iCLEANED

Transforming Livestock for a Sustainable Future

iCLEANED User Process Guide

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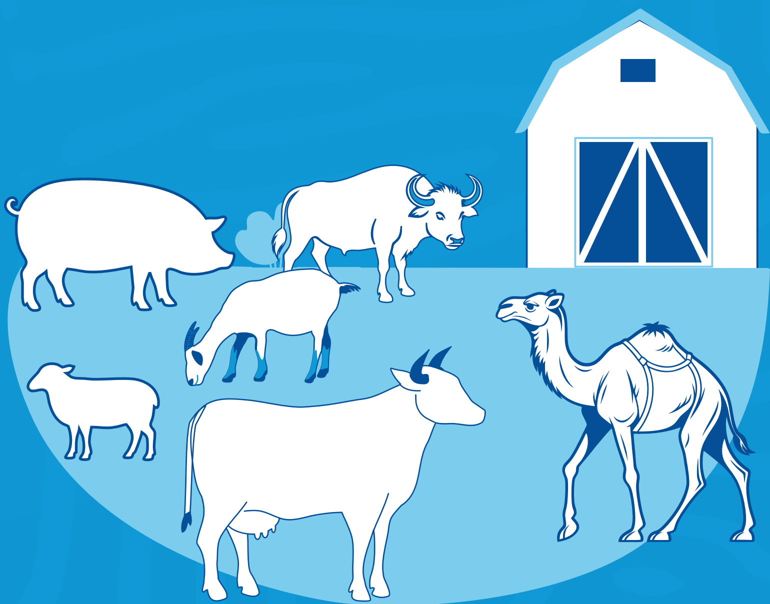

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Contents

Acronym List

ABC	Alliance of Bioversity International and International Center for Tropical Agriculture
AME	Adult Male Equivalent
BBSRC	Biotechnology and Biological Sciences Research Council
CH_4	Methane
CIAT	International Center for Tropical Agriculture
CO_2e	Carbon dioxide equivalent
CSIRO	Commonwealth Scientific and Industrial Research Organization
DM	Dry Matter
ESG	Environmental, Social, and Governance
ET	Evapotranspiration
FAO	Food and Agriculture Organization
FPCM	Fat-Protein Corrected Milk
GHG	Greenhouse Gas
GWP	Global Warming Potential
ha	Hectare
iCLEANED	**I**nclusive and **C**omprehensive **L**ivestock **E**nvironmental **A**ssessment for improved **N**utrition, a secured **E**nvironment and sustainable **D**evelopment along livestock value chains
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
kcal	Kilocalorie
Kg	Kilogram
LVCs	Livestock Value Chains
m	Metre
ME	Metabolizable Energy
mm	Millimetre
N	Nitrogen
N_2O	Nitrous oxide
SAAF	Sustainable Animal and Aquatic Foods
SED	Scenario Enterprise Description
SEI	Stockholm Environment Institute
SOC	Soil Organic Carbon
t	Tons

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We thank all donors who globally support our work through their contributions to the CGIAR System. CGIAR is a global research partnership for a food-secure future dedicated to transforming food, land, and water systems in a climate crisis (https://www.cgiar.org/).

We would like to thank partners and colleagues at the Commonwealth Scientific and Industrial Research Organization (CSIRO), International Livestock Research Institute (ILRI) and Stockholm Environment Institute (SEI) who were fundamental in developing the earlier frameworks.

Preface

The production of livestock products has heavily influenced how we utilise land and is an important avenue for livelihoods across our planet. However, the sector utilises a big portion of our natural resources and often causes negative environmental impacts such as land degradation, air and water pollution, greenhouse gas emissions and the decline in biodiversity. It is thus important to design sustainable livestock systems that work for people, communities, and the planet.

Researchers, practitioners and investors in livestock systems require tools to assess trade-offs, unintended consequences, and synergies. Effective climate-smart programs must thereby also consider the heterogeneity of smallholder farmers, and the dynamics and experiences of different social groups within livestock systems. The purpose of this process guide is to show and demonstrate how the Inclusive and Comprehensive Livestock Environmental Assessment for improved Nutrition, a secured Environment and sustainable Development along livestock value chains (iCLEANED) works. The tool for which this guide is prepared builds on several years of collaborative work by experts from multiple disciplines and organizations. It was initially funded by the CLEANED Livestock Value Chains (LVCs) project supported by the Bill & Melinda Gates Foundation (DCE23232), and later by the Biotechnology and Biological Sciences Research Council (BBSRC, BB/L026503/1). Since then, the model's development has been funded through various CGIAR Research Programs and Initiatives. These include the CGIAR Research Program on Livestock; the One CGIAR Initiative on Sustainable Animal Productivity for Livelihoods, Nutrition and Gender Inclusion; the One CGIAR Initiative on Livestock and Climate Resilience; the CGIAR Science Program on Sustainable Animal and Aquatic Foods (SAAF), and the CGIAR Science Program on Climate Action (CASP).

Upon reviewing this document, you should gain a clear understanding of how the iCLEANED web application functions, along with the underlying conceptual framework guiding its assessments— equipping you to effectively conduct your own assessments of the environmental performance of livestock enterprises. Additionally, you will acquire general knowledge about the model's operations and discover how to utilize the available open-source packages to further develop context-specific model variations.

What this Guide Covers

This document is divided into three parts:

1. **Overview:** This explains the rationale, limitations and boundaries of iCLEANED assessments.

2. **iCLEANED Web Interface:** This depicts iCLEANED input and output processes. It outlines multiple input tabs where the user enters data required to carry out the assessments. With just a few clicks, quantified results can be viewed across multiple environmental dimensions.

3. **Results- The dashboard:** You are given a walkthrough of what to expect in the model outputs and how to interpret them.

What you Need for this Guide

iCLEANED is a web application for assessing the environmental footprint of livestock systems. The app can be accessed here: https://iCLEANED.alliance.cgiar.org/. It is a newly developed R model variation of the existing Excel-based version of the CLEANED X. This model was developed using Shiny, a web framework in R for creating interactive, data-driven applications. Shiny enables dynamic, user-friendly interfaces with real-time reactivity, accessible via web browsers on any platform. It is an open-source application (https://github.com/CIAT/iCLEANED) designed to improve end-user efficiency, enhance collaboration, and overcome the limitations of the Excel version. It is also compatible with livestock master plans and Environmental, Social, and Governance (ESG) investment frameworks, and it supports integration through Application Programming Interfaces (APIs).

Who are the Users

This guide is intended for those who wish to carry out farm or landscape-level environmental impact assessments on livestock enterprises using the iCLEANED methodology. These include but are not limited to development actors, policymakers, research scientists, students, and project managers.

Conventions

In this document, you will find several text styles that distinguish between different kinds of information. Here are some examples of these styles and their meaning.

— When referring to the **inputs** section of the tool, we will be using pronounced terms, e.g., **“Enterprise/ scenario description”** window.

— When presented with → **IMPORTANT NOTE:** short guidance on what to do.

Corrigenda

This document has undergone several rounds of review to reduce clutter and enhance clarity. However, perfection cannot be guaranteed. If you come across any errors or inconsistencies, we warmly invite you to report them via email at **cleaned@cgiar.org**. Your feedback is greatly appreciated and will help us continue to improve.

1. Overview

iCLEANED is a web application that assesses multiple-dimensional environmental footprints (Figure 3) of a livestock enterprise on an annual basis. It also allows user to explore how these footprints change when different animal or feed management practices are implemented. The app is accessible via web browsers on any platform. The model is used to carry out rapid ex-ante impact assessments with the data input requirements kept to a minimum. Read more on the framework behind the tool development here: https://hdl.handle.net/10568/151709.

It serves as a rapid screening tool for evaluating interventions in livestock enterprises and enables the swift environmental assessment of diverse scenarios. This aids in the identification of promising intervention options for more detailed quantitative evaluation and in estimating aggregated impacts at multiple spatial scales. Additionally, it supports users to anticipate the gender-differentiated consequences of implementing specific scenarios and encourages them to consider the feasibility of wide-scale adoption by different (socially differentiated) livestock producers.

1.1 The Concept of "Livestock Enterprise"

Think of a business enterprise in your surroundings with a core business of producing goods in exchange for money. This business must have sub-units or components working together towards a profit gain. This is also how a livestock enterprise operates – producing livestock products (meat and milk) by utilizing and managing the locally available resources (land, water, feeds, etc.). Livestock interacts with these resources coherently to achieve the purpose of livestock production, thus forming a system. Therefore, the iCLEANED "system boundary" for assessment extends to all the inputs needed to sustain the livestock enterprise, but not the whole farm (Figure 1). This includes the livestock herd, manure management practices, feeds (natural or cultivated), including crops whose residue is fed to the livestock, area used to produce feeds, and fertilizer inputs. It does not include the whole farm area or crops grown on the farm that are not fed to the animals (Figure 2). Enterprise input levels and performance depend on who makes key decisions and who controls resources, including where and when they are deployed—a critical cross-cutting consideration for the systems boundary.

→ IMPORTANT NOTE:

The iCLEANED model simulates livestock enterprises for both ruminants and monogastric (pigs).

