FLINT Enteric Fermentation User Guide

Version 1.1

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1. Introduction

1.1. The structure of this document

This document provides:

- a brief overview of emissions from livestock and the modelling of methane emissions from enteric fermentation;
- an overview of the design principals of FLINT and the FLINT Enteric Fermentation model; and
- a step-by-step walkthrough of preparing the input data as well as using FLINT Enteric Fermentation to run simulations and visualize the results.

Section 1 of this document provides an overview of modelling enteric fermentation and the design principals of FLINT Enteric Fermentation. Section 2 provides a quick guide through the main steps necessary for calculating methane emissions with FLINT Enteric Fermentation. Sections 3 to Section 6.8 provide a step-by-step walk-through of all steps from data preparation to visualizing the results. Section 0 gives an overview of the calculation flow and equations used in FLINT Enteric Fermentation.

1.2. Modelling Enteric Fermentation

Methane emissions from enteric fermentation in livestock have a significant impact on climate change. With 3.5 gigatons CO2-eq per annum[1], methane emissions from enteric fermentation in livestock are a globally significant source of greenhouse gas emissions. Methane is produced from natural digestion processes in ruminants (e.g. cattle, sheep, horses, donkeys).

Based on the IPCC 2006 guidelines[2] for emissions from livestock, the FLINT Enteric Fermentation model is driven by the existence of livestock and the digestibility of the energy available to the animals. FLINT Enteric Fermentation calculates monthly methane (CH_4) emissions based on the existence of defined livestock under defined conditions.

In its current version, FLINT Enteric Fermentation can only be used to simulate Tier 2 estimates of methane emissions from enteric fermentation of cattle and buffalo. Other animal classes can be modelled as Tier 1 or Tier 2 with Default emission factors.

Apart from methane from enteric fermentation, livestock production generates additional greenhouse gases which are <u>not</u> calculated by FLINT Enteric Fermentation. These include methane and nitrous oxide (N_2O) from manure management and carbon dioxide (CO_2) from direct energy use (e.g. cooling, ventilation, heating). Additional emissions are generated in upstream processes (feed production, infrastructure) and downstream processes (e.g. transport, refrigeration of products, processing, packaging). According to the IPCC 2006 guidelines, annual net CO_2 emissions by the

[1] FAO, 2020. Global Livestock Environmental Assessment Model (GLEAM): Results. Food and Agriculture Organization of the United Nations. http://www.fao.org/gleam/results/en/ (accessed 19 August 2020).
[2] IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Prepared by the National Greenhouse Gas Inventories Programme, Hayama, Japan, 1 online resource (5 volumes).

animals themselves are assumed to be zero as the CO_2 sequestered by the growth of the fodder plants is returned as respired CO_2.

1.3. FLINT compatibility

The FLINT is a Measurement, Reporting and Verification (MRV) tool for estimating greenhouse gas emissions from the land sector (https://moja.global/). It is an open-source[3] C++ platform which has been developed[4] following several key design principles:

- A flexible and modular structure (model components can be exchanged)
- Ability to produce spatially- and temporally explicit calculations
- Ability to run all three IPCC Tiers and Approaches (allowing for continues improvement)
- Applicable to all land uses and land use changes
- Ability to process large data volumes for fine scale and time-series remote sensing
- Ability to accommodate a range of data products without being tied to any product
- It is policy independent but able to meet policy reporting and scenario analysis requirements
- Configurable interfaces for country specific implementation

The FLINT integrates remote sensing and ground data and allows for the generation of fine resolution time-series data. Its modular design allows for continuous improvement. The FLINT is not restricted to emission reporting but can support multiple objectives for sustainable land-use planning and policy development.

The FLINT controls the simulation and the data integration process. Specific functions are completed in 'modules' which are attached to the FLINT.

FLINT Enteric Fermentation results are generally compatible with the FLINT. However, the current version has not been designed as module that can be attached directly to the FLINT. FLINT Enteric Fermentation it is not a spatially explicit but a spatially referenced model. Outputs of FLINT Enteric Fermentation can be passed to the FLINT based on these spatial references.

Options to design FLINT Enteric Fermentation as a spatially and temporally explicit model are currently explored.

1.4. FLINT Enteric Fermentation design principals

FLINT Enteric Fermentation is designed in a way that minimizes manual data input. The model generally simulates in monthly time steps. For key parameters, data input is only necessary where

[3] The FLINT is managed by moja global, and open-sourced under a Mozilla Public License 2.0 (MPL2.0 licence). This means that the FLINT software is free to be used and modified, but any improvements to the FLINT software must be submitted back to moja global for consideration for inclusion in the FLINT open-source.
[4] Development of the FLINT has been a collaboration between the Canadian Forest Service, the Mullion Group, the Government of Kenya, the Australian Commonwealth Government Department of the Environment and Energy, the Clinton Climate Initiative and several other partners.

changes occur in the timeline. FLINT Enteric Fermentation fills in missing information between two points in time automatically and rolls information forward. While the model runs at monthly time-steps, users can use annual data applied to the month proportioned to a month.

The program can import and export to four different data types: Google Sheets, Microsoft (MS) Excel, SQLite data basis, and Json Files. Importing or exporting data to Google Sheets requires the user to be logged in to a Google account.

2. Quick Guide

A quick overview of the steps necessary for running FLINT Enteric Fermentation is shown in Table 1. The table also includes links to the respective sections of this guide for further information.

Table 1 A quick guide for operating FLINT Enteric Fermentation.

Steps:	Option 1: **Google Sheets** as input/output* data	Option 2: **MS Excel** as input/output* data	Option 3: **SQLite Data Base** as input/output* data	Option 4: **Json File** as input/output* data
1.	Prepare Data (see Section 6.1)	Prepare Data (see Section 6.2)	Prepare Data (see Section 6.3)	Prepare Data (see Section 6.4)
2.	not necessary	not necessary	Install SQLite Studio (see Section 3)	not necessary
3.	Start Program (see Section 4)	Start Program (see Section 4)	Start Program (see Section 4)	Start Program (see Section 4)
4.	Type address 'localhost:8080' in browser (see Section 4)	Type address 'localhost:8080' in browser (see Section 4)	Type address 'localhost:8080' in browser (see Section 4)	Type address 'localhost:8080' in browser (see Section 4)
5.	Login with Google (see Section 4.2)	Login with(out) Google (see Section 4.1)	Login with(out) Google (see Section 4.1)	Login with(out) Google (see Section 4.1)
6.	Select data (see Section 6.5)	Load data from MS Excel (see Section 6.5)	Load data from data base (see Section 6.5)	Load data from json (see Section 6.5)
7.	Run the simulation (see Section 6.6)	Run the simulation (see Section 6.6)	Run the simulation (see Section 6.6)	Run the simulation (see Section 6.6)
8.	Save Results (see Section 6.7)	Save Results (see Section 6.7)	Save Results (see Section 6.7)	Save Results (see Section 6.7)
9.	Data Visualization (see Section 6.8)	Data Visualization (see Section 6.8)	Data Visualization (see Section 6.8)	Data Visualization (see Section 6.8)

* Here it is assumed that the same format is used for input and output. However, it is possible to export the data in a different format than the one used for the data input. Exporting data to a Google sheet requires the user to be logged in with Google (Step 5). Exporting data as SQLite data base requires the installation of SQLite Studio (Step 2).

3. Installing SQLiteStudio

FLINT Enteric Fermentation can import from and export to SQLite data bases, json files and Google Sheets and MS Excel. If you would like to exchange data with an SQLite data base, SQLiteStudio (https://sqlitestudio.pl/) will have to be installed before FLINT Enteric Fermentation is started. Please make sure that you install the 'installer' version and not the 'portable' version of SQLiteStudio (Figure 1).

SQLite can be downloaded from the SQLiteStudio webpage (https://sqlitestudio.pl/). Click on 'Download' on the upper right menu of the SQLiteStudio webpage. This will lead you to the GitHub (https://github.com/pawelsalawa/sqlitestudio/releases) from where you can download the installer versions that fits your system.

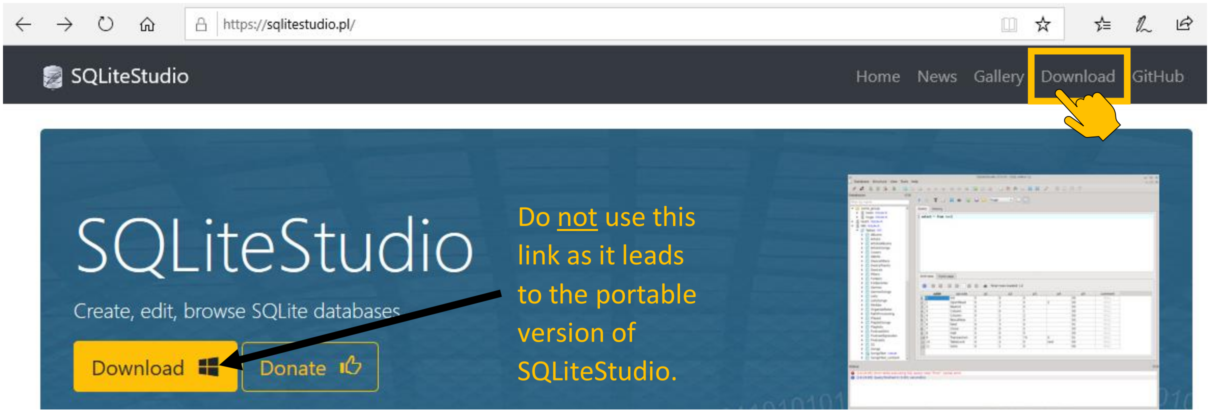


Figure 1 Downloading the installer version of SQLite Studio.

4. Starting FLINT Enteric Fermentation

No installation is required but two subsequent steps are necessary for starting the FLINT Enteric Fermentation program:

First, click on the go-website-windows application icon (for Windows user) or the go-website-linux application icon (for Linux user). A command prompt (Windows) or a Shell Prompt (Linux) will open up which must not be closed by the user (Figure 2).

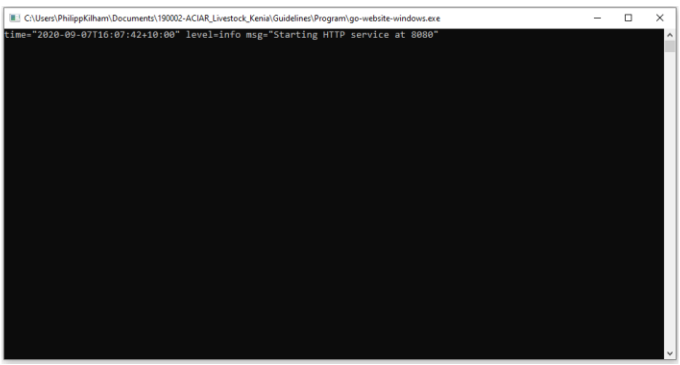


Figure 2 The FLINT Enteric Fermentation command prompt should not be closed (Windows example)

Second, open an internet browser (Google Chrome does not work for this application) and enter 'localhost:8080' into the address bar (URL bar) (Figure 3).

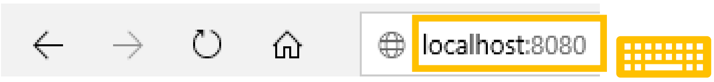


Figure 3 Entering 'localhost:8080' into the address bar.

