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A Benchmarking Framework for Water Use, Soil Health, Land Use, Productivity, Biodiversity, and Climate Change Impacts of Livestock Modelled with CLEANED

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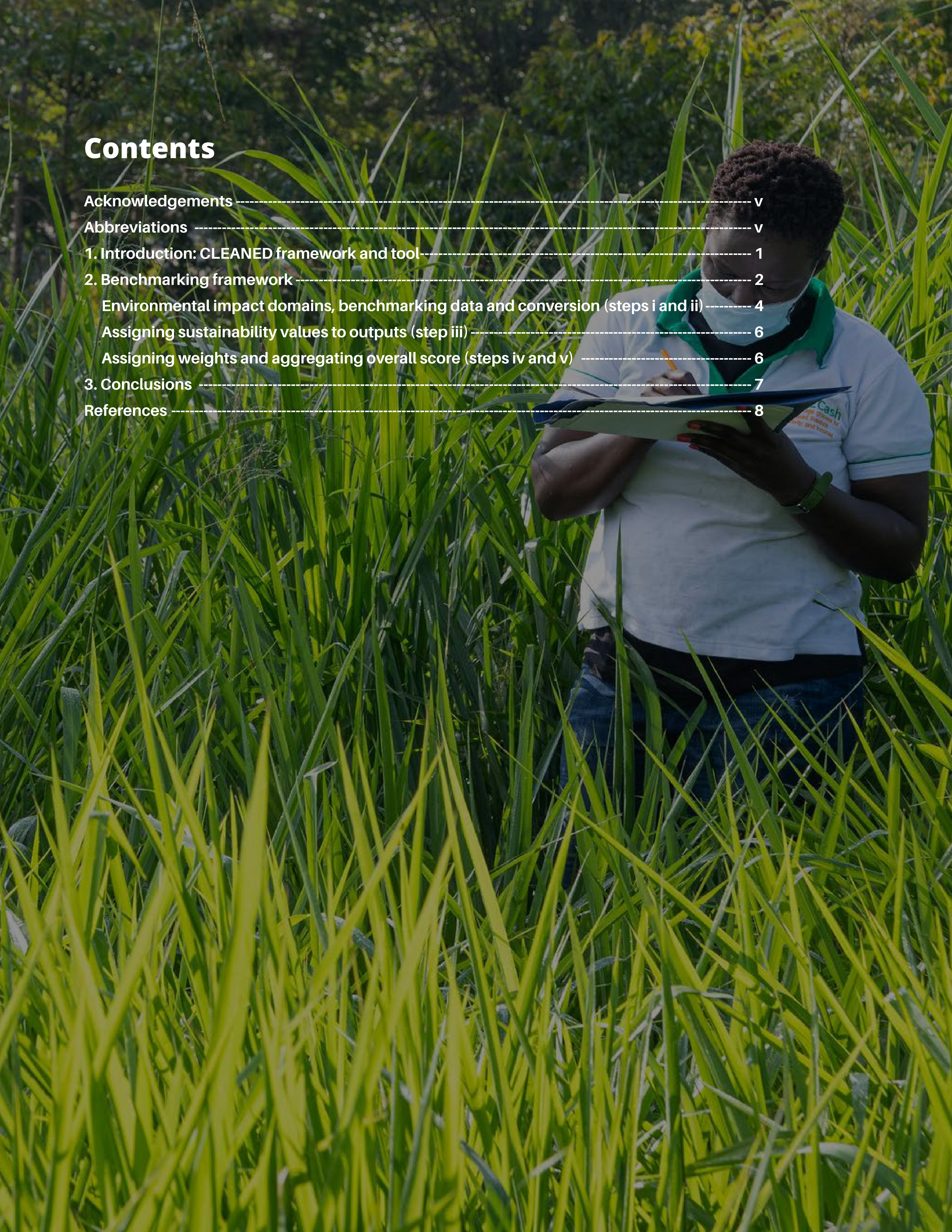
Abbreviations

CLEANED	Comprehensive Livestock Environmental Assessment for Improved Nutrition, a Secured Environment, and Sustainable Development
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse Gas
GIS	Geographic Information System
FPCM	Fat and Protein Corrected Milk