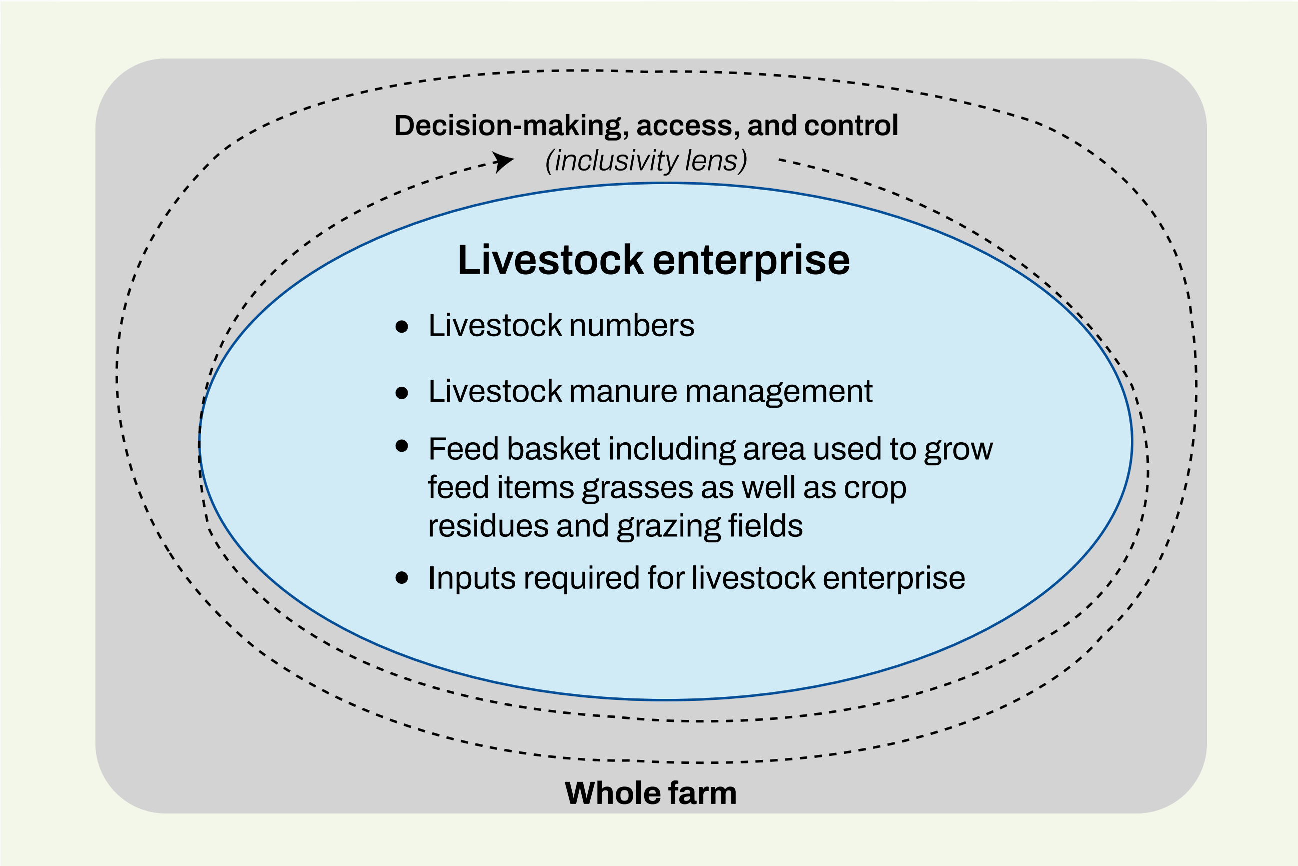


Figure 1: Boundary for assessing a livestock enterprise

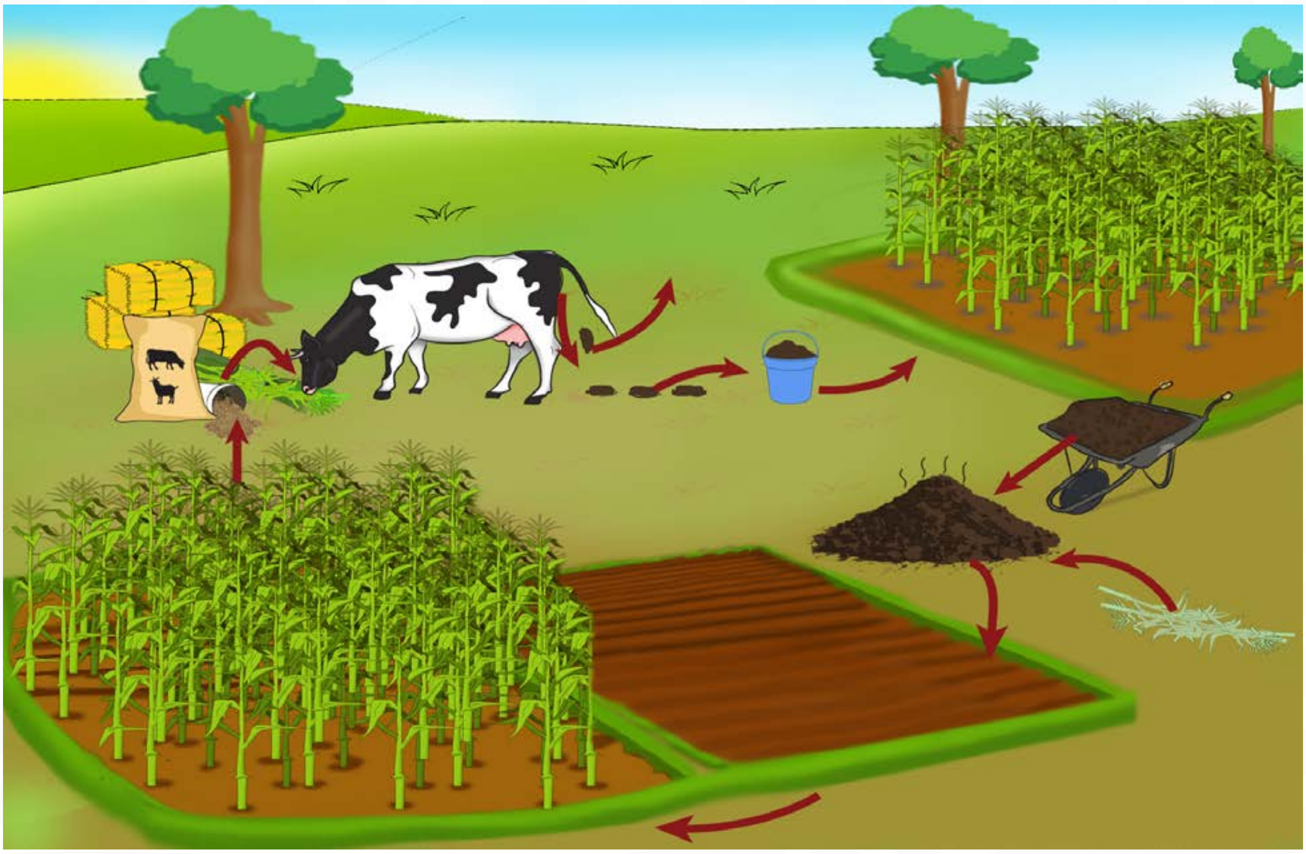
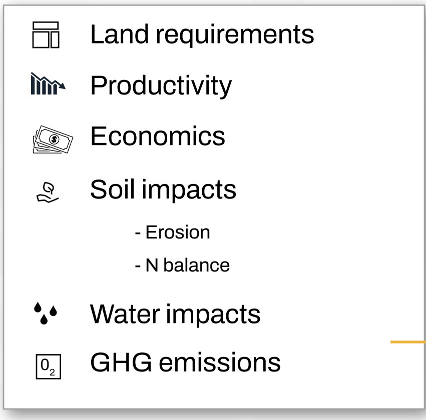


Figure 2: An example of a livestock enterprise adapted from Ruffino et al. 2004; illustration by Michael Githinji.



Based on "minimum data entry", the tool calculates the environmental footprint of a livestock enterprise in terms of land use, productivity, economic performance, soil health, water use and GHG emissions (Figure 3).

Figure 3: Dimensions assessed by ICLEANED

1.2 Scenarios

In the context of iCLEANED, a scenario refers to a specific configuration of livestock enterprise conditions—such as herd size, feeding practices, or manure management—that a user wishes to assess. The tool compares the environmental impact of different scenarios, such as a current baseline situation versus an improved or alternative management option. Scenarios can be based on real farms, typical systems, or projected interventions.

1.3 Typologies and Out-Scaling Across a Study Area

In any given study area—be it a district, watershed, or country—livestock production is rarely homogenous. Multiple types of livestock enterprises typically coexist, differing in herd composition, feed resources, productivity levels, and access to services or markets. To conduct an area-wide environmental assessment using iCLEANED, it is essential to recognize and account for this diversity.

This process involves:

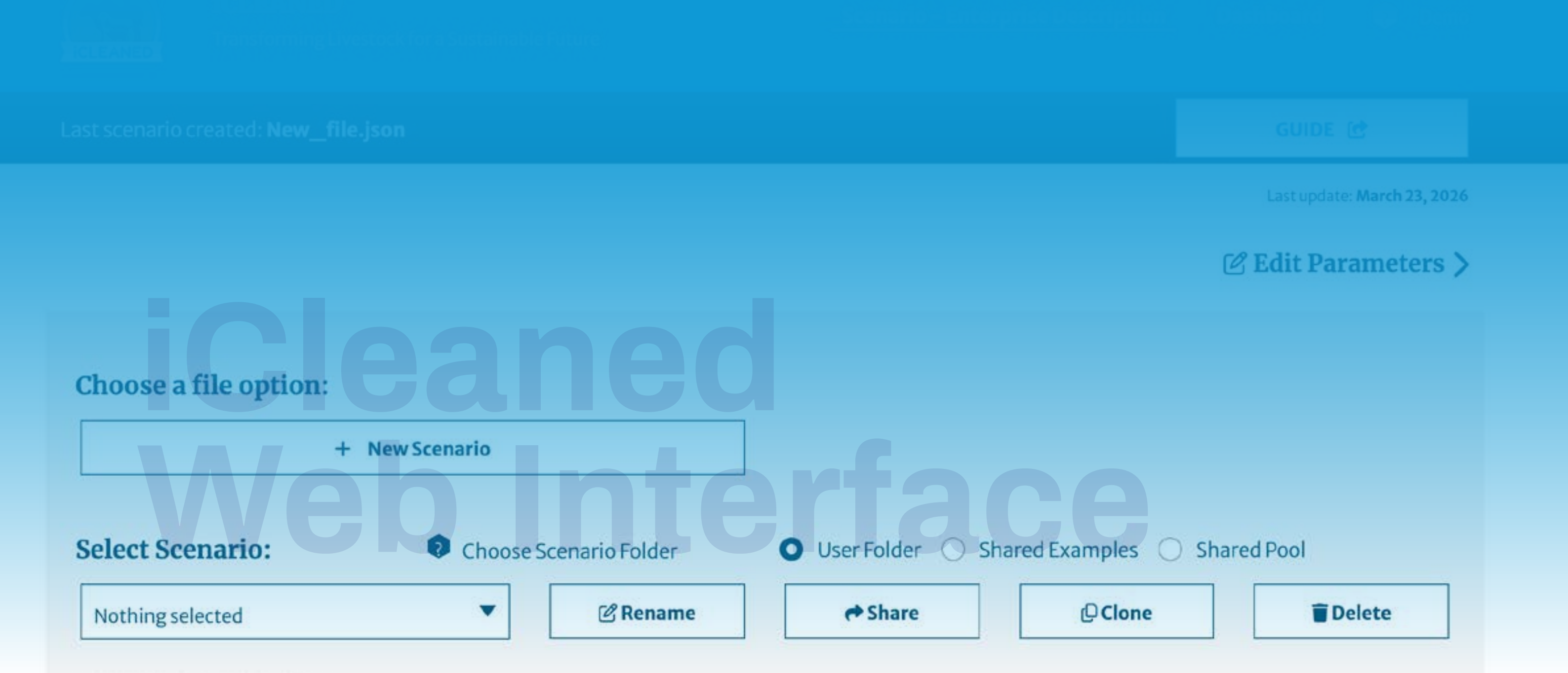
- Defining representative enterprise types (or "typologies") within the study area.
- Estimating the share of the total livestock herd (or population) that falls under each enterprise type.
- Running iCLEANED assessments for each enterprise type individually.

Once the individual enterprise-level assessments are completed, their results can be aggregated ("out-scaled") based on the relative proportions of the herd within each enterprise type. This allows for estimating total environmental impacts at the study area level (e.g., total land use, GHG emissions, or water use for the district), while still maintaining sensitivity to the different production systems present.

This approach also helps identify which enterprise types contribute most to specific environmental impacts and where targeted interventions might yield the greatest benefits—both environmentally and socioeconomically.

→ IMPORTANT NOTE:

- A typology-based approach is especially valuable when planning interventions at scale or informing policy, as it ensures that aggregated impact estimates reflect the actual structure and diversity of livestock systems in the target area.



2. iCLEANED Web Interface

This section outlines the overall framework, architecture processes, and environment that support tool functionality. It describes key components such as input and output windows, control elements, settings, and other operational interfaces. It also highlights user navigational aids that enhance usability and guide efficient interaction with the tool.

2.1 iCLEANED Framework and Process

Use of the tool involves two stages:

1. **Data collection and inputting the baseline data**—farm location, seasons, livestock production systems, feed baskets, farm inputs, amount of precipitation, etc. In the first stage, a livestock enterprise typology is developed through existing data, or via a participatory exercise with various stakeholders, including community members and researchers. Focus group discussions allow for nuances in community dynamics to be reflected, as there might be location-specific experiences that are not fully captured in existing datasets. Within this approach, livestock enterprise conditions such as gender and normative relations, amount and division of labour, household and farm size, and resource endowments at the household level and different roles on the farm are captured to determine inputs for different livestock enterprise types and scenarios of how they could change (Figure 4). Please refer to the full iCLEANED assessment framework here: https://hdl.handle.net/10568/151709

2. **Data analysis and generation of reports.** In addition to baseline environmental footprints of the different types of enterprises being analysed, the tool also allows for comparing different scenarios of how the environmental footprint of livestock production systems might change due to alteration of inputs. Thereby, baseline assessments are conducted for each contextualized livestock enterprise type, followed by estimating the potential impacts of various type-specific intervention scenarios (Figure 3). This enables comparison of the potential impacts, considering the specific constraints and enabling conditions that each type might hold. The user can quantify the impacts using the run or compare scenario buttons displayed on the application window. The result is an overall 'environmental footprint' assessment that is used to come up with feasible recommendations, based on a differentiated interpretation of results by type or after area-wide aggregation.

Resources used in the entire ICLEANED process include human capital (with potentially the associated costs for building technical capacity for users), time and financial resources for an -ideally participatory- data collection exercise and time to carry out the assessments and generate reports (typically between two and four weeks). Where input data is readily available, assessments usually take a maximum of five working days.

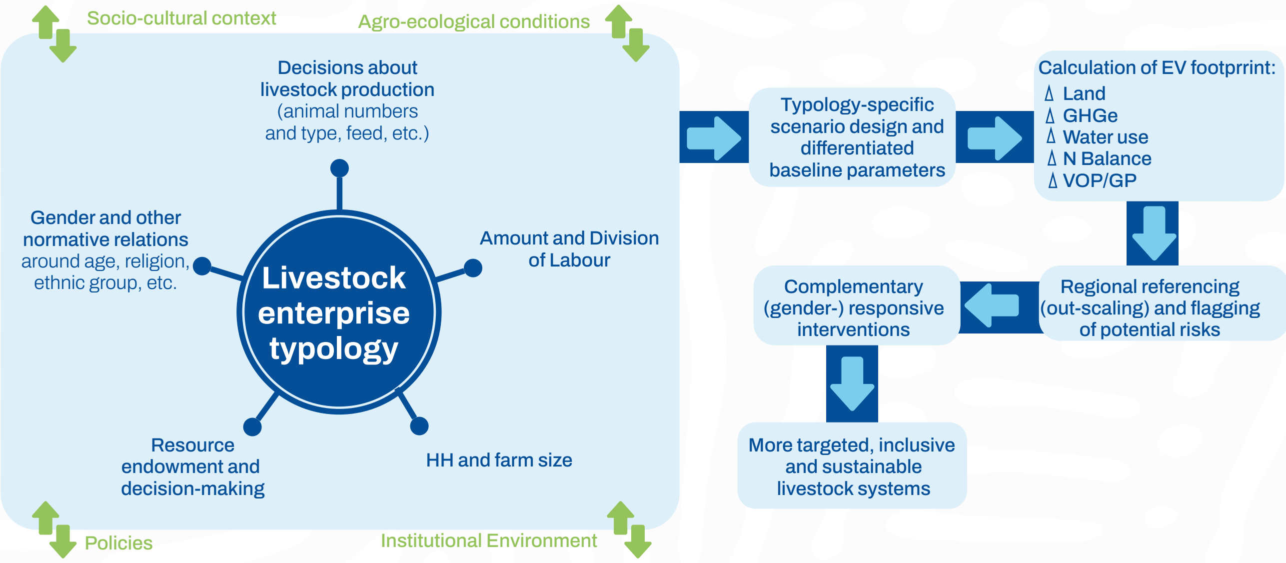
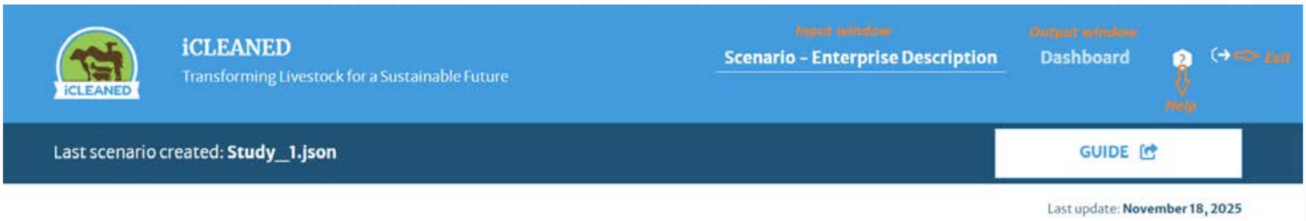


Figure 4: The ICLEANED framework process starts with site-specific typology development (Ewell et al., 2024).