A welcome window appears in the browser window (Figure 4), and you are offered two options:

a. Login without Google
b. Login with Google

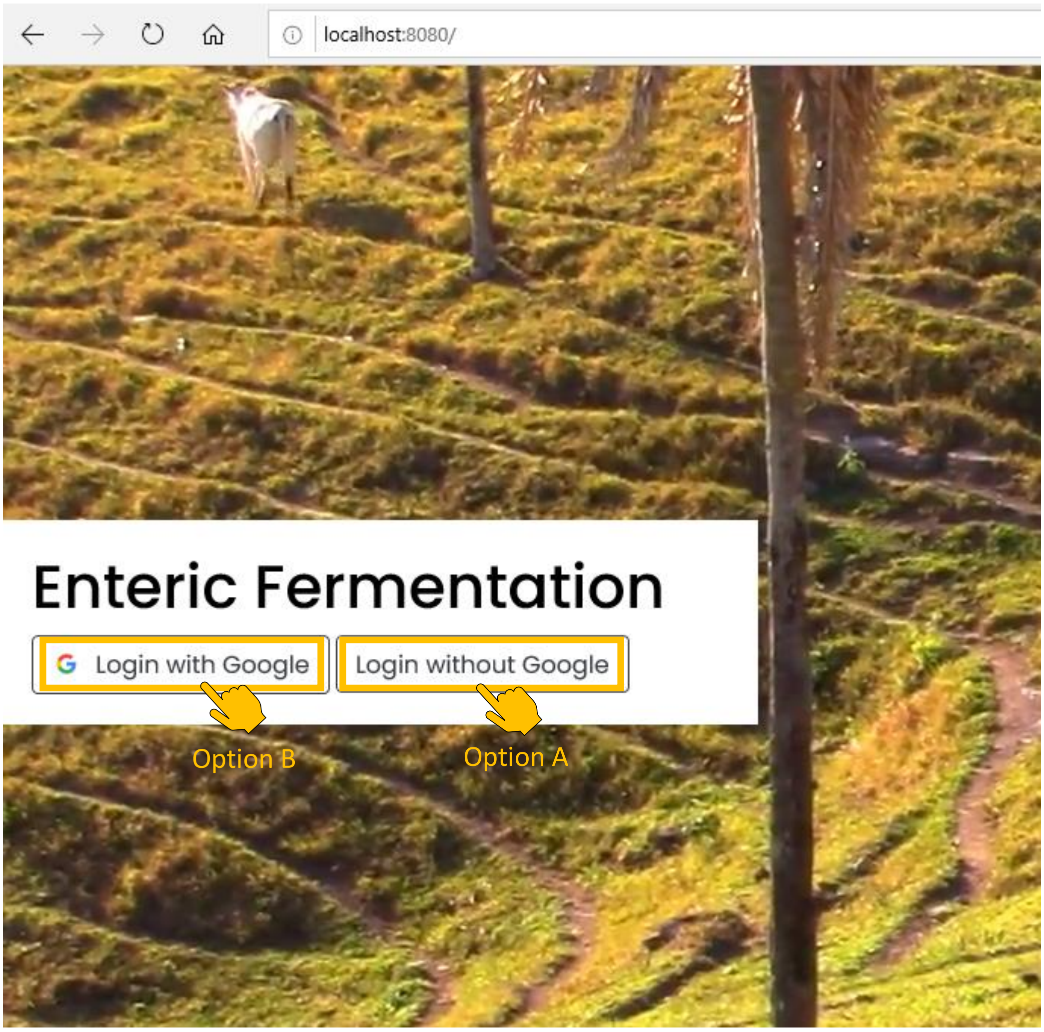


Figure 4 The welcome window with login options.

4.1. Option A: Login without Google

When you choose to login without Google you will be taken directly to the start page of the FLINT Enteric Fermentation interface (you can continue with Section 5, Overview of the FLINT Enteric Fermentation interface). By choosing this option, you will be able to import data from and export data to MS Excel, to an *SQLite* data base and/or to a *json* file. You will not be able to import from and export to Google Sheets. To be able to work with Google Sheets, you must choose 'login with Google' (Option B).

4.2. Option B: Login with Google

If you click on 'Login with Google' you will be asked to enter your Google related email address (Figure 5). Click 'Next' and enter the according password. Click 'Next'.

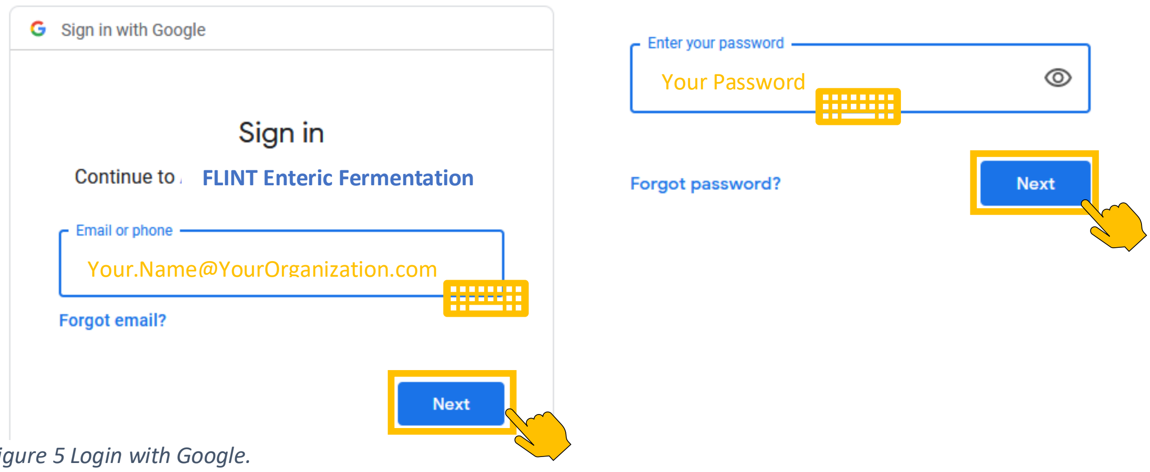


Figure 5 Login with Google.

It is possible that the following warning appears (Figure 6):

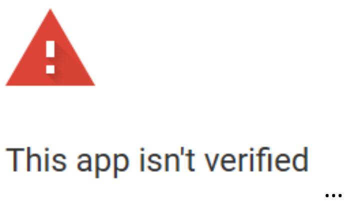


Figure 6 Possible 'App isn't verified' warning during the login with Google.

You can accept to open FLINT Enteric Fermentation under the 'Advanced' option. The detailed procedure is described in the Appendix (Section 8).

5. Overview of the FLINT Enteric Fermentation interface

The start page of FLINT Enteric Fermentation (Figure 7) offers four ways to load data: (a) From an MS Excel File, (b) From a SQLite data base, (c) from a Json file, and (d) from Google Sheets. In the case that you have logged in with Google (see Section 4.2 Option B: Login with Google), all Google Sheets available from your account will be listed in the light grey area in the centre of the screen.

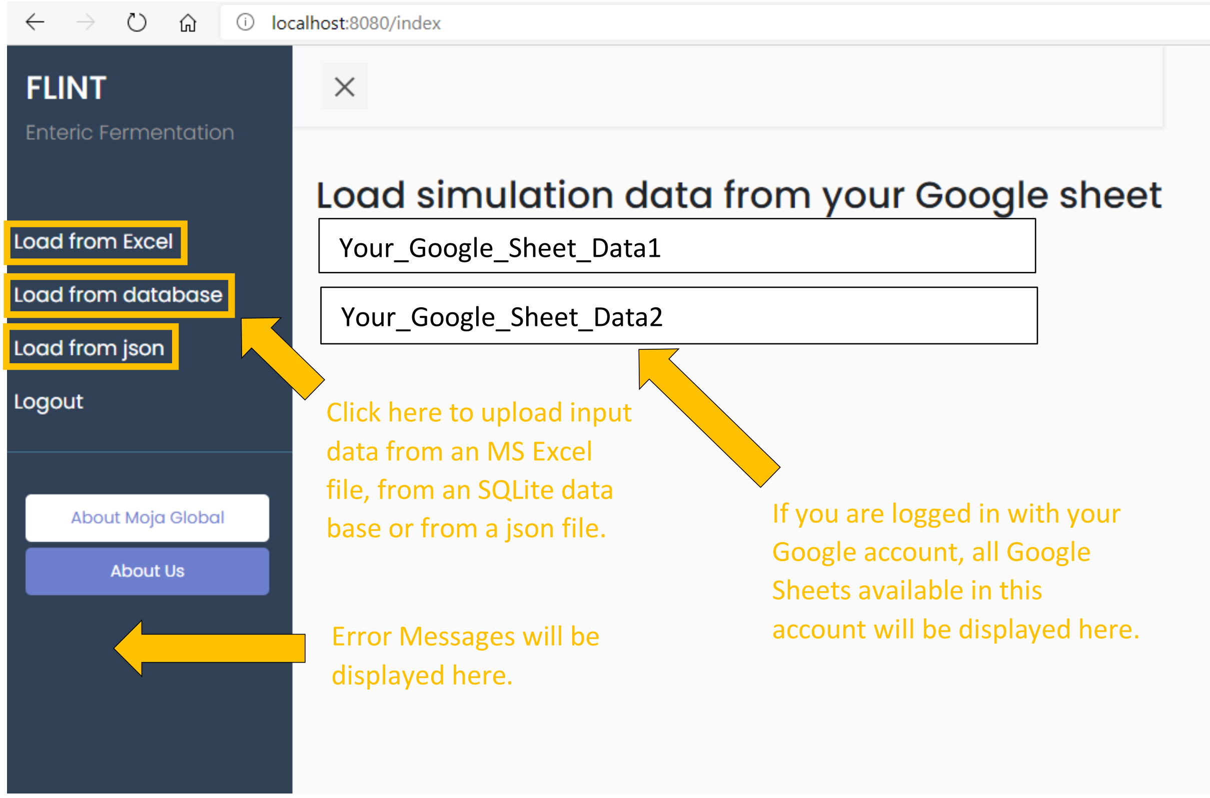


Figure 7 The initial FLINT Enteric Fermentation interface and additional information.

6. Setting up the data

Input data can be setup in three different formats:

a. Google Sheet
b. MS Excel
c. Database
d. Json

Each data type consists of seven tables (data sheets) storing specific information:

- Settings
- Systems
- Location
- Animal Class
- Temperature Location
- Animal Numbers
- Enteric Fermentation Parameters

Slightly different names are used for the different table types in the three data formats (Table 2).

Table 2 Input table types and the respective naming for the four different data formats.

Tables	**Table naming in the different data formats**		
	Google Sheets and MS Excel	**SQLite Data Base**	**Json**
Settings	Settings	setting_data_items	setting_data
Systems	Systems	system_data_items	system_data
Location	Location	location_data_items	location_data
Animal Class	AnimalClass	animal_class_data_itmes	animal_class_data
Temperature Location	TemperatureLocation	temperature_location_items	temperature_location_data
Animal Numbers	AnimalNumbers	animal_number_data	animal_number_data
Enteric Fermentation Parameters	EntericFermEFParameters	Enteric_ferm_ef_parameter_items	enteric_ferm_emission_factor_parameter_data

In the following chapters, the different data format and the different data fields of the different input tables are described in more detail.

6.1. Setting up the data as Google Sheets

In Google Sheets, the different tables are arranged in data sheets (Figure 8). It is important that the specific spelling is maintained (e.g. 'AnimalClass' <u>not</u> 'animalclass' or 'Animal Class').

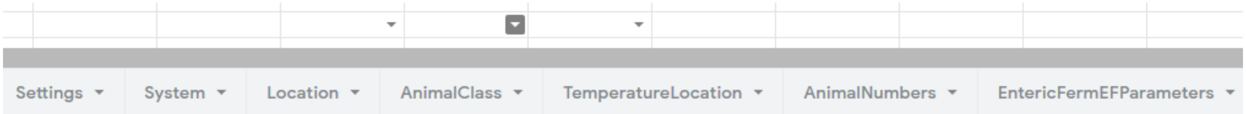


Figure 8 The seven input tables as data sheets in Google Sheets.

The easiest way to set up the Google Sheet for FLINT Enteric Fermentation is to download the pre-designed Google Sheet here. You will not be able to apply changes to the linked Google Sheet directly. To be able to apply changes proceed as follows:

1. Login to your Google Account (blue 'Sign in' button in the top right corner of the Google Sheet).
2. Under 'File', select 'Make a copy'
3. Rename the Google Sheet in the pop-up window

Once you have followed these steps, you can enter the information specific to your simulation.