Contents

1. Introduction: CLEANED framework and tool

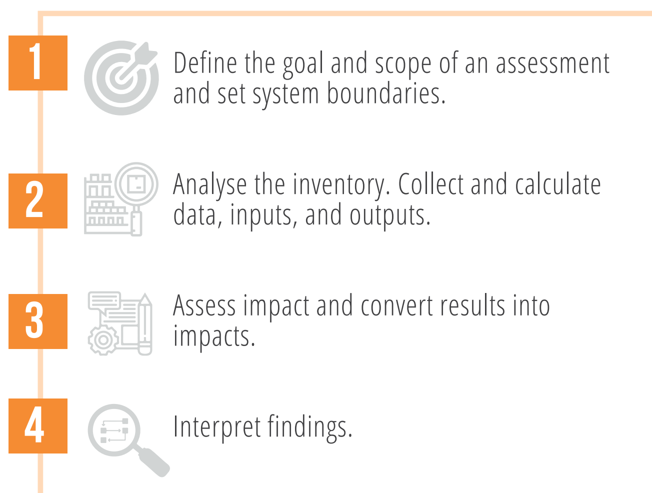
The CLEANED framework and tool intended to support decision making and is intended to help inform governments, donors, non-governmental organisations, and farmer organisations in data-scarce environments. The tool was developed to analyse the environmental impacts of certain production practices in livestock value chains. It evaluates the land requirements, productivity, water use, effects on soil health, and greenhouse gas emissions of a given livestock enterprise.

The first step of any CLEANED assessment is defining the goal and scope of the assessment, which typically starts by delineating an area of study. Descriptors for the study area include agro-ecology, market linkages, production objectives, and farming practices, for example. In the CLEANED model, these units are described as enterprises or systems (Notenbaert et al. 2014). This process allows CLEANED to analyse environmental impacts in the context of each different system/enterprise. These analyses can then be combined to describe the environmental impact of a given livestock production strategy in comparable, standardized units, which is helpful in measuring environmental impact across the system or enterprise and for studying internal change. This process of homogenization into systems or enterprises assumes that the indicators that CLEANED analyses are unlikely to change across systems or enterprises.

CLEANED uses simple minimum-data calculations to analyse environmental footprint indicators. As a static model that calculates these indicators annually, CLEANED estimates biomass, water, and nutrient flows and considers different environmental impact domains (Table 1). Some indicators may be applicable to more than one domain. For instance, the indicators of land requirements, nitrogen balance, and soil erosion are all linked to the land and soil domain. The indicators of land requirements and nitrogen balance are also related to the biodiversity domain. Nitrogen balance also contributes to a third domain: climate change.

Since most of the environmental impacts of livestock value chains can be observed pre-farm gate (Fraval 2014), the main activities that the CLEANED model takes into account are feed and livestock production. The CLEANED model also estimates product losses that occur along the processing, marketing, and consumption stages of the value chain. This estimate factors into the CLEANED model's analysis of the value chain's efficiency, which affects the model's assessment of the value chain's overall environmental impact. Direct environmental impacts and inefficiencies in the processing, marketing, or consumption stages of the value chain are excluded from this assessment. Further, CLEANED focusses on analysing livestock enterprises thus only environmental impacts that are related to livestock and feed, and excludes other non-livestock related crops or farming activities.

A CLEANED assessment roughly follows the steps of an environmental impact assessment as outlined by the Food and Agriculture Organization of the United Nations (FAO) (2020). These steps are as follows (Figure 1):



