. | |
| 9.1.e & 9.1.i/9.2.e & 9.2.i—Externally complemented grass-fed dairy/beef MT with a production objective | MTs with grass in the cattle diet, associated with a high share of complements from external origin, without crop-livestock integration. Specialized management types and associated with an income generation objective. Animals are in semi-confinement, sometimes with only a few hours of grazing/day [43]. Local, locally adapted, or crossbreeds. | Productive MTs typical of high-income countries (e.g., Europe). |
| 10.1.e & 10.1.i/10.2.e & 10.2.i—Grass-fed dairy/beef MT, using industry by-products with a production objective | Associated with the food industry and whose waste is used for animal feed (e.g., beet pulp, whey, brewery waste, vegetable cake, fruit or vegetable waste). It is particularly interesting in countries with little capital [44,45]. Pastoral types without association with agriculture. Animals are kept in semi-confinement, sometimes with only a few hours of grazing/day [43]. Animals are also confined when weather conditions dictate. Local, locally adapted, or crossbreeds. | |
| 11e. Grass-fed MT, using industry by-products with a multi-functional objective | Idem as MTs 10 | |
| 12.1.e & 12.1.i/12.2.e & 12.2.i—Internally complemented grass-fed dairy/beef MT with a production objective | Grass-fed management types with an agricultural component (e.g., cereals such as corn, wheat, or barley and/or soy) for animal feed, mainly produced on-farm. Local, locally adapted, or crossbreeds [2]. | |

**Table A1.** *Cont.*

| Management Type Name | Description | Examples |
|---|---|---|
| 13e.—Internally complemented grass-fed MT with a multi-functional objective | Idem as MTs 12. These management types have a multi-functional objective where animals are present in small herds fed with grass and crop residues. | |
| 14.1/14.2—Zero-grazing dairy/beef MT, with grass, with a production objective | Cattle are housed and stall-fed with cut and carry fodder [34] complemented by cereals and little complements. Crossbreeds or genetically improved breeds/exotic breeds. | Countries were fodder from non-managed grasslands is available to cut (e.g., Kenya, Uganda, intensive family MTs in Vietnam) |
| 15.1—Zero grazing dairy MT without grass, with a production objective | Animals are contained mainly indoors, where cows eat and are milked on the spot [46]. Crossbreeds or genetically improved breeds/exotic breeds. | Middle and high-income countries MTs (e.g., USA and Brazil concentrated feedlots, Europe) |
| 15.2—Zero grazing beef MT without grass, with a production objective | Cattle are mainly kept in outdoor enclosures (sometimes indoors in dry climates) [46]. Crossbreeds or genetically improved breeds/exotic breeds. | Middle and high-income countries feedlot MTs (e.g., USA and Brazil concentrated feedlots, Europe) |
| 16.1/16.2—Scavenging & backyard MT with a production/multi-functional objective | Mainly sheep and goats (especially in high-income countries) but also sometimes cattle. Farming objectives are either production and generation of revenues, mainly in urban and peri-urban areas, or multi-objective, with, in particular, possession of walking financial capital (breeding at a family scale). Most often local or locally adapted breeds [47]. | Mainly present in southern countries (e.g., India, urban and peri-urban areas of low-to-middle income countries) but little practiced in high-income countries today. |

**Table A2.** Animal profile phase ages.

| Phase | Calf | Young Bovine | Heifer | Cow | Young Bull | Bull | Ox |
|---|---|---|---|---|---|---|---|
| Age | Generally less than 8 months or until weaning | Generally 8 to 12 months. 8 months to 24 months from MT14 to MT16. | Generally more than 12 months (without calving). 1 to 4 years in MT1. 1 to 3 years from MT2. | Generally more than 24 months (+ first calving). 4 to 15 years in MT1. 3 to 8 years from MT2 to MT16. | Generally 12 to 20 months. 1 to 2.5 years from MT2 to MT13. | Generally more than 24 months (non-castrated). 1 to 15 years in MT1. 2.5 to 8 years from MT2 to MT13. | Generally more than 24 months (castrated). 2.5 to 8 years in MT4.2, MT5.2, MT12.2, MT13.2. |