A beginners guide for Google Sheets including an instruction of how to create and rename spread sheets can be found here.

6.1.1. The Settings Table in Google Sheets

The 'Settings' Table includes general information about the simulation in simple name/value pairs (Table 3). Options are limited to what the system will recognise.

Note that the entry for 'Start Date' has currently no effect on the start date of the simulation. Instead, the start date of the simulation is determined by the earliest date entered in the 'Enteric Fermentation Parameters' table (see Section 6.5). In contrast, the entry for 'End Date' determines the end of the simulation. It is possible that the end date determined in the Settings Table is beyond the latest data entry in one of the date specific tables ('Temperature Location', 'Animal Numbers', 'Enteric Fermentation Parameters'). In this case, the latest data entry included in these tables will be rolled forward to the 'End Date' determined in the 'Settings' table (see Section 6.5).

Table 3 Information related to the Settings Table in Google Sheets. (information in blue is not included in the actual Table)

Setting	**Value** **(Example)**	**Description**	**Format**
Start Date	1/1/1995	Start date of the simulation including day, month and year	DD/MM/YYYY or D/M/YYYY
End Date	31/12/2020	End date of the simulation including day, month and year	DD/MM/YYYY or D/M/YYYY
Run Identifier	Test run 01	An identifier of the run for later recognition.	Normal text
Run Description	Testing the system data loading	A description of the run.	Normal text

In Google Sheets, the Settings Table is set up in a data sheet named ‘Settings’ (see Figure 8). The specific arrangement of the table is shown in Figure 9. It is important that the displayed arrangement is maintained (e.g. Start Date in Column A, Row 5).

	A	B	C
1	**Settings**		
2	**Replace values in the blue fields with values specific to your simulation.**		
3	Options for settings are limited to what the system will recognise.		
4	**Setting**	**Value**	
5	Start Date	1/1/1995	
6	End Date	31/12/2000	
7	Run Identifier	Test run 01	
8	Run Description	Testing the system data loading	
9			
10			

Figure 9 The Settings Table in Google Sheets.

6.1.2. The Systems Table in Google Sheets

In the ‘Systems’ Table, livestock systems are named and connected to an identifier (ID) (Table 4).

Table 4 Information related to the Systems Table in Google Sheets. (information in blue is not included in the actual Table)

Column	**Entry Example**	**Description**	**Format**
ID	1	Identifier for the System	Integer
System Name	Intensive System	A meaningful name for the system.	Normal text

In Google Sheets, the Settings Table is set up in a data sheet named ‘Settings’ (see Figure 8). The specific arrangement of the table is shown in Figure 10. It is important that the displayed arrangement is maintained (e.g. the first ID should be displayed in Column A, Row 5).

	A	B	C	D
1	System			
2	Replace values in the blue fields with values specific to your simulation.			
3	You can add additional IDs.			
4	ID	System Name		
5	1	Intensive System		
6	2	Semi-intensive system		
7	3	Extensive Sytem		
8				

Figure 10 The Systems Table in Google Sheets.

6.1.3. The Location Table in Google Sheets

In the ‘Location’ Table, locations are named and connected to an identifier (ID) (Table 5).

Table 5 Information related to the Location Table in Google Sheets.
(information in blue is not included in the actual Table)

Column	Entry Example	Description	Format
ID	1	Identifier for location	Integer
Location Name	Kenya	A meaningful name for the location.	Normal text

In Google Sheets, the Location Table is set up in a data sheet named ‘Location’ (see Figure 8). The specific arrangement of the table is shown in Figure 11. It is important that the displayed arrangement is maintained (e.g. the first ID should be displayed in Column A, Row 5).

	A	B	C	D	E
1	Location				
2	Replace values in the blue fields with values specific to your simulation.				
3	You can add additional IDs.				
4	ID	Location Name			
5	1	Location A			
6					

Figure 11 The Location Table in Google Sheets.

6.1.4. The Animal Class Table in Google Sheets

In the ‘Animal Class’ Table, livestock classes are named and connected to an identifier (ID) and a emission factor (Default EF) (Table 6).

The ‘Default EF’ is only used when the calculated emission factor is ≤0.

Table 6 Information related to the Animal Class Table in Google Sheets.
(information in blue is not included in the actual Table)

Column	Entry Example	Description	Format
ID	1	Identifier for the animal class	Integer
Parent Class	Ruminant	The name of a category	Normal text
Animal Class Name	Mature Cow	The name of the animal class	Normal text
Default EF	100	An emission factor in kg CH_4 head^{-1} year^{-1}	floating-point number

In Google Sheets, the Animal Class Table is set up in a data sheet named ‘AnimalClass’ (see Figure 8). The specific arrangement of the table is shown in Figure 12. It is important that the displayed arrangement is maintained (e.g. the first ID should be displayed in Column A, Row 5).

	A	B	C	D	E
1	Animal Class				
2	Replace values in the blue fields with values specific to your simulation.				
3	You can add additional IDs.		in Kg CH4 per head and year (used when calculated EF is =< 0)		
4	ID	Parent Class	Animal Class Na	Default EF	
5	1	Ruminant	Mature Cow	128	
6	2	Ruminant	Heifers	53	
7	3	Ruminant	Mature Males	53	
8	4	Ruminant	Growing Males	53	
9	5	Ruminant	Calves	53	
10					

Figure 12 The Animal Class Table in Google Sheets.

6.1.5. The Temperature Location Table in Google Sheets

In the ‘Temperature Location’ Table, average temperature values are linked to specific regions and dates (

Table 7). Instead of specifying an average temperature for each month, it is possible to indicate an average annual temperature. In this case, only one entry per year is needed and the value for 'Month' must be set to '1'.

Table 7 Information related to the Temperature Location table in Google Sheets. (information in blue is not included in the actual Table)

Column	Entry Example	Description	Format
ID	1	The Identifier for the entry.	Integer
Location	Kenya	The name of the location to which the Average Temperature relates.	Normal Text
Year	1990	Year to which the Average Temperature relates.	YYYY
Month	1	Number of the Month (1-12) to which the Average Temperature relates.	Integer (1-12)
Average Temp Winter Season	20.4	Mean daily temperature during winter season in °C. The value 20 can be used for regions without winter season.	Positive or negative floating-point number

In Google Sheets, the Temperature Location Table is set up in a data sheet named 'TemperatureLocation' (see Figure 8). The specific arrangement of the table is shown in Figure 13. It is important that the displayed arrangement is maintained (e.g. the first ID should be displayed in Column A, Row 5).

The 'Mean Winter Temperature' variable influences the conversion of the coefficient for calculating net energy for maintenance (CF) which is specified in the 'Enteric Fermentation Parameters' Table (

Table 9). For regions without defined winter season, all 'Average Temp Winter Season' values can be set to 20. In this case, the original CF will not be modified (see Equation 2 Section 7). For regions with defined winter periods, the value should be the same for each month of a specific year.

Let us take an example: A country has a winter season lasting from the 1st of November to the 28th of February. In this case the average temperature during winter is the average daily temperature for January, February, November, and December (e.g. 5°C in 1990 and 4.6°C in 1991). This same temperature must be entered for all moths of the respective year. Months 1-12 of the year 1990 would have 5°C as value and months 1-12 of the year 1991 would have 4.6°C as value.

Energy for maintenance requirements can change during the year due to temperature changes. In its current version, FLINT Enteric Fermentation does not account for this effect month by month (e.g. energy for maintenance requirements higher in winter season). Instead, the effect is applied as an annual average as suggested in the IPCC 2006 document (energy for maintenance requirements generally higher in countries with winter seasons).

	A	B	C	D	E
1	**Temperature Location**				
2	Replace values in the blue fields with values specific to your simulation.				
3	You can add additional IDs.	As specified in the field 'Location Name' in the 'Location' sheet.			Mean daily temperature during winter season. The value 20 can be used for regions without winter season.
4	ID	Location	Year	Month	Average Temp Winter Season
5	1	Location A	1990	1	20
6	2	Location A	1990	2	20
7					

Figure 13 The Temperature Location Table in Google Sheets.

6.1.6. The Animal Numbers Table in Google Sheets

In the 'Animal Numbers' Table, animal numbers are linked to specific animal classes on specific locations at a certain point in time (

Table 8). If two rows contain the same values for ID, Location, System, Animal Class, Year, and Month but a different entry for Animal Number, the program will use the second entry for the calculation. Please, check your data for duplicates.

Table 8 Information related to the Animal Numbers Table in Google Sheets.
(information in blue is not included in the actual Table)

Column	Entry Example	Description	Format
ID	1	Identifier of the entry	Integer
Location	Kenya	The name of the location	Exact spelling as in the respective Location table.
System	Intensive	The name of the location	Exact spelling as in the respective Systems table.

Animal Class	Mature Cow	The name of the animal class	Exact spelling as in the respective Animal Class table.
Year	1990	Year to which the Average Temperature relates.	YYYY
Month	1	Number of the Month (1-12) to which the Average Temperature relates.	Integer (1-12) or 0. If set to 0, Annual numbers apply to whole year. If the value is not indicated for a specific month, the system automatically applies the data from the last available data point.
Animal Number	402698.0092	Number of individuals.	Integer or floating-point number

In Google Sheets, the Animal Numbers Table is set up in a data sheet named ‘AnimalNumbers’ (see Figure 8). The specific arrangement of the table is shown in Figure 14. It is important that the displayed arrangement is maintained (e.g. the first ID should be displayed in Column A, Row 5).

	A	B	C	D	E	F	G
1	**Animal Numbers**						
2	Replace values in the blue fields with values specific to your simulation. You can add values beyond the exte						
3	You can add additional IDs.	As specified in the field 'Location Name' in the 'Location' sheet.	As specified in the field 'System Name' in the 'System' sheet.	As specified in the field 'Animal Class Name' in the 'AnimalClass' sheet.		If 0, annual number apply to whole year. Otherwise, specify for each month.	Floating point number, no thousands marker (no comma).
4	**ID**	**Location**	**System**	**Animal Class**	**Year**	**Month**	**Animal Number**
5	1	Location A	Intensive System	Mature Cow	1995	0	402698.0092
6	2	Location A	Intensive System	Mature Cow	1996	0	457325.5167
7	3	Location A	Intensive System	Mature Cow	1997	0	422974.2155
8	4	Location A	Intensive System	Mature Cow	1998	0	464520.7159
9	5	Location A	Intensive System	Mature Cow	1999	0	462094.2127

Figure 14 The Animal Numbers Table in Google Sheets.

6.1.7. The EF Parameters Table in Google Sheets

In the ‘Enteric Fermentation Parameters’ Table, parameters necessary to simulate methane emissions from enteric fermentation are linked to specific animal classes on specific locations in a specific system at a certain point in time (

Table 9).