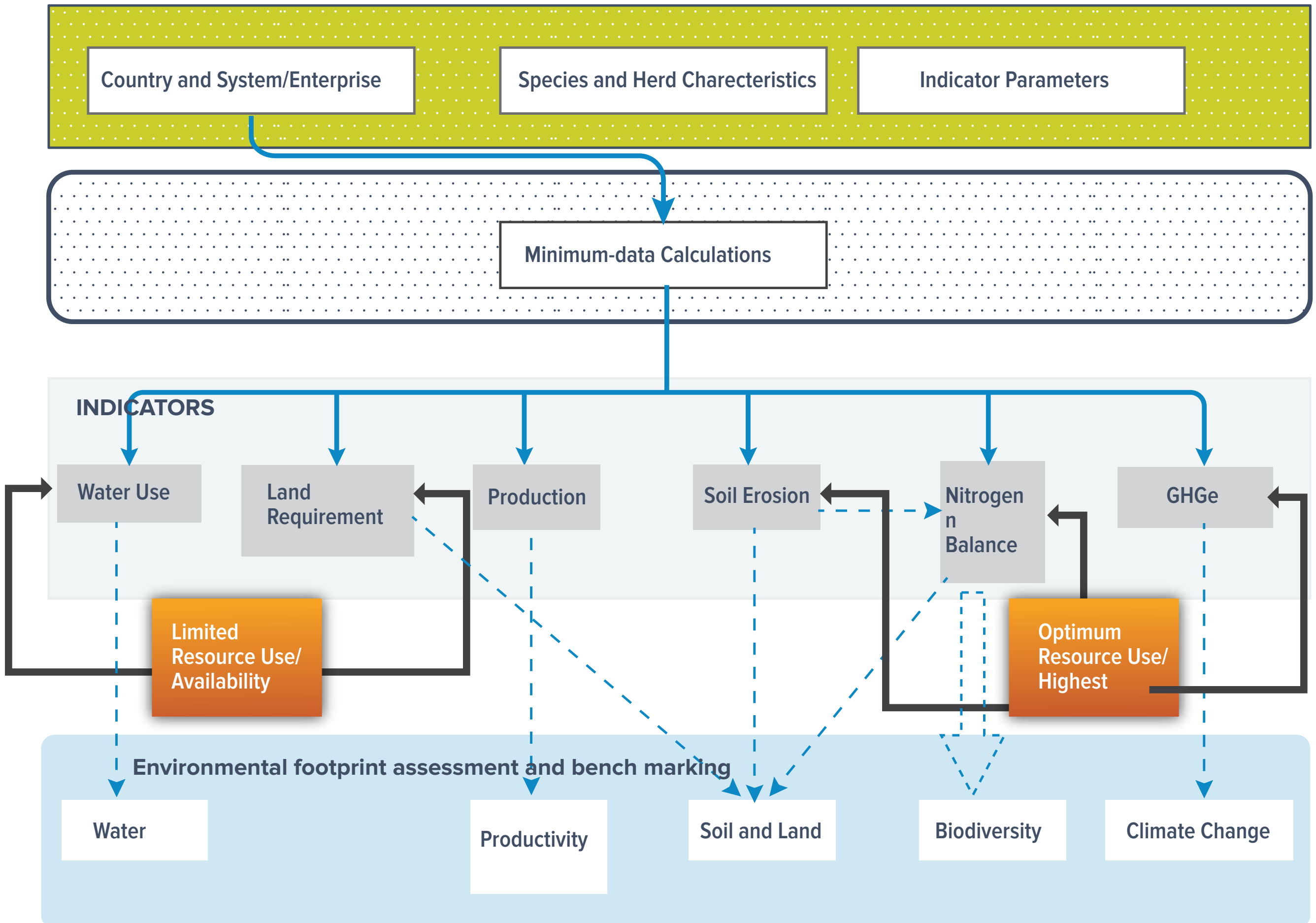


Figure 1. A schematic overview of how the benchmarking system fits into a CLEANED environmental assessment

2. Benchmarking framework

Benchmarking is essential for steps three and four of the CLEANED process, which involve an environmental impact assessment and the interpretation of results (FAO 2020). Benchmarking involves comparing oneself to an industry standard or an organisation with similar production practices or goals. The benchmarking process is usually geared towards improving performance through comparison, learning from others, and identifying actions that will ensure improved outcomes (Franks and Collis 2003, Keszthelyi 2017). A benchmarking system for Comprehensive Livestock Environmental Assessment for improved Nutrition, a secured Environment, and sustainable Development (CLEANED) model would allow users to compare their production practices to sustainability standards within the context of a defined livestock enterprise. Ultimately, the benchmarking tool aims to translate the CLEANED analysis results into a simple 'traffic light' system where red means that the livestock enterprise is unsustainable, amber means that the enterprise is average, and green means that the enterprise is sustainable. An ideal benchmarking system would include annual reference data for every domain and indicator that the user decided to include in their CLEANED assessment. Integrating benchmarking into the CLEANED process provides the user with metrics they can use to interpret how particular farming practices affect sustainability within their enterprise or system (Figure 1). Through this process, the user can better understand the environmental impacts of products like meat and milk. The user can also use this data to determine what changes need to be made in order to close the gap between their ideal environmental impacts, which are represented by the benchmark, and their actual environmental impact (Mekonnen et al. 2020).