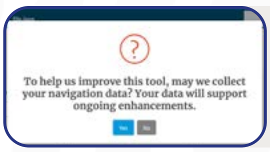
2.2 Understanding and Manoeuvring the Tool’s Environment



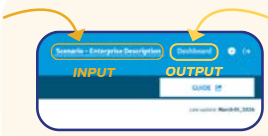
i. Getting Started

Sign up: When accessing the tool at https://iCLEANED.alliance.cgiar.org/ for the first time, you will be required to create your personal user folder by signing up with your personal or, where applicable, your institutional email address. All scenarios you create, simulate, and compare in the ICLEANED app are automatically stored in your user account folder.

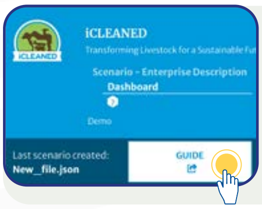
User onboarding questionnaire: A pop-up window prompts users to answer a few optional questions—for example, *“Why are you planning to use the tool?”*—to help map end users and their key areas of interest. This information will help developers to tailor the user experience, guide future improvements, and enable collaborative research around shared priorities.



User tracking consent: Before accessing the interface, you will be asked to consent to the collection of navigational data, used solely to improve the tool and speed up troubleshooting whenever it arises. You may choose to opt in or out.



Input and output window: The tool’s interface provides separate windows for input (Scenario -Enterprise Description) and output (Dashboard) sections. Users can enter livestock enterprise descriptions data and modify parameters in the input window, while results and feedback are displayed in the output window.



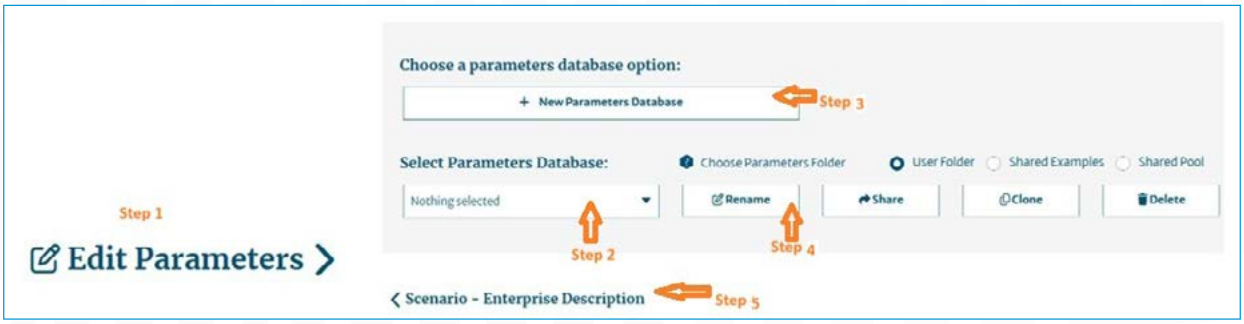
Guide: This process guide will be available when switching between the two windows.

Help menu: Provides information on the tool's objectives, allows users to report issues, suggest improvements, and contact the developers.

ii. Creating Scenarios (Input Object)

In the iCLEANED tool, scenarios (or specific configurations of livestock enterprise conditions) are stored as JSON (JavaScript Object Notation) files. Through the iCLEANED user-interface, users can create, edit, rename, clone, share, delete, and manage multiple versions of such JSON input files and the associated parameter databases. These parameter databases contain key variables that describe the biophysical and management context of the study site. This includes agro-ecological conditions (e.g., altitude, rainfall), climate parameters (e.g precipitation), typical livestock categories (e.g., breed types and their live weights), and the performance characteristics of common feed crops. These parameters serve as defaults to streamline scenario development while maintaining consistency across analyses. The tool is shipped with a default set of region- and system-specific parameter databases from which all input objects must be created. Each JSON input file records the specific parameter database version used at the time of its creation, ensuring that when the file is later loaded, the correct version is automatically applied. This maintains compatibility and prevents data discrepancies.

Creating a New Parameter Database:



Step 1: Navigate to the "**Edit parameters"** section (top right of the Scenario-Enterprise Description (SED) window.

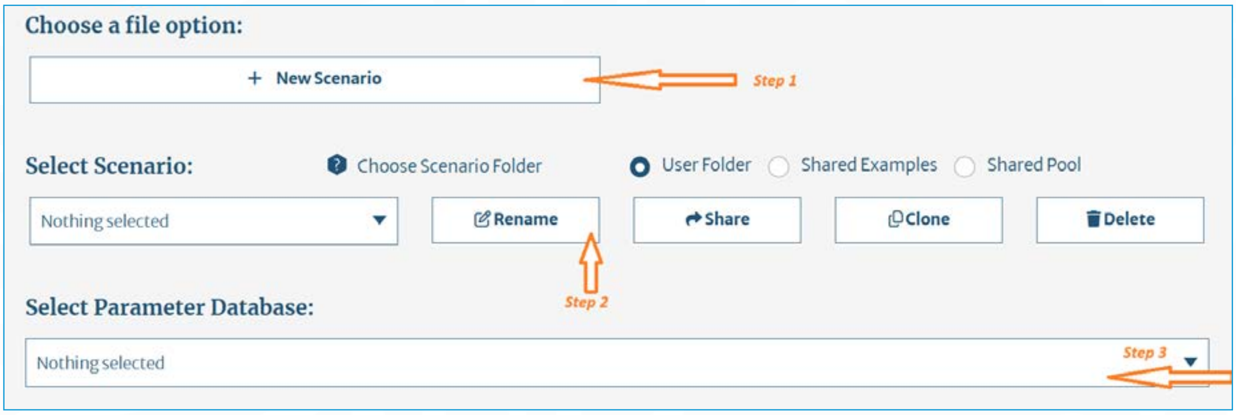
Step 2: Use the "**Select Parameter Database**" dropdown to choose an example database relative to your region.

Step 3: Click on the "**New Parameters Database**" button to create a copy of the default parameter database in the Select parameters database dropdown menu.

Step 4: The new parameter database can be renamed, shared, cloned, or deleted as needed.

Step 5: Go back to the input window to create a new scenario associated with the created parameter database.

Creating a New JSON Input:



Navigate to the JSON Input section on the SED Window.

Step 1: Click on “New Scenario” to generate a new scenario description from the **Choose file option menu**.

Step 2: Rename your input file in the **Select Scenario** dropdown menu.

Step 3: Select the parameter database associated with your scenario from the **Select Parameter Database** dropdown menu**.**

Loading an Existing JSON Input:

- In the JSON Input section, use the “**Select Scenario**” dropdown menu to select a saved JSON file.
- The application automatically loads the associated parameter database version.
- If the associated parameter database is missing, the default parameter database is assigned automatically.

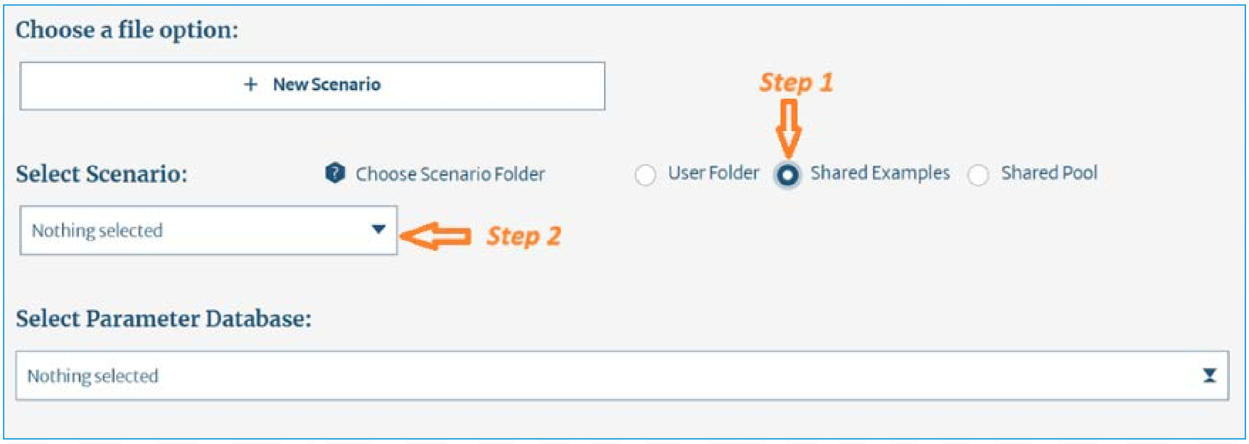
→ **IMPORTANT NOTE:**

- **No Duplicate Names**: Parameter databases must have unique names. The system prevents the creation of parameter databases with duplicate names to avoid confusion and ensure proper association with JSON inputs.
- It is advisable to **create a parameter database before setting up a new scenario**.
- Once you decide to proceed with a default parameter database, you cannot modify the parameters later.

iii. Shared Examples Folder

The “Shared Examples” is a communal space within the application that provides users with access to pre-defined templates and resources curated by the tool developers. These are designed to help users get started quickly by providing exemplary scenarios and parameter databases.

Cloning a Shared Scenario:



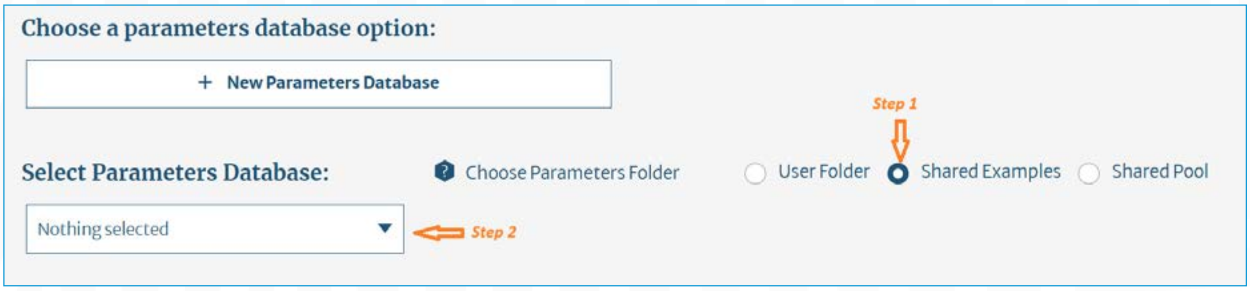
Step 1: Navigate to the “**Shared Examples”** folder of the SED window.

Step 2: Browse available scenarios from the dropdown menu and select the scenario to clone

A confirmation pop-up appears to approve cloning the selected scenario into your personal **User** folder.

If the selected scenario has an associated parameters database, it is automatically cloned into the user’s folder, ensuring that all required components for the scenario are available.

The user can then visualize, edit, rename, or further clone the scenario and its related files as needed.



Cloning a Parameters Database Tab

Navigate to the “**Edit Parameters** “ section (top right) of the SED window.

Step 1: Select the ” **Shared Examples”** folder.

Step 2: Click the “**Select Parameters Database”** drop-down menu to view the list of available parameter databases in the *Shared Examples* section.

When a parameter database is selected, a confirmation pop-up will appear to approve cloning the database into your personal data folder.

- Once cloned, you can **view, edit, rename, or further clone** the parameters database.

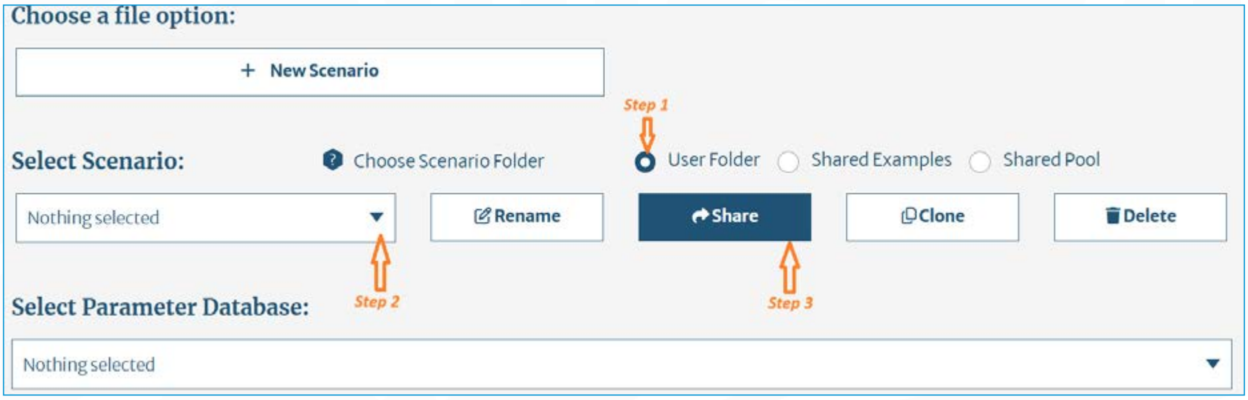
→ IMPORTANT NOTE:

- Users **cannot add, rename, or delete files within the Shared Examples**. This ensures that the templates remain consistent and unaltered for all Users.

iv. Shared Pool

The Shared Pool is a collaborative feature that allows users to share their own scenario descriptions and parameter databases with other users directly within the application. This eliminates the need for external file transfers and facilitates seamless collaboration. Users can share an unlimited number of files.