Table 9 Information related to the Enteric Fermentation Parameters Table in Google Sheets. (information in blue is not included in the actual table)

Column	Entry Example	Description	Format
ID	1	Identifier of the entry	Integer
Year	1995	Year to which the entry relates. Data will be filled out where there are gaps in the data (i.e. a record will be carried forward)	YYYY
Month	1	Number of the Month (1-12) to which the entry relates.	Integer (1-12)
Location	Kenya	The name of the location to which the entry relates.	Exact spelling as in the respective Location table.
System	Intensive	The name of the system to which the entry relates.	Exact spelling as in the respective Systems table.
Animal Class	Mature Cow	The name of the animal class to which the entry relates.	Exact spelling as in the respective Animal Class table.
Body Weight (by month)	354.1021064	The current average body weight for the animal class (kg)	floating-point number
Mature Weight	361.1076842	Weight of an average mature individual of the animal class (kg)	floating-point number
Daily Weight Gain	0.016522589	The average daily body weight gain for the animal class (kg)	floating-point number
Fraction of Month Alive	1	Fraction of the month the animals are alive.	0-1
CF	0.36232	Coefficient for calculating net energy for maintenance (MJ d-1 kg-1) (Table 10.4 in IPCC 2006 Chapter 10)	floating-point number
C	0.8	a coefficient with a value of e.g. 0.8 for females, 1.0 for castrates and 1.2 for bulls (Table 10.6 in IPCC 2006 Chapter 10)	floating-point number
Ca	0.03	Coefficient corresponding to animal's feeding situation	floating-point number
Milk Production	6.169739322	Milk per cow per day (kg). Represents the production of a lactating animal in this class, NOT adjusted by the number of animals that are producing milk.	floating-point number
Fat Content (%)	4	Fat content of the milk (%)	floating-point number
CPregnancy	0.1	Pregnancy coefficient (Table 10.3 in IPCC 2006 Chapter 10).	floating-point number
Proportion Animal Class Pregnant	0.63	Proportion Animal Class Pregnant	floating-point number
Proportion of Animal Class lactating	0.63	Proportion of Animal Class lactating	floating-point number
Fraction of Lactating Days per Month	1	Fraction of Lactating Days per Month	floating-point number between 0 and 1
Hours Worked	0	Number of hours of work per day	floating-point number (0-24)
DE%	59.51961022	Digestible energy expressed as a percentage of gross energy (%)	floating-point number
Ym	6.5	Conversion Factor to Methane	floating-point number

In Google Sheets, the Enteric Fermentation Parameters Table is set up in a data sheet named 'EntericFermEFParameters' (see Figure 8). The specific arrangement of the table is shown in Figure 15 a and b. Note that the original table continues from column A to V and is not split up into two tables. It is important that the displayed arrangement is maintained (e.g. the first ID should be displayed in Column A, Row 5).

	A	B	C	D	E	F	G	H	I	J	K
1	**Enteric Fermentation Parameters**										
2	Replace values in the blue fields with values specific to your simulation. You can add values beyond the extend of the blue										
3	You can add addition al IDs.	Data will be filled out where there are gaps in the data (ie. a record will be carried forward).		As specified in the field 'Location Name' in the 'Location' sheet.	As specified in the field 'System Name' in the 'System' sheet.	As specified in the field 'Animal Class Name' in the 'AnimalClass' sheet.	The current average body weight for the animal class (kg).	Weight of an average mature individual of the animal class (kg)	The average daily body weight gain for the animal class (kg)	Fraction of the month the animals are alive.	Coefficient for calculating net energy for maintenance (MJ d-1 kg-1) (Table 10.4 in IPCC 2006 Chapter 10)
4	**ID**	**Year**	**Month**	**Location**	**System**	**Animal Class**	**Body Weight (by month)**	**Mature Weight**	**Daily Weight Gain**	**Fraction of Month Alive**	**CF**
5	1	1995	1	Location A	Intensive System	Mature Cow	354.1000(	361.10768	0.01652	1	0.36232
6											

(a)

continued

K	L	M	N	O	P	Q	R	S	T	U	V
of the blue fields (rows > 200).											
Coefficient for calculating net energy for maintenance (MJ d-1 kg-1) (Table 10.4 in IPCC 2006 Chapter 10)	A coefficient with a value of e.g. 0.8 for females, 1.0 for castrates and 1.2 for bulls (Table 10.6 in IPCC 2006 Chapter 10)	Coefficient correspondin g to animal's feeding situation	Represents the production of a lactating animal in this class, NOT adjusted by the number of animals that are producing milk.	Fat content of the milk (%)	Proportion of cows pregnant (%)				Number of hours of work per day	Digestible energy expressed as a percentage of gross energy (%)	Conversion Factor to Methane
CF	**C**	**Ca**	**Milk Production**	**Fat Content (%)**	**CPregnancy**	**Proportion Animal Class Pregnant**	**Proportion of Animal Class lactating**	**Fraction of Lactating Days per Month**	**Hours Worked**	**DE%**	**Ym**
0.36232	0.80000	0.03	6.16974	4	0.1	0.63	0.63	1	0	59.51961	6.5

(b)

Figure 15 The Enteric Fermentation Parameters Table in Google Sheets.

6.2. Setting up the data in MS Excel

The data formats MS Excel and Google Sheets are interchangeable. For creating the different tables in MS Excel you can follow the methods outlined for Google Sheets outlined in Sections 6.1.1 to 6.1.7

In MS Excel, the different tables are arranged in data sheets (Figure 16). It is important that the specific spelling is maintained (e.g. ‘AnimalClass’ not ‘animalclass’ or ‘Animal Class’).

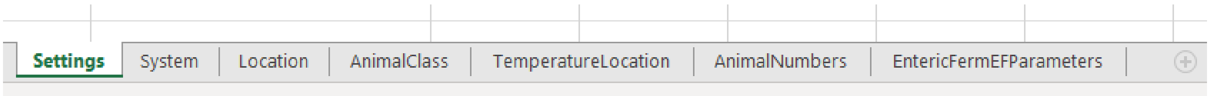


Figure 16 The seven input tables as data sheets in MS Excel.

The easiest way to set up the MS Excel file for FLINT Enteric Fermentation is to download the pre-designed Google Sheet [here](). You can export the file under ‘File’ – ‘Download’ – ‘Microsoft Excel (.xlsx)’

Once you have downloaded the file, you can enter the information specific to your simulation.

6.3. Setting up the data as an SQLite Data Base

In the SQLite data base, the data is arranged in Tables (Figure 17). It is important that the specific spelling is maintained (e.g. ‘animal_class_data_items’).

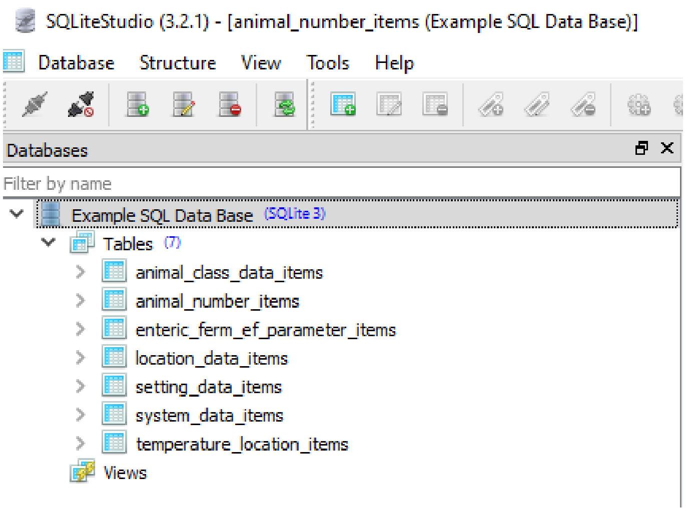


Figure 17 The seven input tables in SQLiteStudio.

6.3.1. The Settings Table in the SQLite Data Base

The Settings table 'setting_data_items' includes general information about the simulation in simple name/value pairs (Table 10). Options are limited to what the system will recognise.

Note that the entry for 'Start Date' has currently no effect on the start date of the simulation. Instead, the start date of the simulation is determined by the earliest date entered in the 'Enteric Fermentation Parameters' table (see Section 6.5). In contrast, the entry for 'End Date' determines the end of the simulation. It is possible that the end date determined in the Settings Table is beyond the latest data entry in one of the date specific tables ('Temperature Location', 'Animal Numbers', 'Enteric Fermentation Parameters'). In this case, the latest data entry included in these tables will be rolled forward to the 'End Date' determined in the 'Settings' table (see Section 6.5).

Table 10 Information related to the Settings table in the SQLite Data Base.
(information in blue is not included in the actual Table)

Setting	**Value (Example)**	**Description**	**Format**
Start Date	1/1/1995	Start date of the simulation including day, month and year	DD/MM/YYYY or D/M/YYYY
End Date	31/12/2020	End date of the simulation including day, month and year	DD/MM/YYYY or D/M/YYYY
Run Identifier	Test run 01	An identifier of the run for later recognition.	Normal text
Run Description	Testing the system data loading	A description of the run.	Normal text

The data structure of the Settings table as an SQLite Data Base in SQLiteStudio is shown in Figure 18. The respective Settings table with example data is shown in Figure 19.

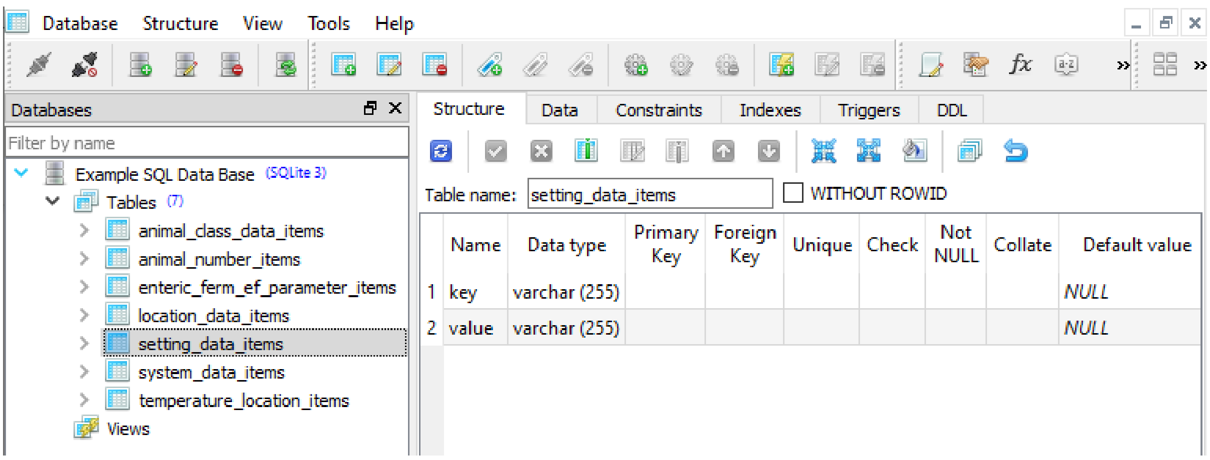


Figure 18 The structure of the Settings Table in SQLiteStudio.

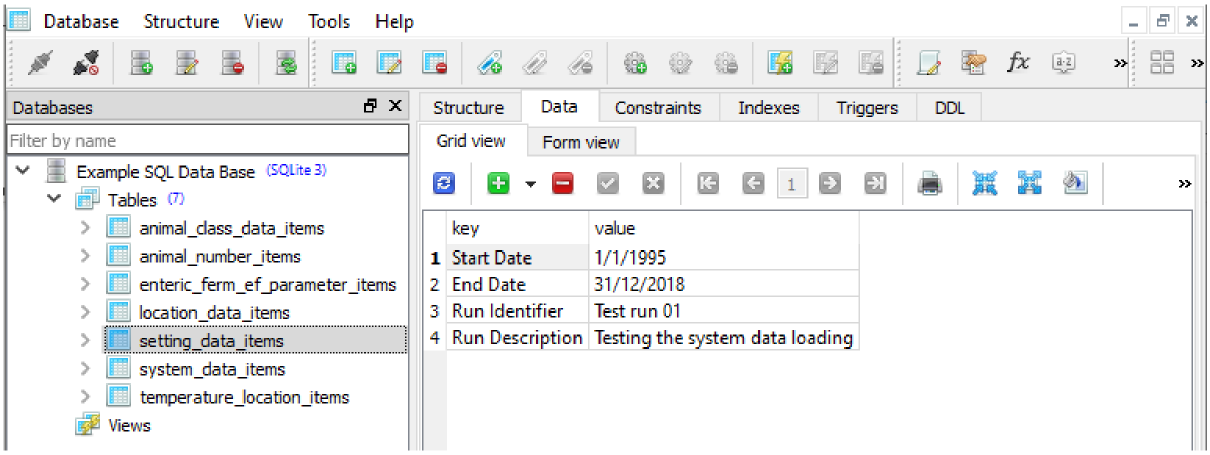


Figure 19 The Settings Table in SQLiteStudio with example data.