For benchmarking, CLEANED indicators are compared against either stocks or flows and limiting resources (Schyns et al. 2019), or the highest productivity levels at different spatial scales. For instance, the water use indicator can be compared to the limited resource of total available water, and therefore it is important to compare the water use indicator against natural stocks. On the other hand, GHG emissions cannot be compared to a natural stock; they contribute to global emissions for a certain footprint, and therefore can only be evaluated against productivity levels. Various methods can be used to set benchmarks for different indicators. These methods vary based on data availability, the scale of the analysis, and the reasons for setting the benchmark, and they include setting a benchmark based on best agricultural practices, based on the highest efficiency of a given indicator, or based on the twentieth or twenty-fifth percentile of the overall range of observed indicator values (Schyns and Hoekstra 2014, Karandish et al. 2018, Mekonnen et al. 2020). All of these methods compare indicators for the study area to other areas that share similar environmental characteristics. It is however difficult to set benchmarks based on comparisons to natural stocks, due to a limited number of studies and analyses that quantify the stocks in question (van Noordwijk and Ellison 2019).

A challenge in benchmarking is the comparability of methods, indicators and units. As a CLEANED analysis is conducted at the system or enterprise level, the tool's data needs to focus on livestock enterprises in order to fit this scale. However, certain studies are not directly linked to providing benchmarks for CLEANED analysis. Therefore, data from the current literature must undergo conversion before being used as a benchmark value. Field studies provide values that could be used as benchmarks (Oweis et al. 2000, Zhang et al. 1998, and Sharma et al. 2016). It is difficult, however, to expand these values to fit national, regional, or global scales. It is helpful to specify the county or system that a certain indicator represents, and identify whether the indicator will be used to assess best practices or to calculate the twentieth or twenty-fifth percentile. Furthermore, expanding the values from these studies to create benchmarks for larger areas like whole countries or regions can also be difficult, because the values do not have enough data for broader comparisons. Modelling and remote sensing in combination with field-scale analysis may help combat this problem and calculate values that are appropriate for wider use.

In the following, we outline a benchmarking framework for CLEANED and illustrate its operationalisation. The benchmarking steps could be as follows:

i. Benchmark values such as best practice indicators, average values, and percentiles are found in literature for each indicator across impact domains.

ii. In instances where these benchmark values and the values from the CLEANED assessment use different units of measurement, the values are converted to allow direct comparison. For example, if CLEANED measures data in Fat and Protein Corrected Milk (FPCM)/ha and the literature measures data in kg/ha, the literature's data would be converted to FPCM/ha.

iii. The system uses these benchmark values to assign low (-1), medium (0), or high (+1) efficiency and sustainability scores to each indicator.

iv. The indicators are assigned weights ranging from -1 to +1.

v. The system combines and aggregates each domain's values and weights for an overall analysis.

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Environmental impact domains, benchmarking data and conversion (steps i and ii)

It is important to define the environmental impact domains in order to help the user understand how an indicator can help determine environmental impact across the domains. CLEANED assesses a total of five domains and thirty-four indicators (Table 1). The domain analyses below expand on the link between the user's values and the benchmark values. These examples are merely illustrative, as more in-depth research and data filtering are required to determine the best benchmark value for each indicator.

Productivity

Production estimates at the enterprise level are measured in kg of FPCM/ha, kg of meat/ha, and kg of protein/ha. Just like the absolute land requirement indicator, the absolute production indicator is critical in measuring other indicators because it helps estimate the other indicators' relative values, and it can be used for benchmarking (Bouwman et al. 2005, Alexandratos and Bruinsma 2012).

Water

Freshwater is essential for human wellbeing and livelihoods, especially in agriculture, which uses about sixty percent of all freshwater. Agriculture is also the backbone of other industries, as it creates many raw materials. Therefore, water security is key to minimising hardship and ensuring sustained socioeconomic activity. Water use in livestock production can be improved through various means. For example, producers can decrease water use per unit of product weight (m^3/tonne), water use per hectare (m^3/ha), water use per unit of protein content in an animal product (m^3/kg protein), water use per kg of FPCM (m^3/kg FPCM), and total water use (m^3) (Chapagain and Hoekstra 2003, Liu et al. 2010, Mekonnen and Hoekstra 2011, Mekonnen and Hoekstra 2012, Liu et al. 2018, Bosire et al. 2019, Heinke et al. 2020). However, in order to draw comprehensive conclusions about the environmental and production impacts of certain practices, researchers need to standardize their findings (Boulay et al. 2021). Just as with productivity values, the values that measure water use often need to be converted to kg of protein content and FPCM to make them comparable.