How to Share:



Step 1: Ensure you are in the User Folder.

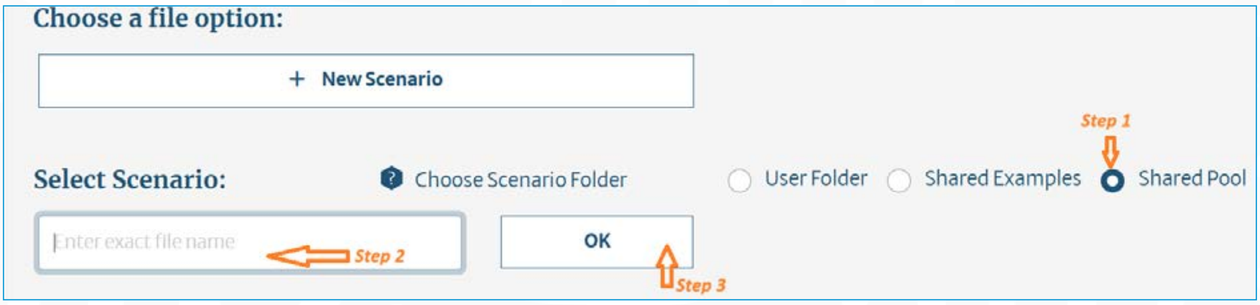
Step 2: Select the scenario or parameter database you want to share.

Step 3: Click the Share button to initiate the sharing process.

A confirmation pop-up will appear requesting permission to share the selected file.

Click OK to confirm and share the file in the Shared Pool under the same name.

Accessing files from the Shared Pool



Step 1: Ensure you are in the Shared Pool folder in the SED window.

Step 2: Users must type the full file name (for scenario objects, include the '.json' extension, e.g., 'example scenario.json'). For Parameter Databases, users should type the exact folder name.

Step 3: Click the "OK" button to verify file availability in the Shared Pool. If the file is found, a pop-up window asks the user to confirm cloning it into their personal folder.

After cloning, the file is available in the user's personal folder for use (e.g., visualization, editing, renaming, or deleting).

→ **IMPORTANT NOTE:**

- Sharing a file with the same name as an existing one in the Shared Pool will overwrite it without additional warnings. **Use unique file names to avoid overwriting others' files.**
- Users **cannot edit or delete files directly within the Shared Pool.** To modify a shared file, clone it to your personal folder, make changes, and then share it back to the pool if desired.

2.2.1 Scenario - Enterprise Description Window Tabs

The "enterprise or scenario description" window is where a user describes the current livestock-keeping practice across the multiple sub-tabs (farm, livestock, feed production, and livestock feeding). This description covers: (i) general farm information including agro-ecological data, wastage of livestock products along the value chain, and farm inputs, (ii) characterization of livestock herd, (iv) how the feed items are produced, and (iii) livestock feeding practices.

As mentioned in section 1, the model is limited to a livestock enterprise only. It is therefore unnecessary to input data outside the system's boundary, e.g., fruits or vegetables that are grown on the farm but not fed to the animals. In each sub-tab, you are asked to either fill cells with specific values or text for a variety of different characteristics. When entering values, note that some cells contain standard values (e.g., IPCC default values) and are automatically prefilled based on your selected options. These values are maintained and updated by the developers as new methods and guidelines become available. Advanced users may alternatively clone the module functions to their local computers and adapt them to experimental data or to develop customized model variants.

The livestock enterprise data provided on this tab can be a real farm observation or the description of a typical or average livestock enterprise. If the latter is the case, data can be sourced from querying farm-level surveys or expert opinions.

2.2.2 Farm

This sub-tab covers the basic information of the study site: Seasons, crop inputs, value chain losses, and agro-ecological context. A description of each sub-tab is outlined below.

i. General Information

Before getting into the description, you are asked to choose the region where your farm is located from the drop-down menu. Currently, the tool is designed to work in three regions –Africa, Latin America, and Asia. You are then prompted to choose the climatic conditions of your study area from a given drop-down list. These are important variables for greenhouse gas computations. Lastly, you are asked to give your farm a code and name – they are not used anywhere in computations but are meant for reference, especially when modelling many enterprises in different or the same regions.

ii. Feeding Periods

The user is asked to provide the name(s) of seasons experienced in the study area and specify the number of days that each season lasts. A season is also defined as "feeding periods" of the year. They represent a time of the year when there is a change in feed basket composition. In the event of multiple seasons, the user is supposed to define the start and the end dates of those periods. This provides the basis for calculating the season length[1]. Below is an example of calculating season length for long and short rain seasons. The dry season days are determined by subtracting the length (days) of long and short rains from 365 days.

- Wet season: the period of the year when the livestock feed basket is determined by a wet season diet, e.g., green forages
- Dry season: The period of the year when livestock feed is determined by the availability of feeds during a dry spell, e.g., residues

Once you define and calculate the feeding periods, please follow the following steps to input your values:

Click Add on the top-left side of the Seasons sub-tab, and a dialog box will pop up.

Enter the name of the season.

Click Ok to add.

Specify the period (number of days) for the added season.

Repeat the same process if you have more than one season.

To delete entered data, select the row by ticking the box in the left margin, then click **Remove.**

→ IMPORTANT NOTE:

- The number of days for all seasons should add up to 365 days.

iii. Manure/Fertilizer Bought

Manure section

This section requests information on manure and other organic inputs:

- Annual purchase of animal manure: if manure is bought, indicate here how much. This is expressed in kg N/year[2].
- Annual purchase of compost: if compost is bought, indicate here how much. This is expressed in kg N/year.
- Annual purchase of other organic N additions: if any other organic sources of N are bought, indicate here how much in kg N/year.
- Annual purchase of bedding materials: if bedding materials such as straw are bought, please indicate the amount in kg N/year.

1 Planting date is based on the period in which the animals are fed a wet season basket while a dry season basket usually comes after harvesting period – when livestock mostly feeds on residues or dry grass.

2 Manure contains roughly 3% of N

Fertilizer Section

Here, you are required to add all inorganic fertilizers that were bought and applied on the farm. Leave it blank if no chemical fertilizer inputs were applied on-farm.

Click Add on the top-right side of the Fertilizer sub-section, and a dialog box will pop up.

Select the fertilizer to add from the dropdown list provided.

Click Ok to add.

Input the percentage nitrogen for NPK only the rest of the fertilizer inputs have standard N.

Repeat the same process if you bought more than one fertilizer.

To delete entered data, select the row by ticking the box in the left margin, then click **Remove.**

→ **IMPORTANT NOTE:** The % N of each fertilizer is added automatically, except for NPK, which varies by region. Please do not change the values for the others.

iv. Waste of Milk and Meat

This section prompts the user to enter the values (in percentage) of wasted milk and meat along the value chain (production, distribution, processing, and consumption).

v. Area Parameters

This sub-tab gives a breakdown of context-specific agro-ecological information required from your study area. Data input includes:

- Annual precipitation: average annual quantity of precipitation in mm/year.
- Rainy season: the number of months in a year that significant rainfall occurs (more than 50mm/month).
- Soil type: the soil type according to the FAO classification scheme – a drop-down list is provided.
- Soil N: the total nitrogen content of the topsoil layer in grams/kg of soil.
- Soil C: the total carbon content in the topsoil layer in grams/kg of soil.
- Soil clay: the content of clay in the soil in % (in terms of soil texture).
- Bulk density: the bulk density of the topsoil layer in g/cm^3.
- Soil depth: the depth of the topsoil layer in m.
- ET_O: Evapotranspiration is the sum of evaporation and plant transpiration from the Earth's land and ocean surface to the atmosphere in millimetres (mm). In a case where field measurements for ETo are missing, one can refer to a value from FAO estimates for different regions (Table 2) using the link: http://www.fao.org/3/x0490e/x0490e04.htm

To help look for soil parameters, users can go to the following website: https://www.isric.org/index.php/explore/soilinfo or download the soilInfo app from a mobile app store.

Precipitation data can be obtained from a local meteorological centre or global datasets at: https://www.worldclim.org/ or https://www.chc.ucsb.edu/data

A separate section on land use (cropland and grassland) provides inputs for changes in soil organic carbon (SOC). Select from the dropdown list the correct cropland and grassland management systems corresponding to your study area. IPCC default values for each system are assigned automatically.

2.2.3 Livestock

In this tab, you provide key information on the livestock in your enterprise, including livestock types and numbers, annual productivity per animal (milk and wool), growth rates of young animals, and manure management practices. Feeding practices are captured in a separate section. Users can add pre-defined livestock categories using the drop-down menu. To add livestock:

- **Click Add** on the top-left side of the livestock tab and a dialog box will pop up.
- Select the livestock category you want to add from the dropdown list provided.
- Click Ok to add.
- Repeat the same process to add other livestock categories present on your farm.
- To delete entered data, select the row by ticking the box in the left margin, then click **Remove.**

For each of the livestock categories selected, you are asked to provide values for:

- **Herd composition:** the number of animals in this category
- **Average annual milk production:** the total annual milk production per animal (considering variances due to lactation period, etc.). This information is only provided for the relevant livestock types (e.g., not for the calves, heifers, or male cattle)
- **Average annual wool:** This is only given if there is a wool-producing sheep or goat in the livestock enterprise
- **Average annual growth per animal:** Also known as liveweight gain (LWG), it is a progressive increase in size or weight of an animal over a period of one year.
- The next columns solicit information about the **whereabouts of the animals**. This information is used in the GHG emission calculations. All times are expressed as "fractions". e.g., if half a day is typically spent in the stable, the value listed under "time spent in the stable" should be 0.5. This number is an annual average across different seasons. The total time spent should add up to 1:
    - **Time spent in the stable**: the fraction of the day that an animal of this type normally spends inside a stable; a stable is any structure where there is some form of closed space, and where the manure that is produced by the livestock remains until it is collected and disposed of.
    - **Time spent in a non-roofed enclosure:** also defined as a yard or tethering area not too far from the house, where the manure produced in that area is subject to the elements.
    - **Time spent grazing pasture/fields on-farm:** Proportion of the day that livestock spends while grazing on grass or stubble/residue within the farm.
    - **Time spent grazing off-farm**: Proportion of the day that livestock spends while grazing outside the farm, i.e., communal grasslands, along the roadsides and riverbanks. It is assumed that all time not spent in the stable, non-roofed enclosure or grazing on-farm is spent grazing off-farm.

For each time spent (in the above systems), you are asked to specify:

- **Manure management system:** How manure is handled where livestock is kept/managed; there are multiple types of manure management techniques along storage, composting, and treatment methods.
- **Fraction of manure collected:** You are required to indicate the amount of manure collected from each site where livestock is managed.
  - **Collection of manure in stable:** Which fraction of the manure that is produced in the stable is collected, vis-à-vis left on the floor?
  - **Collection of manure in a non-roofed enclosure:** which fraction of the manure produced in the yard is collected vis a vis left on the soil.
  - **Collection of manure in pasture /on-farm fields:** which fraction of the manure produced in the field or on the pasture is collected vis-à-vis left on the soil.
- **Distance stable/enclosure to pasture (km):** average distance between stable /enclosure and grazing grounds. This should be set to zero if no time is spent grazing.

→IMPORTANT NOTE:

- The user is required to indicate what fraction of collected manure is **sold** (**in the livestock tab**) or **recycled back to the farm** (**in the feed production tab**).
- Always **double left-click** to edit cell values or select options from a drop-down list.

After defining livestock whereabouts, the user proceeds to key in the reproductive performance data (body weights, milk production, liveweight gain), which impacts the energy and protein requirements of the livestock. Calculations about livestock energy requirements are mainly based on the National Research Council publications (1998 (pigs); 2001 (cattle & Buffalo); 2007 (Sheep/goats). Others include McDonald et al. (1985) and Van Milgen and Dourmad (2015 for pigs' energy and lysine requirements, respectively. These default parameter values are more useful in data-scarce environments, but context-specific parameters can also be set by editing parameters. More details on the calculations are available in a separate document.

Parameters needed vary by species and include:

- Animal body weight.
- Adult body weight.
- live body weights for small ruminants at weaning and year one.
- Hours draught animals spent working.
- Litter size, piglets on milk, and proportion of growth piglets covered by milk for pigs.
- Crude Protein/lysine requirements for Pregnancy, lactation, growth and milk production.
- Calving interval (years).
- Protein and fat content of livestock products (%).
- Carcass fraction.
- Nitrogen content in manure.