6.3.2. The Systems Table in the SQLite Data Base

In the Systems table 'system_data_items', livestock systems are named and connected to an identifier (id) (Table 11).

Table 11 Information related to the Systems table in the SQLite Data Base.
(information in blue is not included in the actual Table)

Column	Entry Example	Description	Format
id	1	Identifier for the System	Integer
name	Intensive System	A meaning full name for the system.	Normal text

The data structure of the Systems table as an SQLite Data Base in SQLiteStudio is shown in Figure 20. The respective Systems table with example data is shown in Figure 21.

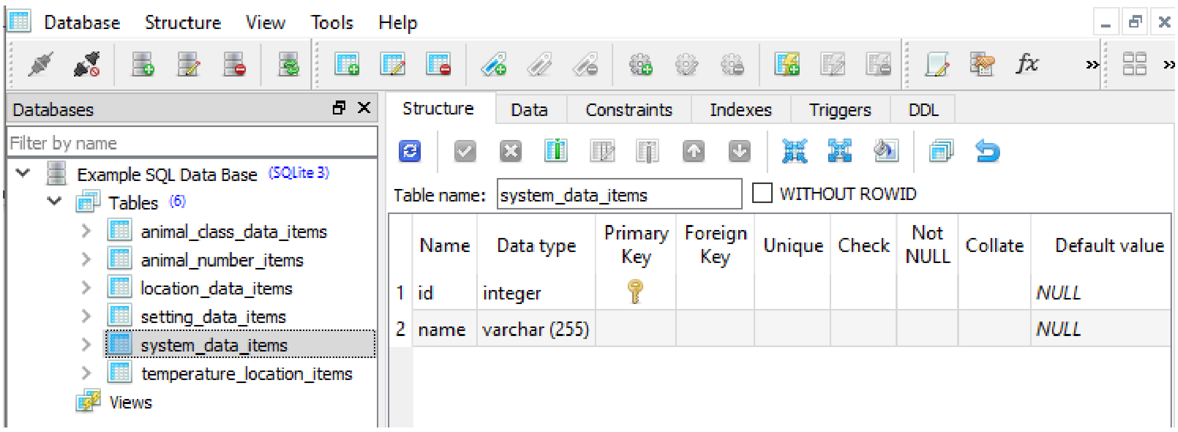


Figure 20 The structure of the Systems Table in SQLiteStudio.

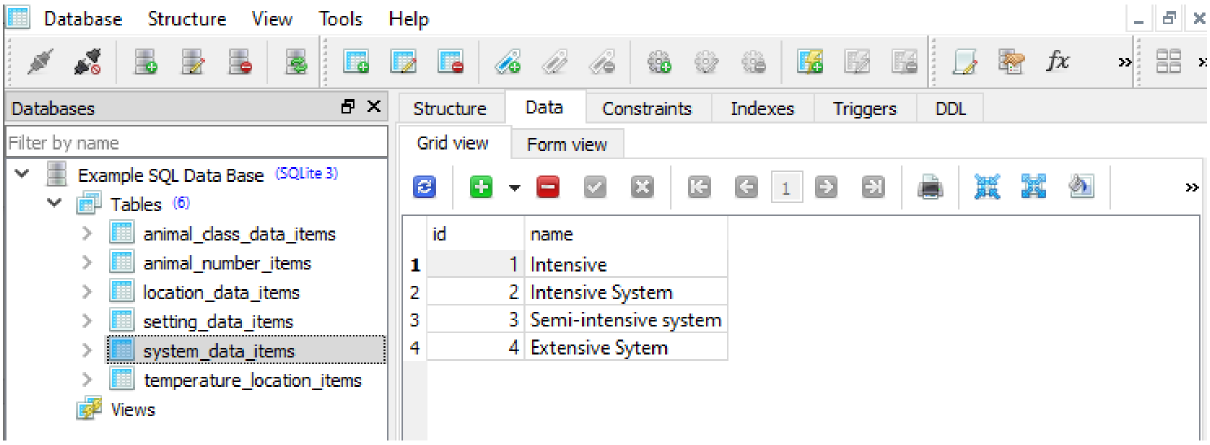


Figure 21 The Systems Table in SQLiteStudio with example data.

6.3.3. The Location Table in the SQLite Data Base

In the Location table 'location_data_items', locations are named and connected to an identifier (id) (Table 12).

Table 12 Information related to the Location table in the SQLite Data Base.
(information in blue is not included in the actual Table)

Column	Entry Example	Description	Format
id	1	Identifier for location	Integer
name	Kenya	A meaning full name for the location.	Normal text

The data structure of the Location table as an SQLite Data Base in SQLiteStudio is shown in Figure 22. The respective Location table with example data is shown in Figure 23.

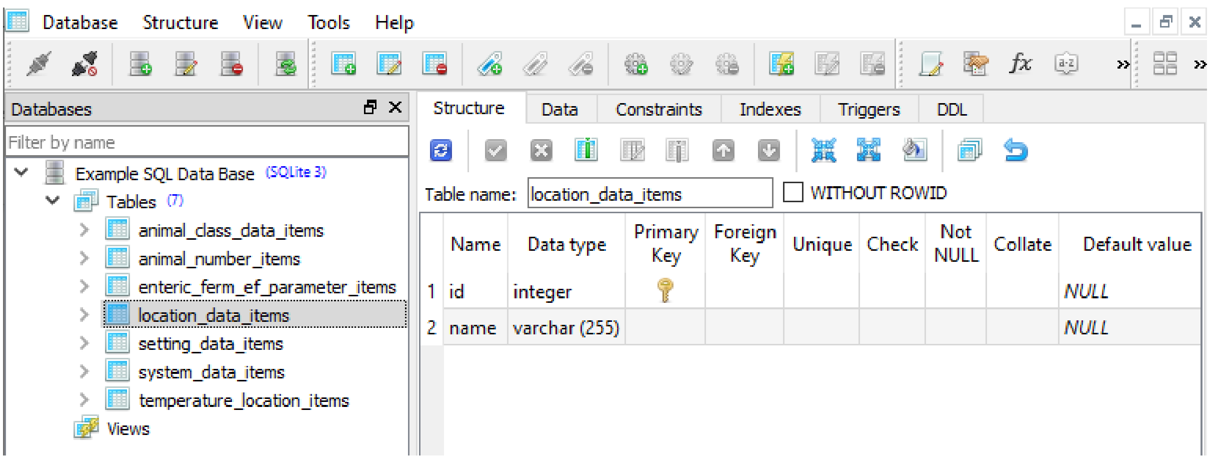


Figure 22 The structure of the Location table in SQLiteStudio.

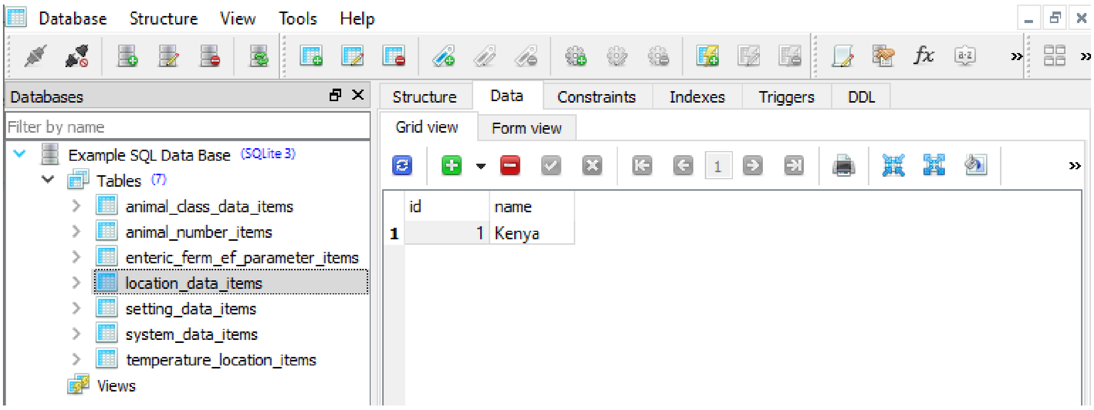


Figure 23 The Location Table in SQLiteStudio with example data.

6.3.4. The Animal Class Table in the SQLite Data Base

In the Animal Class table 'animal_class-data-items', livestock classes are named and connected to an identifier (id) and a default emission factor (default_ef) (Table 13).

The default emission factor is only used when the calculated emission factor is ≤0.

Table 13 Information related to the Animal Class table in the SQLite Data Base. (information in blue is not included in the actual Table)

Column	Entry Example	Description	Format
id	1	Identifier for the animal class	Integer
parent_class	Ruminant	The name of a category	Normal text
name	Mature Cow	The name of the animal class	Normal text
default_ef	100	An emission factor in kg CH_4 head^{-1} year^{-1}	floating-point number

The data structure of the Animal Class table as an SQLite Data Base in SQLiteStudio is shown in Figure 24. The respective Animal Class table with example data is shown in Figure 25.

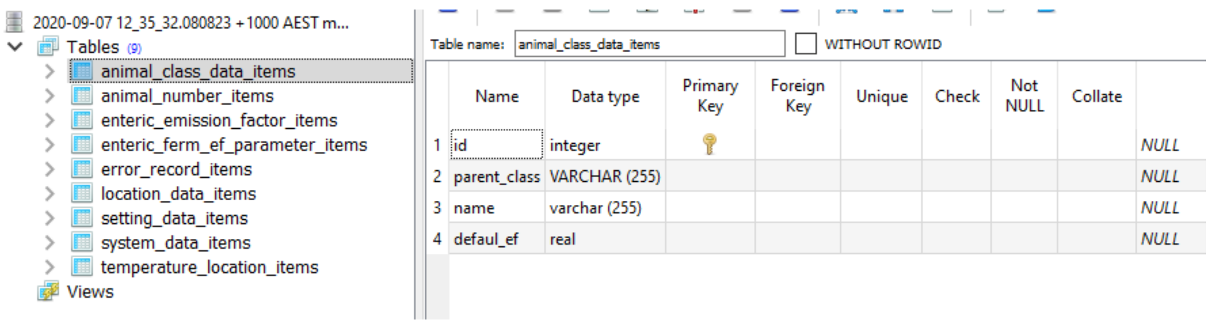


Figure 24 The structure of the Animal Class table in SQLiteStudio.

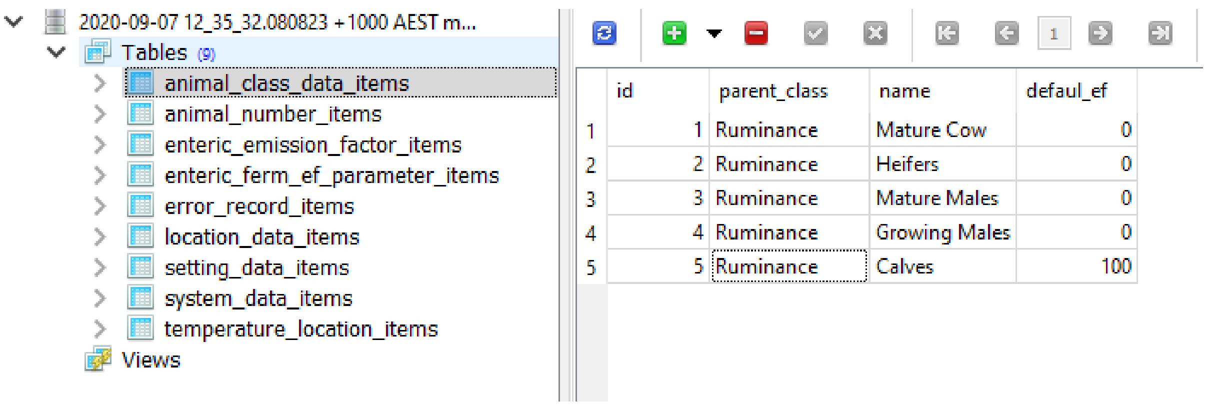


Figure 25 The Animal Class table in SQLiteStudio with example data.