Soil and land

This domain includes indicators for land required for feed production, soil erosion, and nutrient balances. Assessing soil and land impacts are key as about thirty percent of the Earth's surface is dedicated to livestock production (Ramankutty et al. 2008). In this domain, improved efficiency means minimizing competition for land through partitioning or sharing land (DeFries and Rosenzweig 2010). There are numerous sources of useful benchmarking data, which for the most part present values that are compatible with the CLEANED model and do not require conversion (Stoorvogel et al. 1993, Rufino et al. 2006, Davidson 2009, Liu et al. 2010, Bodirsky et al. 2012, Bosire et al. 2016, Aklilu 2018, Jacobs et al. 2018).

Climate change

When measuring greenhouse gas emissions in relation to livestock production, results depend on whether one is measuring on-farm emissions or emissions throughout the life cycle, whether one is measuring all livestock species or specific species, and whether one is accounting for changes in land use the year the measurements are made (Herrero et al. 2008, Gerber et al. 2013, Herrero et al. 2013, Havlik et al. 2014, Herrero et al. 2016, MacLeod et al. 2017). Most of the climate change-related references use values that do not require conversion. However, most of these references necessitate further research, GIS layer matching, and an in-depth selection process to find exactly which values are compatible with the CLEANED model.

Biodiversity

Agricultural production is linked to losses in both terrestrial and freshwater biodiversity (Dudley and Alexander 2017). Because agriculture's effects on biodiversity are measured for many different reasons, researchers in this domain will clearly state their objectives and, if possible, outline the key biodiversity issues they are studying. The CLEANED indicators that are linked to biodiversity focus on 'wild' biodiversity rather than agro-biodiversity, and they include the following examples:

- Changes in land requirements and changes in the allocation between semi-natural grazing and planted crops. Both of these indicators are directly linked to potential habitat change.

- Nutrient concentrations such as nitrogen balances, land area with nitrogen leaching, and nitrogen emissions. These indicators can be linked to both detrimental and beneficial farming practices, such as pollution or activities that increase soil fertility.

- GHG emissions and carbon storage. These indicators are part of the biodiversity domain because climate change plays a role in biodiversity.

	Domains					Comparison for Assessment	
Units	Productivity	Water	Land and Soil	Climate Change	Biodiversity	Stocks	Critical Value
Indicators							
kg of Fat and Protein Corrected Milk (FPCM)	x						x
kg of FPCM/ha	x						x
kg of meat/ha	x						x
kg of protein/ha	x						x
ha of land for feed production			x		x	x	
ha/kg FPCM			x		x		x
Soil loss (kg)			x				x
Soil loss (kg/ha)			x				x
Soil loss (kg/kg FPCM)			x				x
Soil nitrogen balance (kg nitrogen)			x	x	x		x
Soil nitrogen balance (kg nitrogen/ha)			x	x	x		x
Soil nitrogen balance (kg nitrogen/kg FPCM)			x	x	x		x
% of feed production area with nitrogen leaching			x		x		x
% of feed production area with nitrogen mining			x		x		x
Water use (m^3)		x				x	
Water use (m^3/ha)		x					x
Water use (m^3/kg FPCM)		x					x
Water use (m^3/kg protein)		x					x
Water use (% of annual rainfall)		x			x		x
Enteric fermentation-Methane (kg CH4/ha)				x			x
Manure-Methane (kg CH4/ha)				x			x
Manure-Direct N2O (kg N2O/ha)				x			x
Manure-Indirect N2O (kg N2O/ha)				x			x
Soil-Direct N2O (kg N2O/ha)				x	x		x
Soil-Indirect N2O (kg N2O/ha)				x	x		x
OFF-Farm Soil-Direct N2O (kg N2O/ha)				x	x		x
OFF-Farm Soil-Indirect N2O (kg N2O/ha)				x	x		x
Burning (kg - CO2e/ha)				x			x
Rice production-Methane (kg CH4/ha)				x			x
Total GHGe (CO2e)				x			x
Total GHGe (CO2e/ha)				x			x
Total GHGe (CO2e/kg product)				x			x
Carbon stock change (CO2e/ha)				x	x		x

Table 1. Table of domains and indicators

Note: *GHGe* = greenhouse gas equivalent; CH_4 = methane; N_2O = nitrous oxide; CO_2e = carbon dioxide equivalent.

To generate a wide range of benchmark values, results can be obtained from global, spatially explicit modelling exercises using Global Information System (GIS) for the unit of interest, for example the study country, study sites, specific enterprises, or other global units (Robinson et al. 2011, Alexandratos and Bruinsma 2012). Various data are of interest: Firstly, minimum and maximum values that serve as a proxy for best practices; secondly, average values; and thirdly, percentiles. These data facilitate the application of the outputs from environmental impact assessments carried out by the user to infer efficiency at a broader scale, such as on the level of countries, agroclimatic zones, or production systems.