## References


1. Havlík, P.; Valin, H.; Herrero, M.; Obersteiner, M.; Schmid, E.; Rufino, M.C.; Mosnier, A.; Thornton, P.K.; Böttcher, H.; Conant, R.T.; et al. Climate Change Mitigation through Livestock System Transitions. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 3709–3714. [CrossRef]
2. FAO. *Elevage & Changements Climatiques*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2016.
3. FAO. *Environmental Performance of Large Ruminant Supply Chains: Guidelines for Assessment*; Livestock Environmental Assessment and Performance Partnership; Food and Agriculture Organization of the United Nations: Rome, Italy, 2016.
4. Wint, G.; Robinson, T.P. *Gridded Livestock of the World*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2007.
5. Gerber, P.; Chilonda, P.; Franceschini, G.; Menzi, H. Geographical Determinants and Environmental Implications of Livestock Production Intensification in Asia. *Bioresour. Technol.* **2007**, *96*, 263–276. [CrossRef]
6. Herrero, M.; Thornton, P.K.; Gerber, P.; Reid, R.S. Livestock, Livelihoods and the Environment: Understanding the Trade-Offs. *Curr. Opin. Environ. Sustain.* **2009**, *1*, 111–120. [CrossRef]
7. McDermott, J.J.; Staal, S.J.; Freeman, H.A.; Herrero, M.; Van de Steeg, J.A. Sustaining Intensification of Smallholder Livestock Systems in the Tropics. *Livest. Sci.* **2010**, *130*, 95–109. [CrossRef]
8. Tarawali, S.; Herrero, M.; Descheemaeker, K.; Grings, E.; Blümmel, M. Pathways for Sustainable Development of Mixed Crop Livestock Systems: Taking a Livestock and pro-Poor Approach. *Livest. Sci. Spec. Issue Assess. Sustain. Dev. Anim. Prod. Syst.* **2011**, *139*, 11–21. [CrossRef]
9. Alary, V.; Duteurtre, G.; Faye, B. Élevages et sociétés: Les rôles multiples de l'élevage dans les pays tropicaux. *INRA Prod. Anim.* **2011**, *24*, 145–156. [CrossRef]
10. Gerber, P.J.; Steinfeld, H.; Henderson, B.; Mottet, A.; Opio, C.; Dijkman, J.; Falcucci, A.; Tempio, G. *Tackling Climate Change through Livestock—A Global Assessment of Emissions and Mitigation Opportunities*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2014.