6.3.5. The Temperature Location Table in the SQLite Data Base

In the Temperature Location table ‘temperature_location_items’, average temperature values are linked to specific regions and dates (Table 14). Instead of specifying an average temperature for each month, it is possible to indicate an average annual temperature. In this case, only one entry per year is needed and the value for ‘Month’ must be set to ‘1’.

The ‘avg_temp’ corresponds to the ‘Mean Winter Temperature’ variable in Google Sheets. It influences the conversion of the coefficient for calculating net energy for maintenance (CF) which is specified in the ‘Enteric Fermentation Parameters’ Table (Table 16). For regions without defined winter season, all ‘Average Temp Winter Season’ values can be set to 20. In this case, the original CF will not be modified (see Equation 2 Section 7). For regions with defined winter periods, the value should be the same for each month of a specific year.

Let us take an example: A country has a winter season lasting from the 1st of November to the 28th of February. In this case the average temperature during winter is the average daily temperature for January, February, November, and December (e.g. 5°C in 1990 and 4.6°C in 1991). This same temperature must be entered for all moths of the respective year. Months 1-12 of the year 1990 would have 5°C as value and months 1-12 of the year 1991 would have 4.6°C as value.

Energy for maintenance requirements can change during the year due to temperature changes. In its current version, FLINT Enteric Fermentation does not account for this effect month by month (e.g. energy for maintenance requirements higher in winter season). Instead, the effect is applied as an annual average as suggested in the IPCC 2006 document (energy for maintenance requirements generally higher in countries with winter seasons).

Table 14 Information related to the Temperature Location table in the SQLite Data Base. (information in blue is not included in the actual Table)

Column	Entry Example	Description	Format
id	1	The Identifier for the entry.	Integer
locationid	Kenya	The name of the location to which the Average Temperature relates.	Integer
year	1990	Year to which the Average Temperature relates.	YYYY
month	1	Number of the Month (1-12) to which the Average Temperature relates.	Integer (1-12)
avg_temp	20	Mean daily temperature during winter season in °C. The value 20 can be used for regions without winter season.	Positive or negative floating-point number

The data structure of the Temperature Location table as an SQLite Data Base in SQLiteStudio is shown in Figure 26. The respective Temperature Location table with example data is shown in Figure 27.

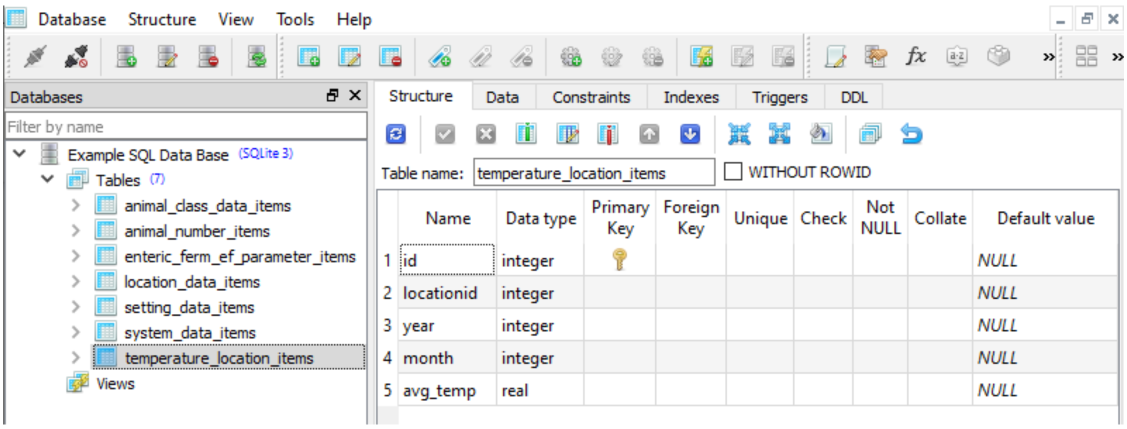


Figure 26 The structure of the Temperature Location Table in SQLiteStudio.

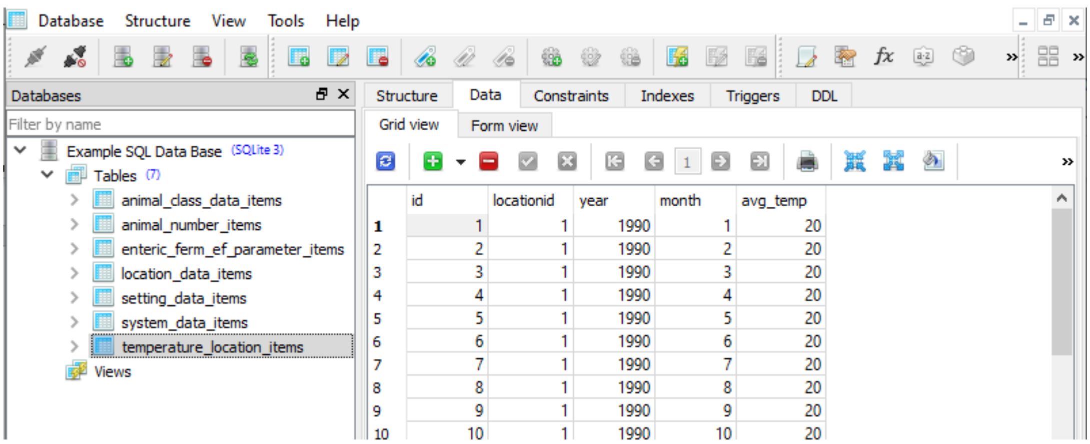


Figure 27 The Temperature Location Table in SQLiteStudio with example data.

6.3.6. The Animal Numbers Table in the SQLite Data Base

In the Animal Numbers table ‘animal_number_items’, animal numbers are linked to specific animal classes on specific locations at a certain point in time (

Table 15). If two rows contain the same values for ID, Location, System, Animal Class, Year, and Month but a different entry for Animal Number, the program will use the second entry for the calculation. Please, check your data for duplicates.

Table 15 Information related to the Animal Numbers Table.
(information in blue is not included in the actual Table)

Column	Entry Example	Description	Format
id	1	Identifier of the entry	Integer
locationid	1	Identifier of the location	Integer
systemid	1	Identifier of the system	Integer
animal_classid	1	Identifier of the animal class	Integer
year	1990	Year to which the Average Temperature relates.	YYYY
month	1	Number of the Month (1-12) to which the Average Temperature relates.	Integer (1-12) or 0. If set to 0, Annual numbers apply to whole year. If the value is not indicated for a specific month, the system automatically applies the data from the last available data point.
animal_number	402698.0092	Number of individuals.	Integer or floating-point number

The data structure of the Animal Numbers table as an SQLite Data Base in SQLiteStudio is shown in Figure 28. The respective Animal Numbers table with example data is shown in Figure 29.

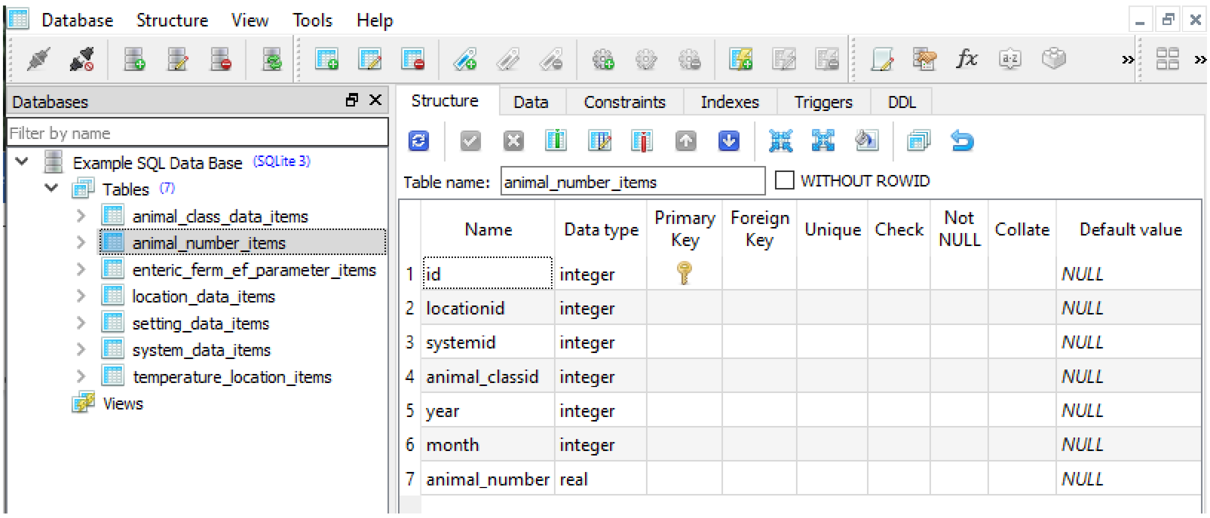


Figure 28 The structure of the Animal Numbers Table in SQLiteStudio.

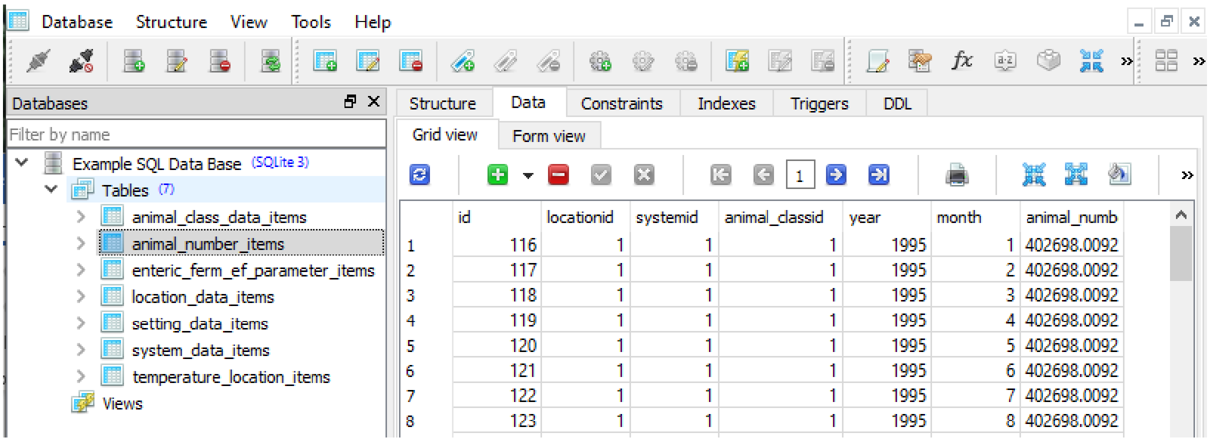


Figure 29 The Animal Numbers Table in SQLiteStudio with example data.

6.3.7. The EF Parameters Table in the SQLite Data Base

In the Enteric Fermentation Parameters table ‘enteric_ferm_ef_parameter_items’, parameters necessary to simulate methane emissions from enteric fermentation are linked to specific animal classes on specific locations in a specific system at a certain point in time (

Table 16).