Assigning sustainability values to outputs (step iii)

As a next step, benchmarking needs to assign sustainability scores to the output of the model. The aim of this step of the process is to assign a value of -1, 0, or +1 to each indicator: -1 represents low sustainability and +1 represents high sustainability. Depending on the domain, the user may seek to assess efficiency by comparing against a mean, a percentile, or a minimum or maximum value. When comparing against a mean value, the user's enterprise will be designated low efficiency (-) if the CLEANED result falls below the benchmark's mean value and high efficiency (+) if the result falls above the mean value. When comparing against a percentile, the enterprise is considered inefficient when the CLEANED result falls below the set percentile that the benchmark considers efficient. Within the benchmarking framework, this value is set at the tercile level in order to ensure consistency (Karandish et al. 2018). For instance, if the user's CLEANED value falls below the lower tercile, then the enterprise will be considered efficient. If the CLEANED value falls above the higher tercile, then the enterprise will be considered inefficient. When comparing against minimum and maximum values, the enterprise will be considered inefficient if the CLEANED value falls above the benchmark's maximum value, and efficient if the CLEANED value falls below the benchmark's minimum value. The range between the minimum and maximum values can be considered an acceptable efficiency range. Comparing values against natural resource stocks is slightly different, because the enterprise is defined as efficient if its CLEANED value falls below the total or a defined percentage of stocks available. This comparison method requires an additional comparison with the productivity domain's indicators.

Assigning weights and aggregating overall score (steps iv and v)

Once the indicators have been assessed, they can help estimate an enterprise's environmental impact across more than one domain. For instance, the indicators of soil health, land used for feed, total water allocated to feed production, and GHG emissions can be used to assess the domains of water, soil and land, climate change, and biodiversity.

A weighted average of the indicators can help a user assess a domain. For instance, if an enterprise's soil erosion, nitrogen balance, and land requirement indicators are all valued as highly efficient, then the enterprise's soil and land domain could also be described as highly efficient. An assessment of the biodiversity domain would follow a similar process. The various indicators are first estimated separately, then the domain's overall efficiency is determined by the weights assigned to each indicator. The weights can be assigned by coefficients that are designated to each domain or indicator (Alkemade et al. 2009, Alkemade et al. 2013, Teillard et al. 2016). An alternative approach could be to express the domain's overall environmental footprint as the ratio of indicators that are considered inefficient to the total number of indicators in the domain.


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3. Conclusions

The benchmarking framework is a first steps towards allowing CLEANED users to assess the sustainability of livestock enterprises by providing a basis for users to arrive at informed conclusions on how to meet standards. This framework has also necessitated a vigorous assessment of the CLEANED model's data needs and user interface, which justifies an assessment of and potential improvements to the tool that will help CLEANED reach a broader audience.

The main gap in this process is the lack of a consistent approach to assess an enterprise's efficiency. More specifically, the following issues arise when developing benchmarks for various indicators:

1. Scarcity of available research on important indicators hinders the development of a database and makes it difficult to set benchmarks.
2. Most benchmarks are very well established in business or corporate environments. However, very few benchmarks exist in agriculture. Benchmarks are especially lacking in the livestock sector (Mekonnen and Hoekstra 2012). Data often requires processing in order to be useful in setting benchmarks. While data from crop analyses can often be directly used as general benchmarks, this is not the case for livestock (Chukalla et al. 2018, Zhuo et al. 2019, Mekonnen et al. 2020).
3. The scale of the CLEANED model's analyses may be difficult to merge with global or regional analyses that provide values that can be used as benchmarks.
4. Within existing, relevant literature, it is often difficult to obtain the datasets used for the publications without further efforts. Researchers can seek direct contact with authors to track data that has been recorded in formats that are compatible with the minimum-data calculations of CLEANED, but this is time-consuming.
5. CLEANED uses units to measure and assess indicators that may differ from the units found in literature.

Next steps to improve and operationalize the CLEANED benchmarking framework include the following:

1. Identifying literature with data that can help set benchmarks.
2. Populating the database with this data. This process includes converting the values to appropriate units.
3. Integrating this database with the CLEANED tool.
4. Assessing the success of this integration and its iterations to avoid bottlenecks.
5. Implementing the CLEANED benchmarking assessment as the final output of the CLEANED analysis.

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