2.2.4 Feed Production

This tab is divided into two main sections: (i) crop areas and residue management and (ii) crop inputs. The crop areas and residue management is further split into six sub-sections:

- Enterprise/scenario data: Describes the **feed production and management practices.**
- Feed parameters: Provides **nutritional information** of the feed basket.
- Rice cultivation practices: Describes **rice management practices** when rice or its byproducts are included in the feed basket.
- Stock change parameters: **Auto-filled** based on selected grassland management practice in the Enterprise/scenario data sub-section.
- Soil erosion parameters: **Auto-filled** based on selected land cover and inclination in the Enterprise/scenario data sub-section.
- Crop parameters: Describes **crop characteristics and trees on-farm.**

In the first table, "Crop areas and residue management", you need to add a typical annual feed basket for your livestock enterprise. To add a feed:

- **Click Add** on the top-left side of the feed production tab, and a dialog box will pop up showing lists of crop items and associated feeds.
- **Select a feed item** you want to add from the dropdown list, and **the associated crop** type will be auto-selected.
- **Click Ok** to add the feed.
- **Repeat** the same process to complete the feed basket.
- To delete entered data, select the row by ticking the box in the left margin, then click **Remove.**

→**IMPORTANT NOTE:**

- Always **double left-click** to edit cell values or select options from a drop-down list.

The description of each section of the crop areas and residue management is outlined below.

i. Feed Production and Management Practices

Here the user is required to indicate the source of the feed items, describe intercropping and harvesting practices. In the drop-down list menu, user will define:

- **Source type:** indicate whether the feed is the main crop, crop residue or purchased (i.e., concentrate).
- **Intercropping:** indicate whether the feed is intercropped with another crop (e.g., legumes with cereals). Also, provide the fraction of field occupied if intercropped.
- **Cut and carry fraction:** indicate what fraction of the feed is removed from the field.

The next seven columns required to be filled are used in the erosion, land and GHG calculations.

- **Land cover** depends on the crop. i.e., for beans the cover crop is "pulses". In most cases, the user will select among "maize, cereals, pulses, dense or degraded grass". In the case of tuber crops, it is suggested to select either "cereals "or "pulses"
- **Slope:** this is an estimation of the degree of surface inclination.
- **Length of slope:** average estimate (in m)
- **Grassland management:** user will select the degree of management from the dropdown list given.
- **Main product removal:** if main crop is feed, indicate the fraction of the crop that is removed from the field for feeding animals.
- **Crop residue removal:** if crop residue is feed, indicate the fraction of the crop residues that is removed from the field for feeding animals.
- **Crop residue burnt**: In the event where residues are burnt during land preparation, indicate here the fraction burnt of the total residues left in the field.

ii. Feed Parameters

This is where the user provides nutritional characteristics of the livestock diet i.e., the dry matter, energy, and crude protein contents of the individual feedstuffs.

iii. Soil Erosion Parameters

Soil characteristics are based on estimates from Adigun, A et al 2014. It can, however, be adjusted based on experimental data.

- **Land cover C factor:** compares soil loss from land under specific crop and management systems to the corresponding loss from continuously fallow and tilled land.
- **Slope p factor:** erosion parameter to measure the level of soil management along the slopes.

iv. Rice Cultivation Practices

If the feed basket consists of rice, the user must describe the rice cultivation practices that are linked to additional GHG emissions calculated from the rice-managed fields. These include:

- Cultivation period: number of days the rice cultivation takes.
- Rice ecosystem type.
- Water regime prior to rice cultivation.
- Organic amendment inputs.

v. Stock Change Parameters

The grassland change factor is an IPCC default value, and it reflects how changes in grassland management or condition influence pasture productivity and greenhouse gas emissions.

vi. Crop Parameters

Here, the user provides detailed information on crop characteristics. Characteristics include:

- Dry yield (whether fed as main or residue) given in t/DM/ha/year: The yields are indicative of annual cumulative harvest, e.g., considering multiple cropping seasons in a year.
- N content of main crop or residue (kg N/kg DM).
- Crop water requirements (Kc): Coefficient values for initial, midseason, and late stages.
- Feed category, i.e., if a cereal, pulse, or tree crop, etc.
- Trees/ha; number of trees in hectares.
- Trees DBH: observed tree diameter at given diameter breast height.
- Trees' annual growth (kg).
- Trees' annual removal (kg).
- Time horizon for trees given in years.

Useful websites for crop and feed parameters include:

a. https://www.feedipedia.org/
b. http://www.tropicalforages.info/
c. https://ndb.nal.usda.gov/ndb/search/list
d. https://cowsoko.co.ke/kmdp/rumen8
e. http://www.globallometree.org/

In the crop input section, for each feed, provide the following information:

- The proportion of collected manure applied as fertilizer on-farm.
- The rate of synthetic fertilizer application (kg/ha).

These are used to calculate nutrient balances, field-level N_2O emissions, and emissions from fertilizer production.

→**IMPORTANT NOTE:**

- **Observe the units of measurement** and, where necessary, convert them to match the tool's requirements (e.g., g to kg).
- **Double left-click** to select from the drop-down list options provided.

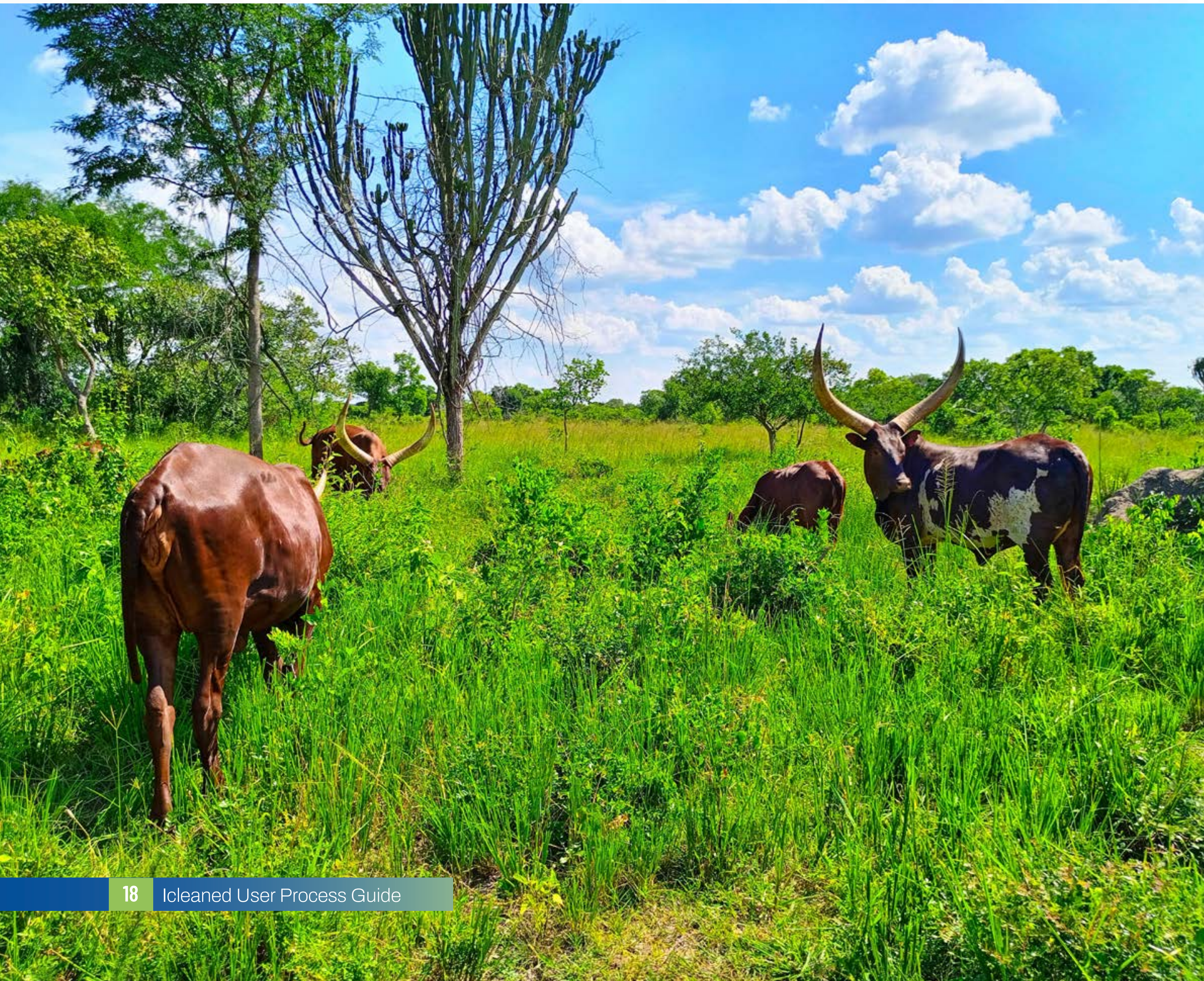
2.2.5 Livestock Feeding

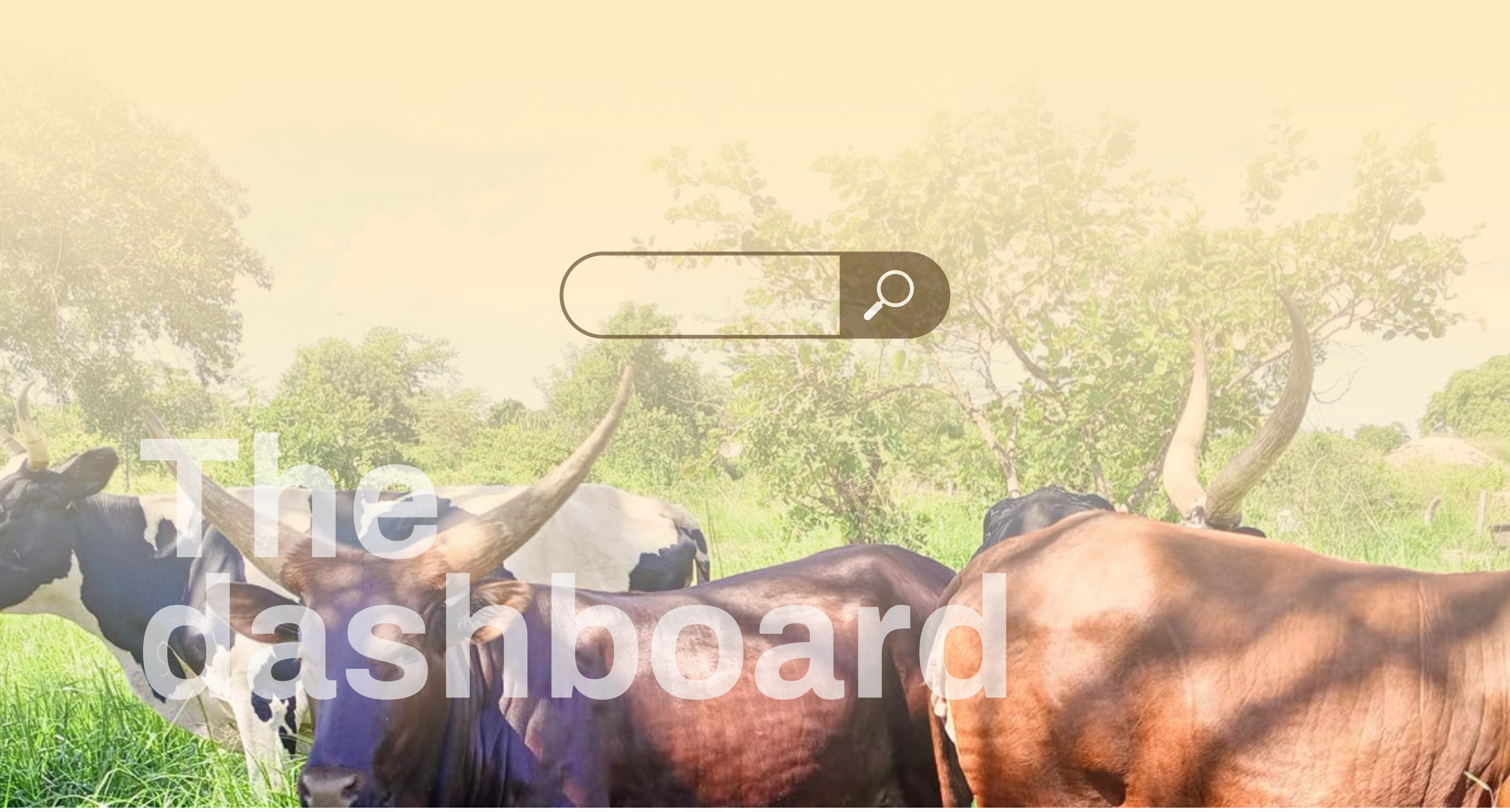
In this section, provide a detailed description of seasonal feed baskets for each livestock category. Feed baskets are defined by their composition—the different feed items offered and the percentage contribution of each item to the total diet. Seasons and feeds selected in the feed production section will automatically appear here. Users only need to enter the proportional diet intake for each livestock category by season. To add proportional diet intakes:

- **Double-left click** on the cell under each feed item and enter the percentage intake.
- **Repeat** this process for all seasons and livestock categories.