Table 16 Information related to the Enteric Fermentation Parameters Table in the SQLite Data Base. (information in blue is not included in the actual table)

Column	Entry Example	Description	Format
id	1	Identifier of the entry	Integer
locationid	1	Identifier of the location	Integer
systemid	1	Identifier of the system	Integer
animal_classid	1	Identifier of the animal class	Integer
year	1995	Year to which the entry relates. Data will be filled out where there are gaps in the data (i.e. a record will be carried forward)	YYYY
month	1	Number of the Month (1-12) to which the entry relates.	Integer (1-12)
body_weight	354.1021064	The current average body weight for the animal class (kg)	floating-point number
mature_weight	361.1076842	Weight of an average mature individual of the animal class (kg)	floating-point number
daily_weight_gain	0.016522589	The average daily body weight gain for the animal class (kg)	floating-point number
Fraction_of_month_alive	1	Fraction of the month the animals are alive.	0-1
cf	0.36232	Coefficient for calculating net energy for maintenance (MJ d^{-1} kg^{-1}) (Table 10.4 in IPCC 2006 Chapter 10)	floating-point number
c	0.8	a coefficient with a value of e.g. 0.8 for females, 1.0 for castrates and 1.2 for bulls (Table 10.6 in IPCC 2006 Chapter 10)	floating-point number
ca	0.03	Coefficient corresponding to animal's feeding situation	floating-point number
milk_prod	6.169739322	Milk per cow per day (kg). Represents the production of a lactating animal in this class, NOT adjusted by the number of animals that are producing milk.	floating-point number
fat_content	4	Fat content of the milk (%)	floating-point number
c_pregnancy	0.1	Pregnancy coefficient (Table 10.3 in IPCC 2006 Chapter 10).	floating-point number
proportion_animal_class_pregnant	0.63	Proportion Animal Class Pregnant	floating-point number
proportion_animal_class_lactating	0.63	Proportion of Animal Class lactating	floating-point number
fraction_of_month_lactating	1	Fraction of Lactating Days per Month	floating-point number between 0 and 1
hours_worked	0	Number of hours of work per day	floating-point number (0-24)
de	59.51961022	Digestible energy expressed as a percentage of gross energy (%)	floating-point number
ym	6.5	Conversion Factor to Methane	floating-point number

The data structure of the Enteric Fermentation Parameters table as an SQLite Data Base in SQLiteStudio is shown in Figure 30. The respective Enteric Fermentation Parameters table with example data is shown in Figure 31.

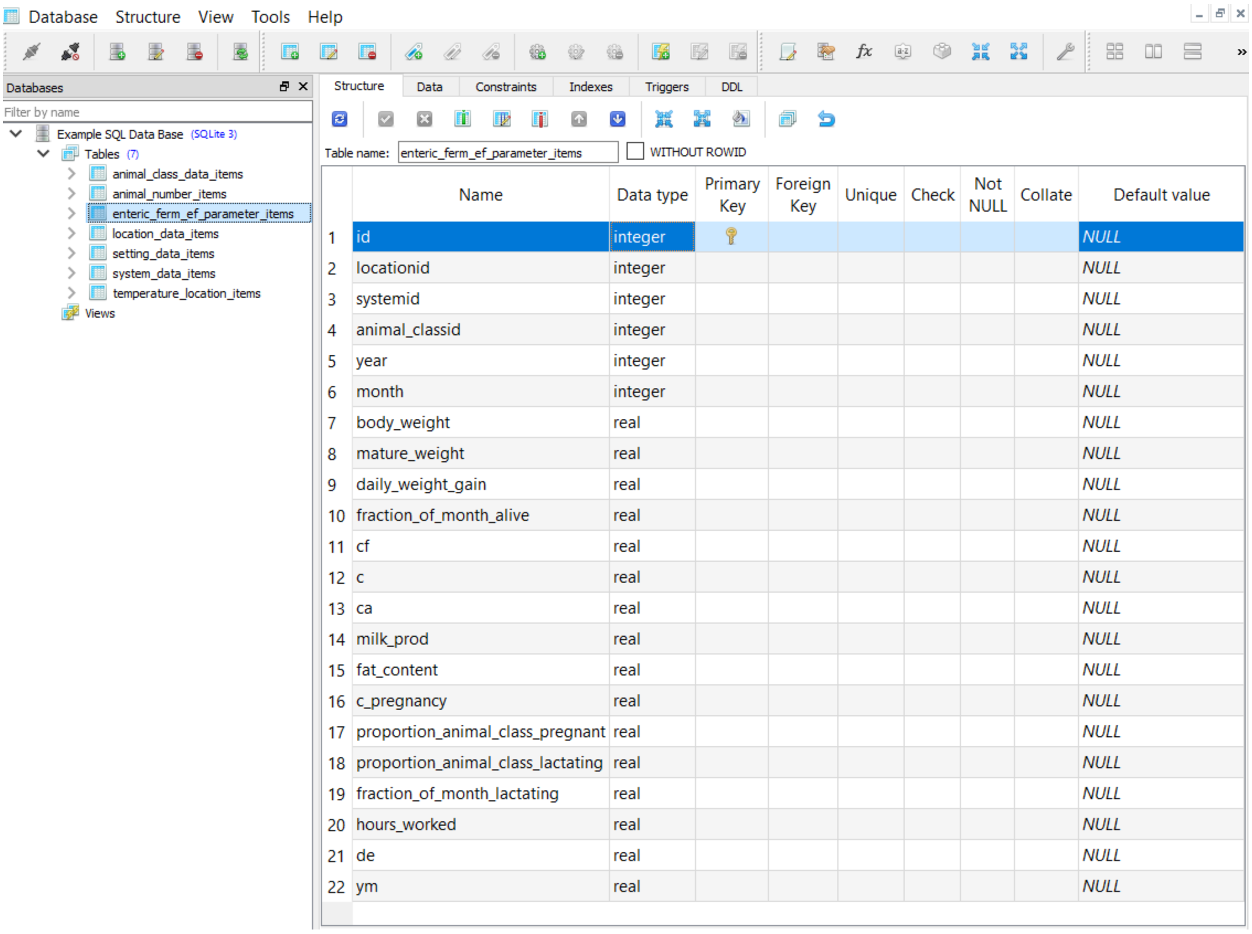


Figure 30 The structure of the Enteric Fermentation Parameters Table in SQLiteStudio.

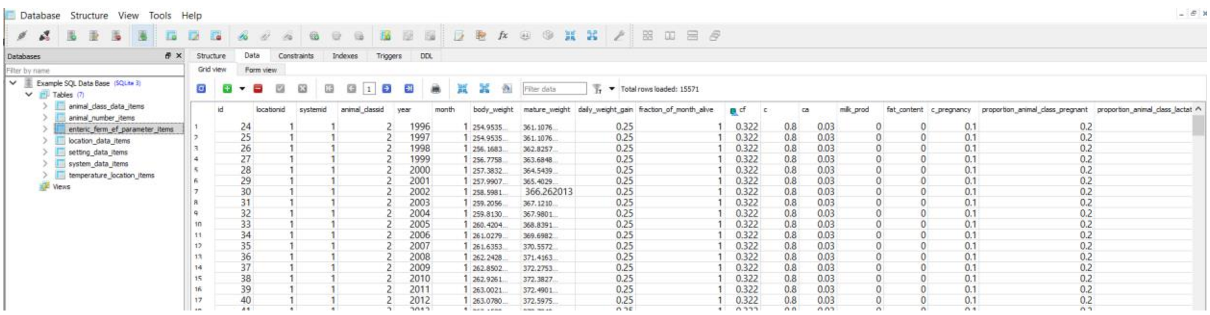


Figure 31 The Enteric Fermentation Parameters Table in SQLiteStudio with example data.

6.4. Setting up the data as a Json File

To be added.

6.4.1. The Settings Table in a Json File

To be added.

6.4.2. The Systems Table in a Json File

To be added.

6.4.3. The Location Table in a Json File

To be added.

6.4.4. The Animal Class Table in a Json File

To be added.

6.4.5. The Temperature Location Table in a Json File

To be added.

6.4.6. The Animal Numbers Table in a Json File

To be added.

6.4.7. The EF Parameters Table in a Json File

To be added.

6.5. Up-loading the data

Google Sheets data is loaded directly by selecting the correct input data from the list of Google Sheets displayed in the grey field in the centre of the browser (Figure 32). Only those Google Sheets will be displayed that belong to the Google account to which you have logged in.

MS Excel, SQLite database and json data can be loaded into FLINT Enteric Fermentation by clicking the respective buttons on the left menu bar (Figure 32).

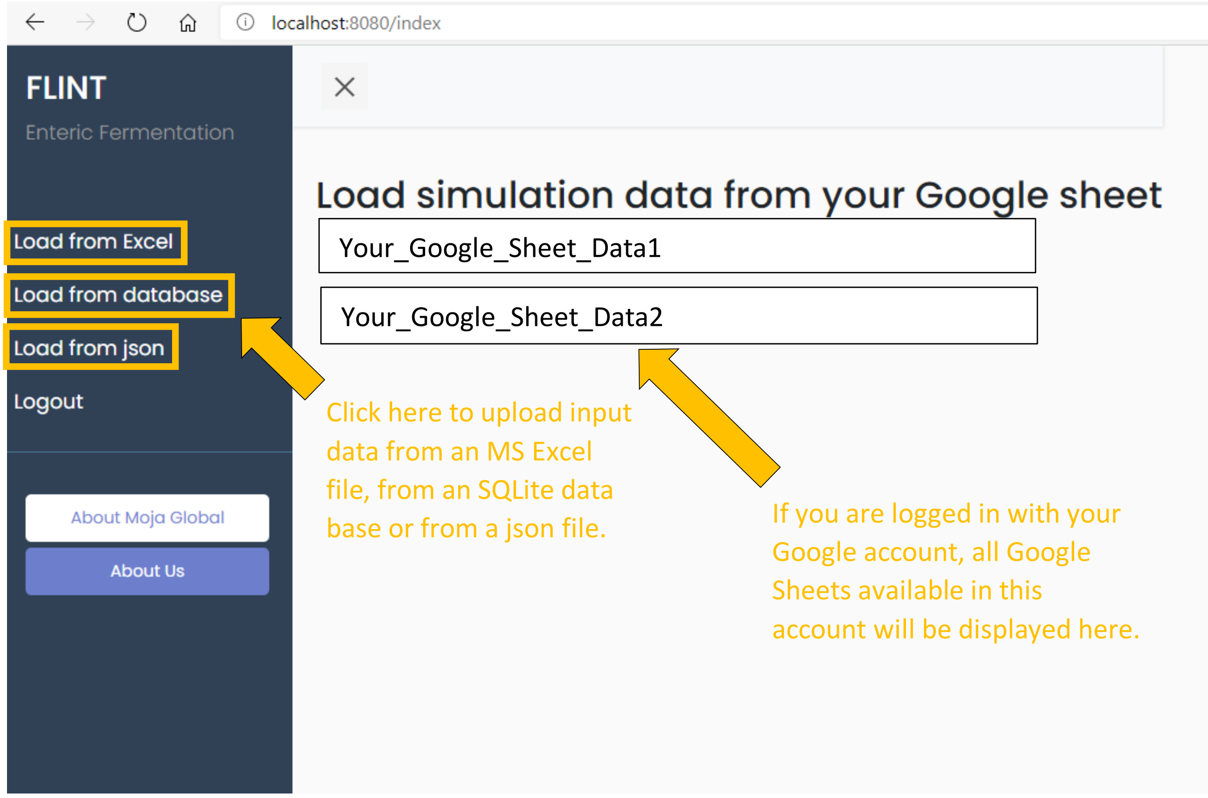


Figure 32 The initial FLINT Enteric Fermentation interface with highlighted data upload buttons.

An upload window for an MS Excel file, a data base (Figure 33a) or Json file (Figure 33b) will appear. Click first on the 'Choose File' button. A file browser window will appear (Figure 34). In the case that you have stored the data in multiple file types, take care to select the appropriate file type (.xlsx file for MS Excel uploads, SQLite database for data base uploads, or JSON File for Json File uploads). Then click upload (Figure 33).