11. Opio, C.; Gerber, P.; Mottet, A.; Falcucci, A.; Tempio, G.; MacLeod, M.; Vellinga, T.; Henderson, B.; Steinfeld, H. *Greenhouse Gas Emission From Ruminant Supply Chains*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2013.
12. Martinez, J.; Burton, C. Manure Management and Treatment: An Overview of the European Situation. In Proceedings of the 11th International Congress in Animal Hygiene, Mexico City, Mexico, 23–27 February 2003.
13. Eychenne, C. Le pastoralisme entre mythes et réalités: Une nécessaire objectivation—l'exemple des Pyrénées. *Géocarrefour* **2018**, *92*, 9123987. [CrossRef]
14. Styles, D.; Gonzalez-Mejia, A.; Moorby, J.; Foskolos, A.; Gibbons, J. Climate Mitigation by Dairy Intensification Depends on Intensive Use of Spared Grassland. *Glob. Chang. Biol.* **2018**, *24*, 681–693. [CrossRef]
15. Beauchemin, K.A.; Janzen, H.; Little, S.M.; McAllister, T.A.; McGinn, S.M. Life Cycle Assessment of Greenhouse Gas Emissions from Beef Production in Western Canada: A Case Study. *Agric. Syst.* **2010**, *103*, 371–379. [CrossRef]
16. Bouwman, A.F.; Van der Hoek, K.W.; Eickhout, B.; Soenario, I. Exploring Changes in World Ruminant Production Systems. *Agric. Syst.* **2005**, *84*, 121–153. [CrossRef]
17. Herrero, M.; Havlik, P.; Valin, H.; Notenbaert, A.; Rufino, M.C.; Thornton, P.K.; Blümmel, M.; Weiss, F.; Grace, D.; Obersteiner, M. Biomass Use, Production, Feed Efficiencies, and Greenhouse Gas Emissions from Global Livestock Systems. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 20888–20893. [CrossRef]
18. Seré, C.; Steinfeld, H. *World Livestock Production Systems—Current Status, Issues and Trends*; Food and Agriculture Organization of the United Nations: Rome, Italy, 1996.
19. Otte, M.J.; Chilonda, P. Production parameters of ruminants in non-traditional systems. In *Cattle and Small Ruminant Systems in sub-Saharan Africa—A Systematic Review*; Food and Agriculture Organization of the United Nations: Rome Italy, 2002.
20. Laca, E.A.; Demment, M.W. Livestock Production Systems. In *Management of Agricultural, Forestry, and Fisheries Enterprises*, 1st ed.; Hudson, R.J., Ed.; EOLSS Publications: Abu Dhabi, United Arab Emirates, 2009.
21. Teufel, N.; Markemann, A.; Kaufmann, B.; Valle Zárate, A.; Otte, J. *Livestock Production Systems in South Asia and the Greater Mekong Sub-Region, PPLPI Working Paper 48*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2010.
22. Lhoste, P. *L'étude et le Diagnostic des Systèmes D'élevage*; Atelier de Formation des agronomes SCV; Campus de Baillarguet: Montpellier, France, 2001.
23. Alvarez, S.; Timler, C.J.; Michalscheck, M.; Paas, W.; Descheemaeker, K.; Tittonell, P.; Andersson, J.; Groot, J.C.J. Capturing Farm Diversity with Hypothesis-Based Typologies: An Innovative Methodological Framework for Farming System Typology Development. *PLoS ONE* **2018**, *13*, e0194757. [CrossRef]
24. Notenbaert, A.; Herrero, M.; Kruska, R.; You, L.; Wood, S.; Thornton, P.K.; Omolo, A. *Classifying Livestock Production Systems for Targeting Agricultural Research and Development in a Rapidly Changing World*; ILRI Discussion Paper 19; International Livestock Research Institute (ILRI): Nairobi, Kenya, 2019.
25. Robinson, T.P.; Thornton, P.; Franceschini, G.; Kruska, R.; Chiozza, F.; Notenbaert, A.; Cecchi, G.; Herrero, M.T.; Epprecht, M.; Fritz, S.; et al. *Global Livestock Production Systems*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2011.
26. FAO. Global Livestock Environmental Assessment Model. In *Version 2.1-Data Reference Year: 2010*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2017.
27. Dairy, N.Z. Available online: https://www.dairynz.co.nz/animal/heifers/rearing-options/ (accessed on 6 December 2021).
28. FAO. Livestock Production Systems Spotlight—Kenya—Cattle and Poultry Sectors. In *Africa Sustainable Livestock 2050*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2018.
29. FAO. Integrated Snapshot—Kenya—Cattle and Poultry Sectors. In *Africa Sustainable Livestock 2050*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2018.
30. van der Lee, J.; Bebe, B.O.; Oosting, S. Sustainable Intensification Pathways for Dairy Farming in Kenya. In *A Case Study for PROIntensAfrica WP2, Deliverable 2.3997*; Wageningen Livestock Research: Wageningen, The Netherlands, 2016.
31. Bebe, B.O.; Udo, H.M.J.; Rowlands, G.J.; Thorpe, W. Smallholder Dairy Systems in the Kenya Highlands: Breed Preferences and Breeding Practices. *Livest. Prod. Sci.* **2003**, *82*, 117–127. [CrossRef]
32. Ochungo, P.; Lindahl, J.; Kayano, T.; Sirma, A.J. Mapping Aflatoxin Risk from Milk Consumption Using Biophysical and Socio-Economic Data: A Case Study of Kenya. *Afr. J. Food* **2016**, *16*, 11066–11085. [CrossRef]
33. ILRI. *USAID Kenya Crops and Dairy Market Systems Activity—Dairy Value Chain Assessment*; Technical Report; RTI International: Nairobi, Kenya, 2018.
34. Odero-Waitituh, J.A. Smallholder Dairy Production in Kenya; a Review. *Livest. Res. Rural Dev.* **2017**, *29*, 139.
35. Kibogy, M.R. Kenya Dairy Industry: Status and Outlook. In *15th Esada Dairy Conference and Exhibition*; Kenyatta International Conference Centre: Nairobi, Kenya, 2019.
36. Makoni, N.; Mwai, R.; Redda, T.; van der Zijpp, A.; van der Lee, J. *White Gold: Opportunities for Dairy Sector Development Collaboration in East Africa*; CDI Report CDI-14-006; Centre for Development Innovation, Wageningen UR: Wageningen, The Netherlands, 2014.
37. AFAF. *Agroforesterie et Élevage Ovin—Produire et Protéger*; Association Française d'agroforesterie (AFAF): Auch, France, 2013.
38. Happy Feeds Limited. Available online: https://www.happyfeeds.co.ke/product/dried-machicha-cattle-feed/ (accessed on 12 May 2022).
39. Thévenot, A.; Aubin, J.; Tillard, E.; Vayssières, J. Accounting for farm diversity in life cycle assessment studies—the case of poultry production in a tropical island. *J. Clean. Prod.* **2013**, *57*, 280–292. [CrossRef]