→ IMPORTANT NOTE:

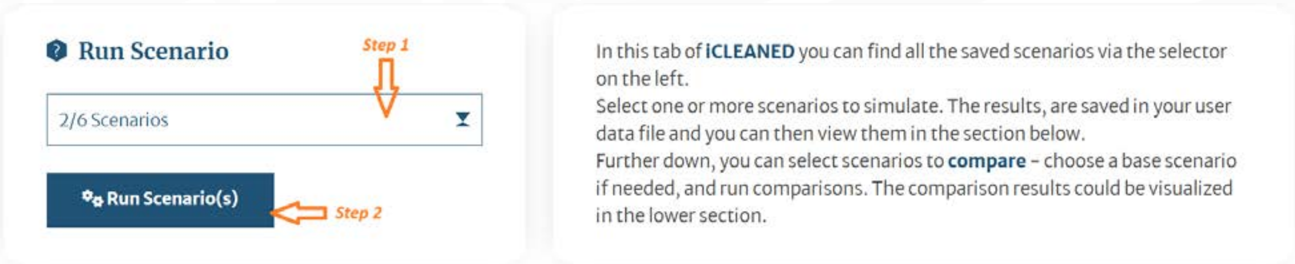
- This section displays only the seasons, livestock, and feed baskets selected in the previous tabs.
- Any edits made on the interface are saved automatically. If needed, more description is provided to the user through tooltips.





3. Results Overview – The Dashboard

After you have filled out the farm info, livestock, livestock feeding and feed production sections, you can explore the likely environmental footprints by executing the run scenarios button on the dashboard window.



To enhance efficiency and productivity, users can now run multiple scenarios at the same time. This feature is particularly useful when users need to process several scenarios without waiting for each one to finish individually.

How to run:

Navigate to the "**dashboard**" window of the tool.

Step 1: In the "Run Scenario" dropdown menu, select one or more Scenarios by clicking on them. Multiple selections are allowed.

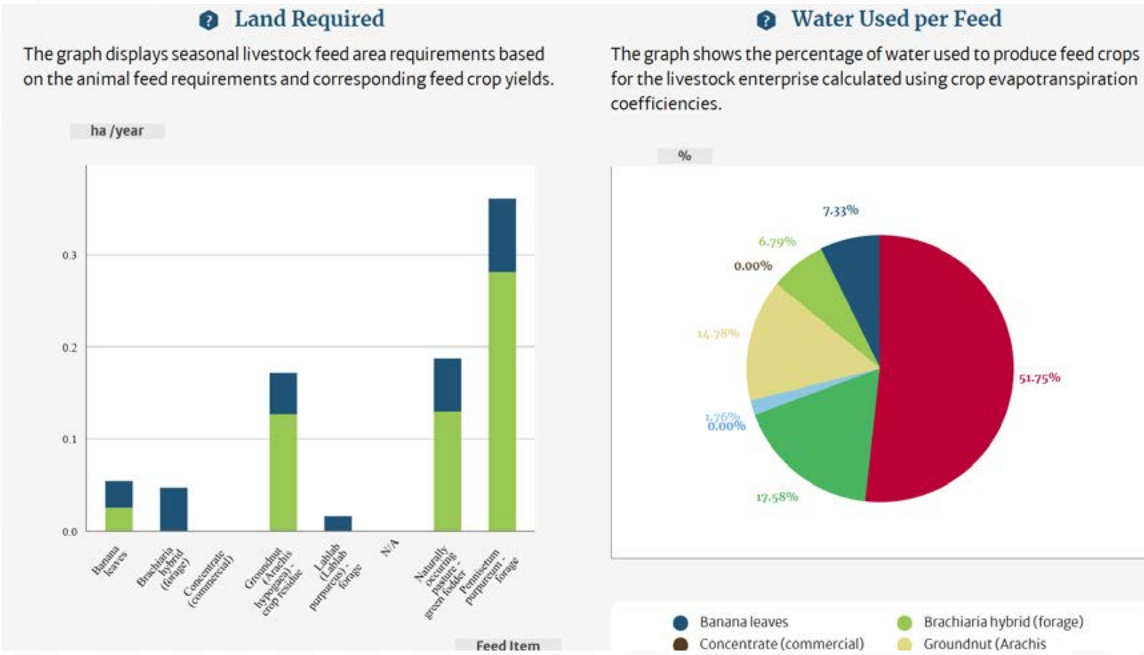
Step 2: After selecting the desired scenarios, click on the "Run Scenario(s)" button.

The application will initiate the execution of all selected scenarios simultaneously. While scenarios are running, a **progress indicator** is displayed at the bottom right of the execution window. This visual feedback allows users to monitor the execution status.

3.1 Visualizing and Downloading Results

Upon completion, scenario results are stored in the user's 'Scenarios' folder, and users can view both a detailed and a snapshot of the results. For each run, a dropdown menu allows users to select from available iCLEANED output indicators. Results can be visualized along 3 pathways:

a. **Exploring results of the different runs:** Enables the user to view indicator results for a single run at a time. It presents absolute values in graphs.



→ IMPORTANT NOTE:

- Before results are visualized in pathways **b** and **c** below, the user must select scenarios to be compared and click the Run Compare button to generate outputs for comparison. This additional step allows footprints to be expressed per unit of livestock product or per unit area. Below is a stepwise guide:

Step 1: **Select the runs/scenarios** to compare from the dropdown list. Multiple selections are allowed.

Step 2: Click the" **Run Comparison"** button to generate the comparison.

Step 3: **Choose** the specific comparison pair (e.g., Study_1 – Study_2) from the dropdown.

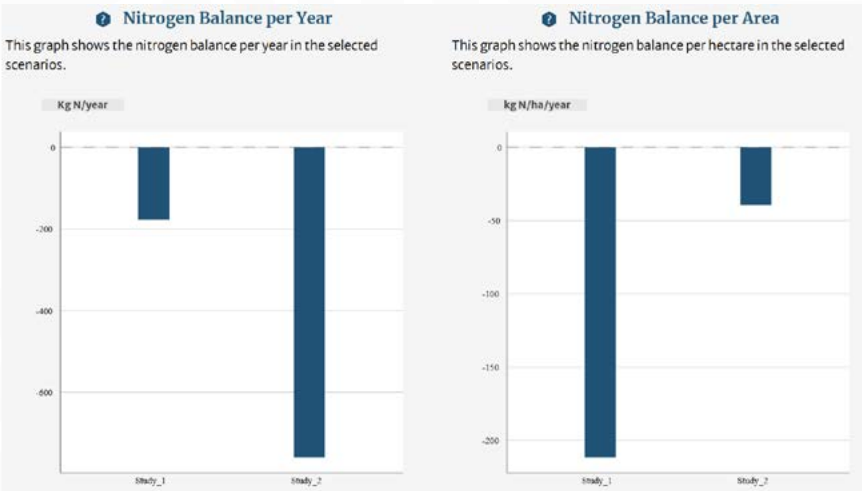
Step 4: **Select** the output indicator to display (e.g., GHG Emissions).

Step 5: **Choose** the base scenario:

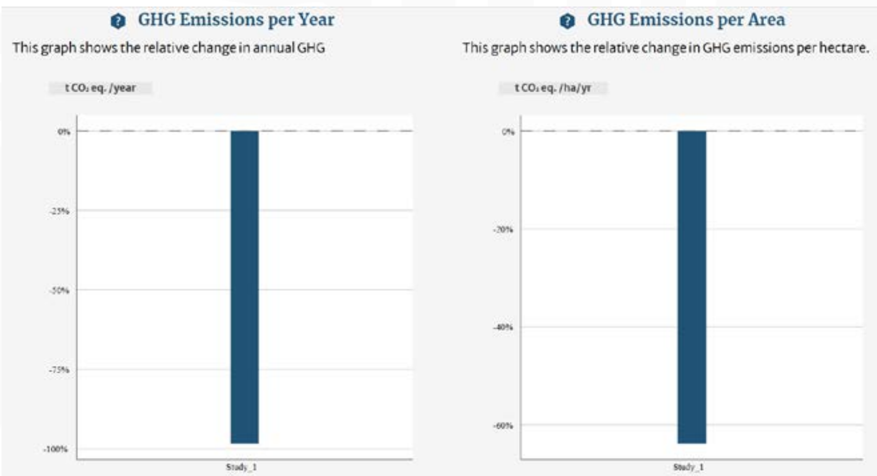
- **None** to view runs side by side, absolute values side by side, or
- **Select** a specific study to view relative changes against it.

Additional options allow users to **delete a comparison** or **download results.** Users can click the question mark next to each indicator result to learn more.

b. **Viewing the results side by side:** Presents indicator results of the different runs next to each other for comparison.



c. **Comparing differences between scenarios:** Users can view graphical summaries of **relative changes in environmental footprints** across scenarios. The app presents the main outputs as graphs in the dashboard, while detailed indicator results can be downloaded in Excel-supported files.



→ **IMPORTANT NOTE:**

- Scenarios can be **viewed side-by-side** by selecting **"None"** or as **relative changes** by **selecting a specific scenario as the baseline**.
- If the result folder with the same name already exists, it will be overwritten by the new scenario run. Overwriting is irreversible and will permanently replace previous results.
- To preserve existing results, consider renaming the existing Scenario Input before running the scenario.

3.2 Extrapolating Results to a Regional, Sub-Regional or Country Context

Baselines can be defined at multiple spatial scales, including farm, regional, or national levels. Where modelling is conducted at lower levels, e.g, a single livestock enterprise, the site-specific results can be extrapolated to represent impacts at regional, sub-national or national levels to support strategic planning, policy, and investment. However, the data requirements, assumptions, and calculation steps outlined below must be followed.

3.2.1 Data Requirements for Extrapolation

Users must represent the landscape using one of the following approaches:

a. **Enterprise type representation**

Distribution of enterprise types within the region or country, i.e., Percentage (%) of total enterprises per type, or absolute number of enterprises per type.

b. **Livestock-based representation:**

Total livestock population in the region or country, and the proportion (%) of the herd managed under each production system or enterprise type.

→ **IMPORTANT NOTE:**

- Approach **A** is preferred where enterprise typologies and household statistics are available, while Approach **B** is suitable where reliable livestock population statistics exist.

3.2.2 Key Assumptions

The extrapolation of iCLEANED results to a broader spatial scale is based on the following assumptions:

- Each CLEANED model run represents a typical enterprise for a given farm type, production system, and agro-ecological context.
- All enterprises of the same type are assumed to perform identically to the modelled enterprise, i.e., each enterprise is treated as a single management unit (e.g. one farm or household).
- Intervention scenarios are assumed to be technically feasible for all enterprises of that type, subject to adoption rates.

→ **IMPORTANT NOTE:**

- These assumptions should also be considered when interpreting out-scaled results.

3.2.3 General Extrapolation Principle

Landscape-level impacts are calculated by multiplying enterprise-level indicators by the number of enterprises represented in the landscape and summing across enterprise types. Baseline extrapolation represents the current situation, assuming no intervention is implemented.

Required inputs:

- Baseline enterprise-level indicator impacts generated by iCLEANED, e.g. greenhouse gas emissions, land requirements, nitrogen balance, etc.
- Estimated number of farm types or enterprises with similar characteristics in the landscape.

For each farm type:

Landscape baseline impact = **Baseline enterprise-level impact** × **Number of similar enterprises**

Scenario extrapolation represents future or alternative farm configurations in which intervention strategies are fully or partially adopted.

Additional required input:

- Adoption rate (% of enterprises expected to implement the intervention)

For each intervention scenario and farm type:

Landscape scenario impact = **Scenario enterprise-level impact** × **Number of similar enterprises** **× Adoption rate**

→ IMPORTANT NOTE:

- Total landscape-level baseline or scenario impacts are obtained by summing results across all enterprise types.

3.2.4 Comparing Scenarios with The Baseline

To assess the relative effect of intervention scenarios, landscape-level results can be expressed as a percentage change relative to the baseline:

Percentage change (%) = (**Scenario impact** – **Baseline impact**) / **Baseline impact** × 100

3.3 Interpretation of the Outputs

For each of the impact categories (land requirement, productivity, soil impacts, water impacts and GHG emissions), separate result sheets are provided. The text below provides guidance on interpreting the iCLEANED results. All results should be interpreted at the livestock enterprise scale and reflect annual performance under the defined scenario. When comparing scenarios, users should focus on relative changes rather than absolute values alone, and ensure comparisons are made using the same functional unit (e.g., per kg FPCM, per kg meat, per ha). In the interpretation of environmental impact indicators, considerations must also be made for the diverse social impacts of environmental changes, particularly concerning gender roles and power dynamics that may affect the ability of women or marginalized groups to take up recommendations that involve greater investment or changes in land allocation.

1. Land Requirements

This sheet presents the amount of land required (in hectares per year) to meet the feed needs of the herd in the livestock enterprise. It's important to note that land is a valuable but finite resource, with many competing demands such as producing staple foods, animal production, preserving forests and natural habitats, building settlements and infrastructure, and more. Interpretation should focus on whether scenarios increase or reduce total land demand and whether changes occur on-farm, off-farm, or through imported feeds. The more efficient the feed production, the more land is available for other purposes. Converting non-agricultural land for feed production can have negative impacts on biodiversity. This is particularly problematic when forests, wetlands or other natural vegetation are converted into cropland or pastures.

1.2 Land Requirement for Feed Production Per Associated Crop (Ha)

In this table, you will find the list of feed items used in the livestock enterprise. For each of these, it is indicated how many hectares of the associated crop need to be planted to fulfil the feed requirements of the animals per season and year-round. The total area used for feed production adds up to the annual area requirements per feed item. This is thus the total area of land that the livestock enterprise should "set aside" for feed production. Large values for a specific feed indicate high land intensity or low yields and may signal opportunities for productivity improvement. The area for feed is further classified into four distinct categories depending on the production source:

- Area required on-farm (ha) – Area required to produce feeds within the livestock enterprise.
- Area required roughages off-farm (ha) – Area for roughages produced outside the livestock enterprise.
- Area required concentrates off-farm (ha) – Area linked to the production of concentrates outside the livestock enterprise.
- Area required imported concentrates (ha) – Area linked to the production of imported concentrates.

Shifts from on-farm to imported land indicate displacement of environmental pressure rather than absolute reduction.

1.3 Area Per Milk Unit (ha/kg FPCM)

In addition to the absolute values, the tool also calculates an efficiency indicator, i.e., how much land is required for the feed production for one kg of FPCM (Fat/protein-corrected milk). FPCM is calculated based on the milk fat and protein contents in percentage, which are livestock parameters. This indicator shows land-use efficiency per unit of milk.

1.4 Dry Matter Requirements (kg)

In the second table, the quantities in kg of dry matter (DM) per season per feed and in total are presented. The dry matter requirements per crop and per season do not consider the actual time at which the crop is cultivated, only what is required by the herd annually. Increases in DM demand may reflect higher herd size, higher intake per animal, or longer feeding periods.

Total estimated annual quantities in kg of dry matter are also presented based on the production source.

- DM required on-farm (kg) – requirement (expressed in kg DM) for feeds produced within the livestock enterprise.

- DM required roughages off-farm (kg)– requirement (expressed in kg DM) for roughages produced outside the livestock enterprise.
- DM required concentrates off-farm (kg) – requirement (expressed in kg DM) for concentrates produced outside the livestock enterprise.
- DM required imported concentrates (kg) – requirement (expressed in kg DM) for imported concentrates.

Compare on-farm versus off-farm DM to assess dependency on external feed markets.

1.5 Feed Per Milk Unit (kg/kg FPCM)

In addition to the absolute values, the tool also calculates an efficiency indicator, i.e., how much DM of feed is required to produce one kg of FPCM. FPCM is calculated based on the milk fat and protein contents in percentage, which are livestock parameters. Lower values indicate better conversion of feed into milk. Improvements should be interpreted cautiously if driven by higher concentrate inclusion or assumptions about animal performance.

2. Productivity

2.1 Productivity Indicators

Productivity is a potential supply indicator that calculates the total amount of calories embedded in the livestock products produced by the livestock enterprise. Use productivity indicators to understand how much food energy is supplied by the enterprise. Higher values indicate increased food supply potential, but should be interpreted together with environmental intensities. Productivity gains may reduce emission intensities even if absolute emissions increase. The table in this sheet lists productivity indicators for different livestock products, i.e.:

- Cattle meat.
- Cattle Fat-Protein Corrected Milk (FPCM).
- Meat and Fat-Protein Corrected Milk (FPCM) from other ruminants, e.g., goats, sheep, buffalo.
- Meat from pigs.

Besides the animal-sourced foods, annual manure production from cattle, buffalo, sheep, goats, and pigs is estimated.

The productivity indicators include:

- Production: the number of kilograms (kgs) of this product that is produced in the year.
- Energy: the number of kilocalories (kcal) that this production represents (calculated by multiplying the quantity produced by the calorie content of the product).
- AME (adult male equivalent) days: assuming an adult male requires 2500 kcal/day, the value listed here represents the number of days that the livestock enterprise can fulfil the energy requirements of one adult male.

2.2 Tropical Livestock Units

The tool converts the total number of animals present in a livestock enterprise into a common unit. This is used as the reference point to factor livestock of different species by biomass. Generally, 1TLU = 250 kgs of liveweight. TLU/ha measures the intensity of animals managed in a hectare of (feed-producing) land. Increasing TLU/ha indicates intensification, while decreasing values indicate extensification. Interpret changes alongside land requirement results to avoid misreading stocking pressure.

3. Soil Impacts

3.1 Overall Soil Impacts

The soil impacts are expressed in terms of Nitrogen balance and erosion. Both totals from the enterprise and disaggregation by production source are outlined in this table. We calculate (i) the percentage of the feed-producing fields with negative N balance as "% mining" and (ii) the percentage of feed-producing fields with positive N balance as "% leaching". The N balance is the difference between N added to the feed-producing areas of the livestock enterprise and the N removed in the form of feed or food. A positive N balance is desired, as otherwise nutrient mining might result in severe soil fertility depletion over time. However, the N balance of >150 kg N/ha is also undesirable as this could result in N leaching in groundwater and higher GHG emissions.. Aim for low shares of both extremes. High "% mining" indicates potential soil fertility depletion risk; high "% leaching" indicates surplus risk and potential environmental losses. Use scenario comparisons to see whether interventions reduce the area under deficit or surplus, not just average balances.

Erosion: Erosion is expressed in annual t of soil loss. The total amount of soil lost from the enterprise (t soil/year), per area hectare (t soil/ha/year), and per unit product (kg soil/kg FPCM or kg soil/kg meat or kg soil/kg protein) is quantified. Read erosion per ha as land-degradation pressure and erosion per product as eco-efficiency. If per product improves mainly due to higher output while per ha stays high, land degradation risk may remain.

3.2 Feed Items Specific N Balance

For each feed item, the N inputs and N outputs, as well as the resulting N balance, are listed separately. The N balance considers the N for feed production used for animal production, and also the N balance for food production. If the feed used to feed the animal is a food crop residue, e.g., maize stover, the N balance for the maize grain is calculated and used to assess the N balance of the livestock enterprise. Use crop-level balances to target specific feed crops driving deficits or surpluses, enabling focused nutrient management rather than blanket changes.

4. Water Impacts

4.1 Overall Water Impacts

The model calculates from the annual rainfall the percentage of available water which is utilized for feed production. It also calculates an efficiency indicator, i.e., the percentage of water used to produce a kg of milk, meat, and protein. Lower water per kg output indicates higher water-use efficiency, but check for trade-offs (e.g., land expansion, increased purchased feed reliance) and interpret in the local climatic context.

5. Ghg Emissions

5.1 GHG Balance

In this table, you will find the Tier 2 results (computed using context-specific data) for GHG emissions, differentiating footprints from different sources of carbon dioxide at farm and off-farm levels. These include:

- Methane emissions from enteric fermentation, manure production and storage, and rice production.
- Direct and indirect nitrous oxide (N_20) emissions from soil inputs and manure production and storage.
- Carbon dioxide from the production of synthetic fertilisers and the burning of crop residues.

When both methane (CH_4) and nitrous oxide (N_2O) are emitted from the same source, the emissions are detailed per gas, i.e., Manure-Methane and Manure-Direct N_2O, etc. Carbon dioxide equivalent (CO2e) is obtained by multiplying the GHG emissions by their respective Global Warming Potential (GWP): 28 for methane and 265 for nitrous oxide.

The contribution of the different GHG emissions to the total GHG on-farm balance is given in percentage, while the total GHG balance is given in t CO_2e. Emissions are further expressed on a per area basis (t CO_2/ha/year) and per kg product (kg CO_2e/kg FPCM, kg CO_2e/Kg meat, and kg CO_2e/Kg protein). Per area basis emissions are further split into source types, i.e., originating from the farm, off-farm roughages and concentrates or imported concentrates.

- Use total t CO_2e to assess mitigation potential;
- Use kg CO_2e/kg product to assess efficiency;
- Use source contributions to identify dominant mitigation levers. Always interpret intensity and totals together, because productivity gains can lower intensity without lowering total emissions.

Increases in off-farm or imported contributions can indicate displacement of emissions to external supply chains; interpret alongside land and feed sourcing indicators.

3.4 Benchmark Environmental Footprints for Livestock Systems in Africa

Annex 1: Benchmark Environmental Footprints of Cattle Systems in Africa

Livestock species	Region	Livestock Production System	Productivity (kg milk cow^{-1} year^{-1})			Greenhouse gas emissions (kg CO_2eq kg FPCM^{-1})			Water footprint/water use (m^3 kg FPCM $^{-1}$)			Land requirement (ha ton FPCM^{-1} year^{-1})		
			Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Dairy Cattle	North Africa	Regional average	3965.0	686.9	11935.5	4.9	2.0	14.5	1.3	0.9	2.2	––	––	––
		Intensive	6755.5	2170.0	11935.5	2.2	2.0	2.4	1.4	0.9	2.2	––	––	––
		Semi-int.	2342.2	798.62	2973.7	3.6	––	––	––	––	––	––	––	––
		Extensive	`1258	686.93	1662.6	14.5	––	––	2.0	––	––	––	––	––
	East Africa	Regional average	1878.4	395.0	3347.1	5.7	1.1	23.8	2.0	1.2	3.1	0.4	0.2	0.7
		Intensive	2251.14	536.6	3347.1	2.39	1.1	5.9	1.61	1.2	2.2	0.3	0.2	0.3
		Semi-int.	2147.81	2244.8	2697.4	9.86	2.3	16.6	3.13	-	_	0.4	0.3	0.7
		Extensive	932.00	395.0	2007.0	13.71	1.8	23.4	2.03	_	_	0.5	0.3	0.7
	Central Africa	Regional average	1168.0	418.4	2079.4	4.1	––	––	––	––	––	––	––	––
		Intensive	1598.7	571.7	2079.4	4.1	––	––	––	––	––	––	––	––
		Semi-int.	1199.0	513.2	1513.8	––	––	––	––	––	––	––	––	––
		Extensive	709.9	418.4	914.6	––	––	––	––	––	––	––	––	––
	West Africa	Regional average	959.9	323.4	2197.8	7.3	3.7	12.8	––	––	––	––	––	––
		Intensive	1307.8	854.1	2197.8	5.10	3.7	6.9	––	––	––	––	––	––
		Semi-int.	934.3	876.9	988.8	––	––	––	––	––	––	––	––	––
		Extensive	755.1	323.4	1315.8	10.2	6.5	12.8	––	––	––	––	––	––
	South Africa	Regional average	6876.8	1722.8	11988.0	1.4	1.1	1.6	1.3	1.0	1.4	––	––	––
		Intensive	7116.2	5924.0	11988.0	1.28	1.1	1.5	1.24	1.0	1.4	––	––	––
		Semi int.	6912.0	6413.1	7411.0	1.34	1.2	1.5	1.4	––	––	––	––	––
		Extensive	5642.54	1722.8	7499.0	1.46	1.4	1.6	1.4	––	––	––	––	––

Livestock specie	Region	Livestock Production System	Productivity (kg meat day^{-1})			Greenhouse gas emissions (kg CO_2eq kg meat^{-1})			Water footprint/water use (m^3 kg meat^{-1})			Land requirement (ha ton meat^{-1} year^{-1})			Nitrogen balance (kg N ha^{-1})		
			Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Beef Cattle	North Africa	Regional average	0.82	0.70	0.95	8.45	5.45	11.50	15.20	4.05	23.52	---	---	---	-23.33	---	---
		Intensive	0.82	0.70	0.95	8.45	5.45	11.50	15.33	4.05	23.52	---	---	---	---	---	---
		Semi-int.	---	---	---	---	---	---	14.27	---	---	---	---	---	---	---	---
		Extensive	---	---	---	---	---	---	---	---	---	---	---	---	-23.33	---	---
	East Africa	Regionlal average	0.71	0.31	1.17	54.05	6.80	144.40	48.40	22.30	75	9.35	3.80	12.50	-17	-28	-6
		Intensive	0.76	0.35	1.17	12.24	6.80	17.69	---	---	---	3.90	3.80	4.00	---	---	---
		Semi-int.	---	---	---	47.50	21.33	74.10	22.30	---	---	12.20	11.90	12.50	-17	-28	-6
		Extensive	0.31	---	---	93.17	28.33	144.41	75.00	---	---	11.95	11.90	12.00	---	---	---
	Central Africa	Regional average	0.12	0.08	0.37	---	---	---	---	---	---	---	---	---	---	---	---
		Intensive	0.3	0.21	0.37	---	---	---	---	---	---	---	---	---	---	---	---
		Semi-int.	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
		Extensive	0.10	0.08	0.12	---	---	---	---	---	---	---	---	---	---	---	---
	West Africa	Regional average	0.21	0.13	0.40	27.30	15.80	44.50	---	---	---	---	---	---	11.40	10.60	11.90
		Intensive	0.22	0.17	0.40	19.53	15.80	22.80	---	---	---	---	---	---	10.60	---	---
		Semi-int.	---	---	---	37.00	25.80	44.50	---	---	---	---	---	---	---	---	---
		Extensive	0.16	0.13	0.36	---	---	---	---	---	---	---	---	---	11.90	---	---
	South Africa	Regional average	0. 43	0.10	1.04	19.10	---	---	25.41	0.44	38.23	---	---	---	---	---	---
		Intensive	0.60	0.10	1.04	---	---	---	25.41	0.44	38.23	---	---	---	---	---	---
		Semi-int.	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
		Extensive	0.26	0.10	0.39	19.10	---	---	---	---	---	---	---	---	---	---	---

Appendix 2: Benchmark Environmental Footprints for Sheep Production Systems in Africa

Livestock specie	Region	Livestock Production System	Productivity (kg milk sheep^{-1} year^{-1})			Greenhouse gas emissions (kg CO_2eq kg FPCM^{-1})		
			Mean	Min	Max	Mean	Min	Max
Dairy Sheep	North Africa	Regional average	202.59	69.76	598.6	8.7	---	---
		Intensive	214.22	117.4	598.6	---	---	---
		Semi-intensive	172.48	---	---	8.7	---	---
		Extensive	69.76	---	---	---	---	---
	West Africa	Regional average	139.56	40.85	371.23	---	---	---
		Intensive	158.45	94.41	371.23	---	---	---
		Semi-intensive	---	---	---	---	---	---
		Extensive	40.85	---	---	---	---	---