40. Dutilly, C.; Alary, V.; Bonnet, P.; Lesnoff, M.; Fandamu, P.; de Haan, C. Multi-Scale Assessment of the Livestock Sector for Policy Design in Zambia. *J. Policy Model.* **2020**, *42*, 401–418. [CrossRef]
41. Murgueitio, E.; Calle, Z.; Uribe, F.; Calle, A.; Solorio, B. Native Trees and Shrubs for the Productive Rehabilitation of Tropical Cattle Ranching Lands. *For. Ecol. Manag.* **2011**, *261*, 1654–1663. [CrossRef]
42. Allen, V.G.; Batello, C.; Berretta, E.J.; Hodgson, J.; Kothmann, M.; Li, X.; McIvor, J.; Milne, J.; Morris, C.; Peeters, A.; et al. An International Terminology for Grazing Lands and Grazing Animals. *Grass Forage Sci.* **2011**, *66*, 2–28. [CrossRef]
43. Barbin, G.; Chaumet, J.M.; Chotteau, P.; Le Gall, A.; Lelyon, B.; Monniot, A.; Perrot, C.; Mottet, A.; Richard, M.; Trossat, C.; et al. La filière laitière en Nouvelle-Zélande—Une furieuse volonté de croissance contrariée par l'environnement. In *Le dossier Economie de l'Elevage*, 404th ed.; Institut de l'Elevage: Paris, France, 2010.
44. FAO. *Résidus Agricoles et Sous-Produits Agro-Industriels en Afrique de L'ouest—Etat des Lieux et Perspectives Pour L'élevage*; Bureau régional pour l'Afrique de la FAO: Accra, Ghana, 2014.
45. Chapoutot, P.; Rouillé, B.; Sauvant, D.; Renaud, B. Les coproduits de l'industrie agro-alimentaire: Des ressources alimentaires de qualité à ne pas négliger. *INRAE Prod. Anim.* **2018**, *31*, 201–220. [CrossRef]
46. Endres, M.I.; Schwartzkopf-Genswein, K. Overview of Cattle Production Systems. In *Advances in Cattle Welfare*; Elsevier: Amsterdam, The Netherlands, 2018.
47. Maman Lawal, A.A.; Chaibou, M.; Mani, M.; Garba, M.M.; Gouro, A.S. Pratiques d'éleveurs et résultats économiques d'élevage dans les exploitations urbaines et périurbaines de Niamey. *Int. J. Biol. Chem. Sci.* **2018**, *12*, 294. [CrossRef]