Livestock specie	Region	Livestock Production System	Productivity (kg meat day^{-1})			Greenhouse gas emissions (kg CO_2eq kg meat^{-1})			Water footprint/water use (m^3 kg meat $^{-1}$)		
			Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Sheep meat	North Africa	Regional average	0.14	0.05	0.25	43.10	28.70	57.50	8.10	3.49	24.50
		Intensive	0.16	0.12	0.25	28.70	---	---	6.80	4.15	13.30
		Semi-intensive	0.13	0.09	0.17	---	---	---	7.10	3.49	12.80
		Extensive	0.05	---	---	57.50	---	---	24.50	---	---
	East Africa	Regional average	0.11	0.01	0.15	---	---	---	---	---	---
		Intensive	0.13	0.06	0.19	---	---	---	---	---	---
		Semi-intensive	0. 11	0.10	0.13	---	---	---	---	---	---
		Extensive	0.09	0.01	0.44	---	---	---	---	---	---
	West Africa	Regional average	0.07	0.01	0.18	---	---	---	---	---	---
		Intensive	0.11	0.05	0.18	---	---	---	---	---	---
		Semi-intensive	0.06	0.05	0.06	---	---	---	---	---	---
		Extensive	0.01	0.01	0.04	---	---	---	---	---	---

Livestock specie	Region	Livestock Production System	Productivity (kg meat day^{-1})			Greenhouse gas emissions (kg CO_2eq kg meat^{-1})			Water footprint/water use (m^3 kg meat $^{-1}$)		
			Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
	Central Africa	Regional average	0.10	0.08	0.12	---	---	---	---	---	---
		Intensive	0.10	0.08	0.12	---	---	---	---	---	---
		Semi-intensive	---	---	---	---	---	---	---	---	---
		Extensive	---	---	---	---	---	---	---	---	---
	South Africa	Regional average	0.24	0.10	0.31	---	---	---	---	---	---
		Intensive	0.30	0.30	0.31	---	---	---	---	---	---
		Semi-intensive	0.27	0.26	0.29	---	---	---	---	---	---
		Extensive	0.18	0.10	0.25	---	---	---	---	---	---

Appendix 3: Benchmark Environmental Footprints for Goat Production Systems in Africa

Livestock specie	Region	Livestock Production System	Productivity (kg milk goat^{-1} year^{-1})		
			Mean	Min	Max
Dairy goat	North Africa	Regional average	161.1	109.50	180.46
		Intensive	—-	—-	—-
		Semi-intensive	171.43	161.65	180.46
		Extensive	109.5	—-	—-
	Central Africa	Regional average	101.61	70.99	132.33
		Intensive	—-	—-	—-
		Semi-intensive	132.33	—-	—-
		Extensive	70.99	—-	—-
	East Africa	Regional average	836.52	51.97	2,153.50
		Intensive	1514.75	912.5	2,153.50
		Semi-intensive	322.28	116.8	500.05
		Extensive	51.97	—-	—-
	West Africa	Regional average	170.62	152.75	188.52
		Intensive	—-	—-	—-
		Semi-intensive	170.62	152.75	188.52
		Extensive	—-	—-	—-
	South Africa	Regional average	745.96	488.735	1,445.40
		Intensive	1113.43	501.14	1,445.40
		Semi-intensive	432.34	375.95	488.735
		Extensive	220.1	112.785	292

	Region	Livestock Production System	Productivity (kg meat day^{-1})			Greenhouse gas emissions (kg CO_2eq kg meat^{-1})		
			Mean	Min	Max	Mean	Min	Max
Goa meat	North Africa	Regional average	0.12	0.01	1.12	15.82	—-	—-
		Intensive	—-	—-	—-	—-	—-	—-
		Semi-intensive	0.12	0.01	1.12	15.82	—-	—-
		Extensive	—-	—-	—-	—-	—-	—-
	East Africa	Regional average	0.08	0.01	0.11	—-	—-	—-
		Intensive	0.10	0.01	0.11	—-	—-	—-
		Semi-intensive	0.09	—-	—-	—-	—-	—-
		Extensive	0.03	0.01	0.05	—-	—-	—-

	Region	Livestock Production System	Productivity (kg meat day^{-1})			Greenhouse gas emissions (kg CO_2eq kg meat^{-1})		
			Mean	Min	Max	Mean	Min	Max
Goat meat	Central Africa	Regional average	0.04	0.01	0.06	–-	–-	–-
		Intensive	–-	–-	–-	–-	–-	–-
		Semi-intensive	0.05	0.02	0.06	–-	–-	–-
		Extensive	0.03	0.01	0.04	–-	–-	–-
	West Africa	Regional average	0.07	0.01	0.08	–-	–-	–-
		Intensive	0.09	0.02	0.08	–-	–-	–-
		Semi-intensive	0.03	–-	–-	–-	–-	–-
		Extensive	0.02	0.01	0.03	–-	–-	–-
	South Africa	Regional average	0.06	0.01	0.18	–-	–-	–-
		Intensive	0.14	0.08	0.18	–-	–-	–-
		Semi intensive	–-	–-	–-	–-	–-	–-
		Extensive	0.04	0.01	0.05	–-	–-	–-

Appendix 4: Benchmark Environmental Footprints for Camel Production Systems in Africa

Livestock specie	Region	Livestock Production System	Productivity (kg milk camel^{-1} year^{-1})		
			Mean	Min	Max
Dairy Camel	North Africa	Regional average	1669.08	165.41	2721.88
		Intensive	1993.03	665.43	2721.88
		Semi. I	1539.52	165.41	2631.65
		Extensive	1507.1	330.84	2436.16
	East Africa	Regional average	1559.7	375.95	2594.06
		Intensive	2088.67	1774.48	2594.06
		Semi Int.	1345.9	1075.22	2180.51
		Extensive	1324.21	375.95	2330.89
	West Africa	Regional average	1780.35	492.75	2,518.50
		Intensive	–-	–-	–-
		Semi. Int.	2292.01	1985.02	2,518.50
		Extensive	1012.88	492.75	1533

Livestock specie	Region	Livestock Production System	Productivity (kg meat day^{-1})		
			Mean	Min	Max
Camel meat	North Africa	Regional average	0.49	0.18	0.82
		Intensive	0.67	0.59	0.82
		Semi-intensive	0.48	0.34	0.77
		Extensive	0.35	0.18	0.57
	East Africa	Regional average	0.4	0.17	0.76
		Intensive	0.47	0.21	0.76
		Semi-intensive	––	––	––
		Extensive	0.3	0.17	0.45

Appendix 5: Benchmark Environmental Footprints for Buffalo Production Systems in Africa

Livestock specie	Region	Livestock Production System	Productivity (kg milk buffalo^{-1} year^{-1})			Greenhouse gas emissions (kg CO_2eq kg FPCM^{-1})		
			Mean	Min	Max	Mean	Min	Max
Dairy buffalo	North Africa	Regional average	2718.17	1349.00	3657.30	3.20	––	––
		Intensive	3061.60	2383.67	3657.30	––	––	––
		Semi-intensive	2413.62	1349.00	3259.45	3.20	––	––
		Extensive	1487.12	––	––	––	––	––

Livestock specie	Region	Livestock Production System	Productivity (kg meat day^{-1})		
			Mean	Min	Max
Buffalo meat	North Africa	Regional average	0.63	0.39	0.91
		Intensive	0.81	0.62	0.91
		Semi-intensive	0.55	0.44	0.75
		Extensive	0.39	––	––

Appendix 6: Benchmark Environmental Footprints for Pig Production Systems in Africa

Livestock specie	Region	Livestock Production System	Productivity (kg meat day^{-1})			Greenhouse gas emissions (kg CO_2eq kg meat^{-1})			Water footprint/water use (m^3 kg meat $^{-1}$)		
			Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Pig meat	Sub saharan Africa	Regional average	---	---	---	6.4	4.47	7.94	---	---	---
		Intensive	---	---	---	5.94	4.47	7.94	---	---	---
		Semi-intensive	---	---	---	---	---	---	---	---	---
		Extensive	---	---	---	6.86	5.75	7.55	---	---	---
	Central Africa	Regional average	0.34	0.07	0.63	---	---	---	---	---	---
		Intensive	0.36	0.16	0.63	---	---	---	---	---	---
		Semi-intensive	---	---	---	---	---	---	---	---	---
		Extensive	0.07	---	---	---	---	---	---	---	---
	East Africa	Regional average	0.29	0.06	0.62	---	---	---	---	---	---
		Intensive	0.36	0.12	0.62	---	---	---	---	---	---
		Semi-intensive	0.19	0.15	sss	---	---	---	---	---	---
		Extensive	0.08	0.06	0.11	---	---	---	---	---	---
	West Africa	Regional average	0.27	0.08	0.59	---	---	---	---	---	---
		Intensive	0.28	0.1	0.59	---	---	---	---	---	---
		Semi-intensive	0.26	0.12	0.37	---	---	---	---	---	---
		Extensive	0.18	0.08	0.29	---	---	---	---	---	---
	South Africa	Regional average	0.71	0.18	0.94	---	---	---	4.8	---	---
		Intensive	0.8	0.3	0.94	---	---	---	---	---	---
		Semi-intensive	0.25	0.18	0.32	---	---	---	---	---	---
		Extensive	0.18	---	---	---	---	---	4.8	---	---

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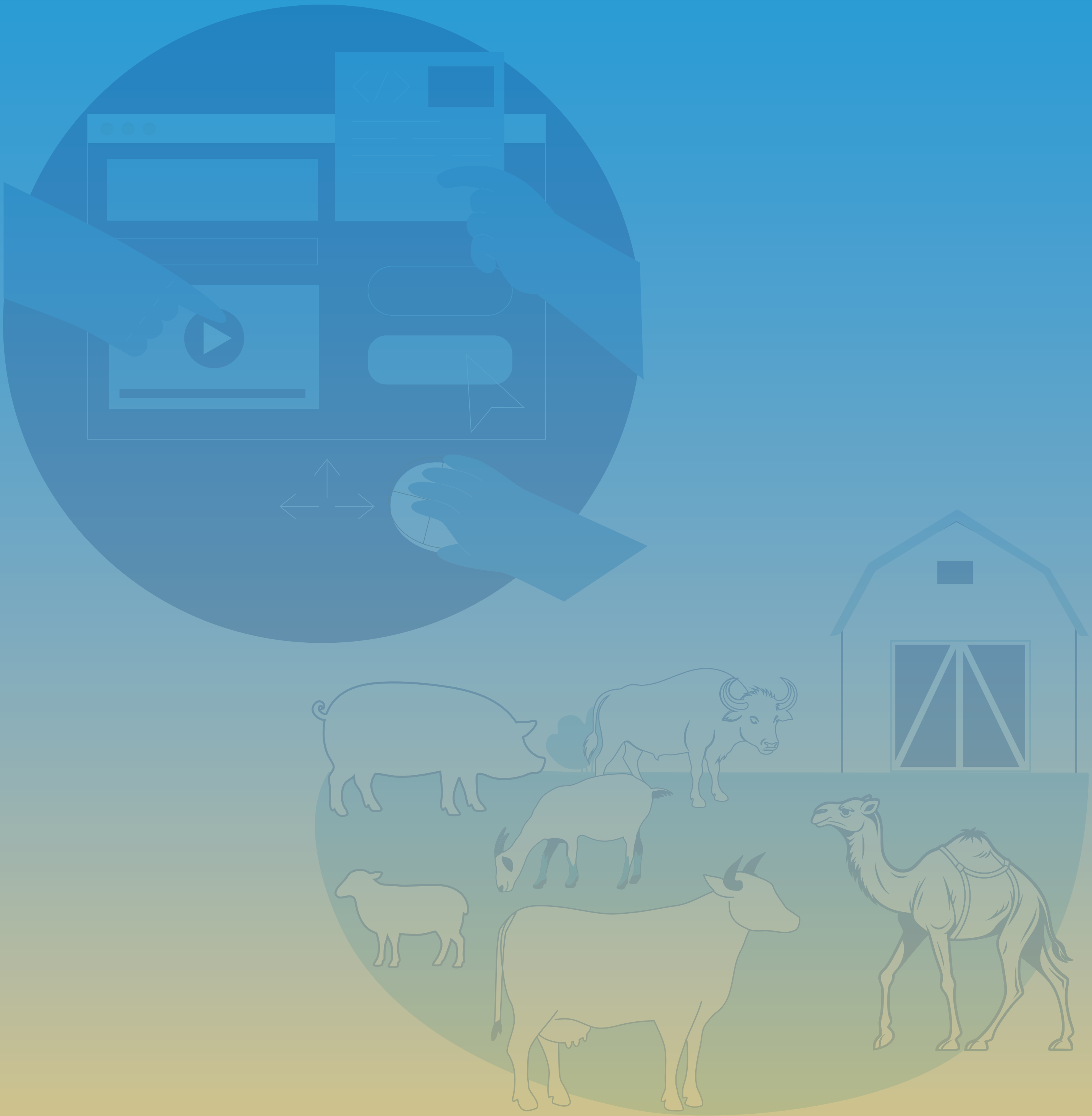

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