(a)

(b)

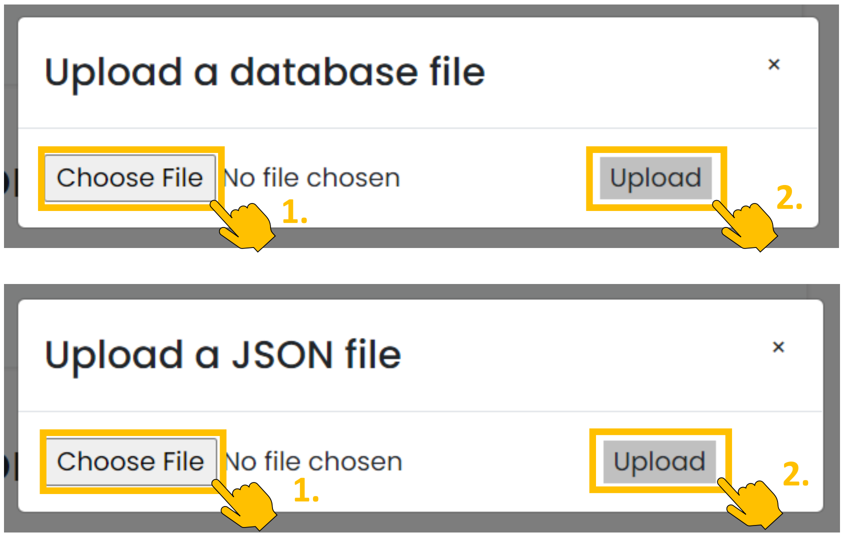


Figure 33 Upload window for data base (a) or Json file (b).

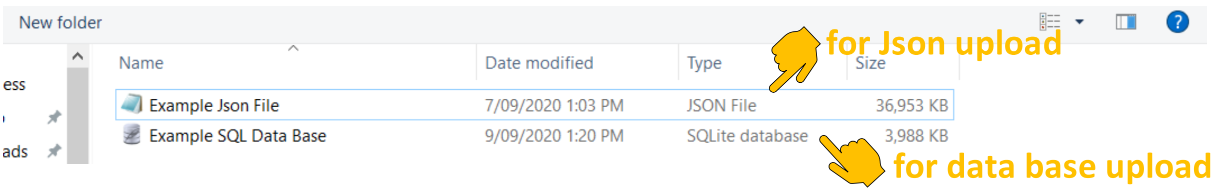


Figure 34 Pop-up window for selecting the file.

Once the data is uploaded, it will be displayed in the grey area in the centre of the browser (Figure 35). The different tables can be selected for display.

Note that the system complements missing data in all tables that contain the variables year and month (‘Temperature Location’, ‘Animal Numbers’, ‘Enteric Fermentation Parameters’). The start date of the simulation is determined by the earliest date entered in the ‘Enteric Fermentation Parameters’ table. The end date of the simulation is determined by the latest date entered in the ‘Enteric Fermentation Parameters’ tables. If the ‘End Date’ specified in the ‘System’ table is set to a date beyond the latest date present in the ‘Enteric Fermentation Parameters’ table, data entries of that date (for data in the ‘Temperature Location’, ‘Animal Numbers’, ‘Enteric Fermentation Parameters’ tables) will be rolled forward to the specified ‘End Date’ of the simulation.

Let us take the following example:

- Start Date (System Table): 1/1/1990
- End Date (System Table): 31/12/2010
- Earliest date entered in the ‘Enteric Fermentation Parameters’ table: Year=1992; Month=5
- Latest date entered in the ‘Enteric Fermentation Parameters’ table: Year=2005; Month=12
- Earliest date entered in the ‘Temperature Location’[5] table: Year=1995; Month=1
- Latest date entered in the ‘Temperature Location’[6] table: Year=2003; Month=1

[5] The same principals apply to the ‘Animal Numbers’ table.
[6] The same principals apply to the ‘Animal Numbers’ table.

In this example the simulation will run from the 1st of Mai 1992 to the 31st of December 2010. In the 'Enteric Fermentation Parameters' table, all months from January 2006 to December 2010 will have the same data entries as December 2005. In the 'Temperature Location' table, all months from January 2006 to December 1994 will have '0' as data entries. All months from February 2003 to December 2010 will have the same data entries as January 2003.

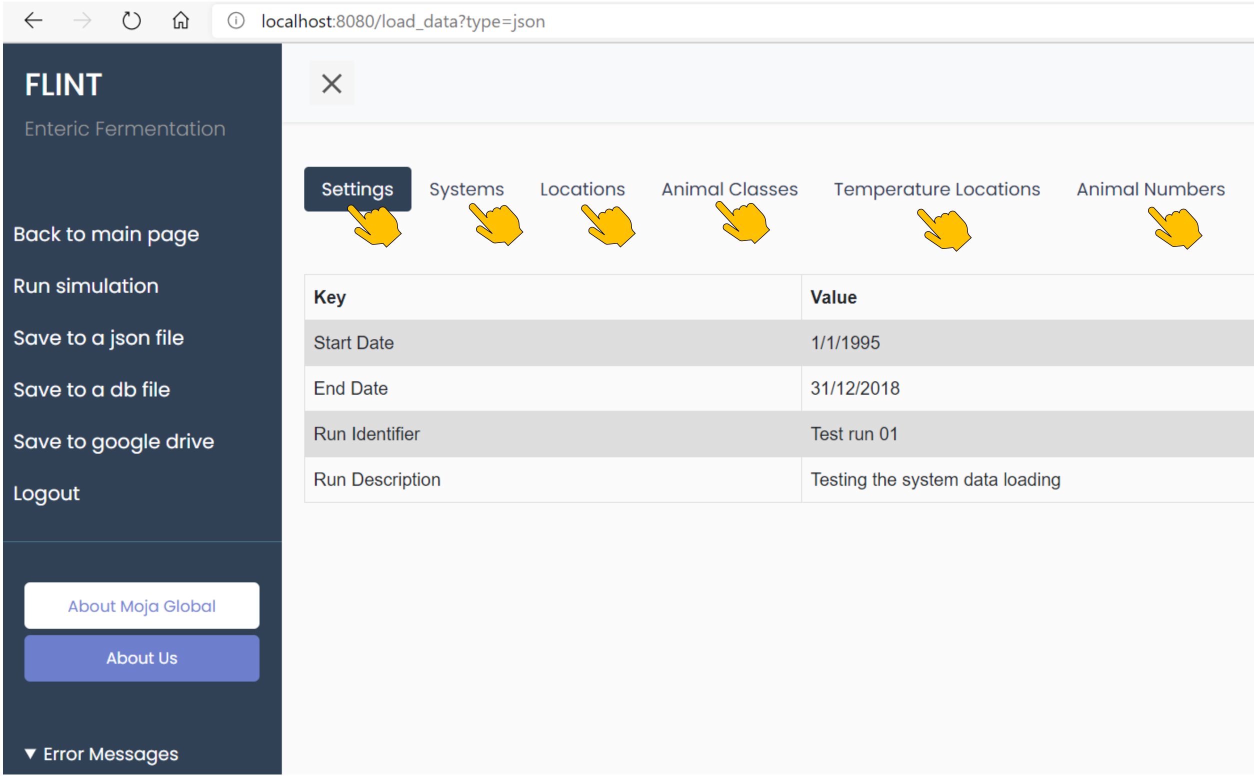


Figure 35 FLINT Enteric Fermentation interface with uploaded data.

6.6. Running the simulation

The simulation is started by clicking the 'Run simulation' button in the left menu bar (Figure 36).

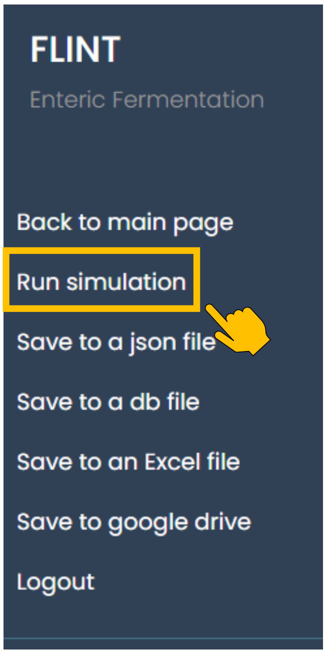


Figure 36 Starting the simulation.

A pop-up window will appear which indicates that the simulation is currently running (Figure 37). Note that for smaller simulations this window will not disappear automatically. The appearance of the fields 'Enteric Emission Factors' and 'Pivot table' (see arrows in Figure 37) is an indication that the simulation is completed. Depending on the size of your screen it is possible that the new tabs appear to the right of the original tabs or in a new row below the original tabs. Click anywhere into the browser window. The 'Running your simulation' pop-up window will disappear, and the FLINT Enteric Fermentation interface will change back to a lighter grey (

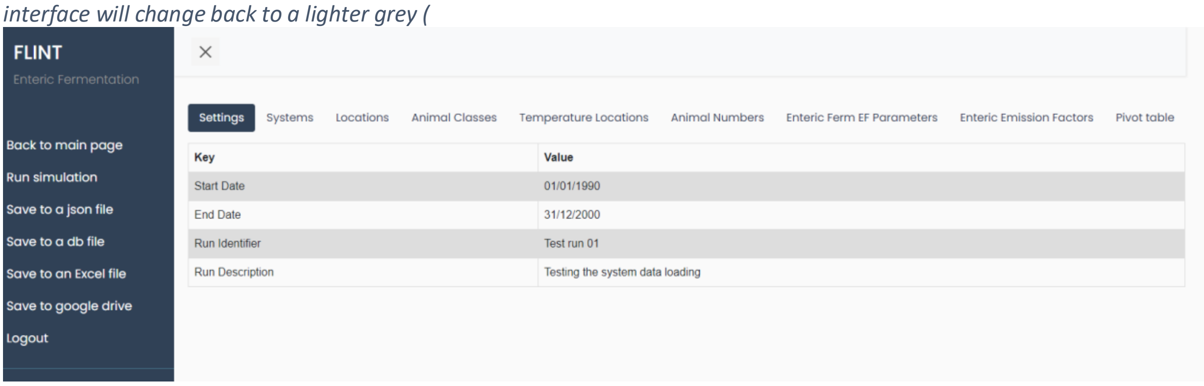


Figure 38).

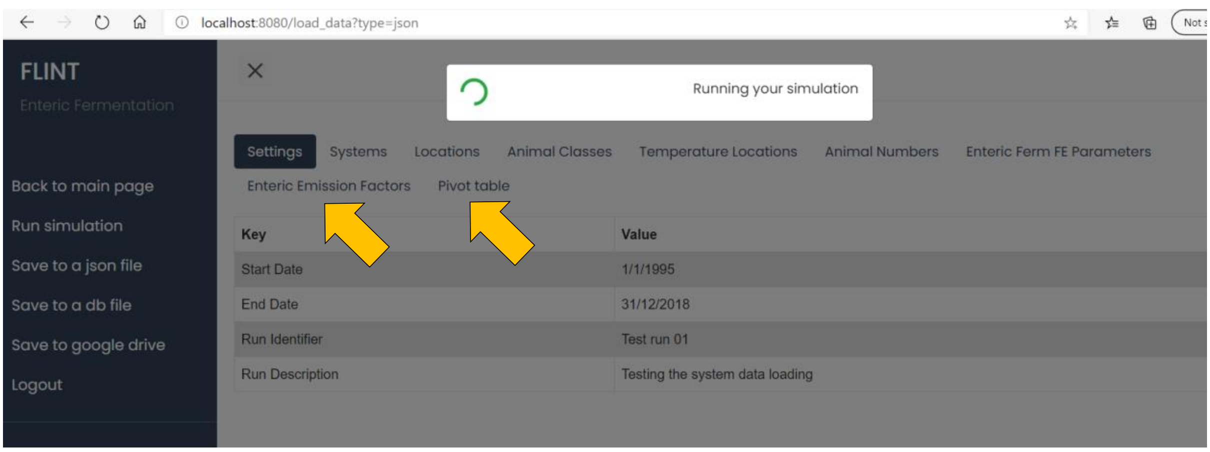


Figure 37 The 'Running you simmulation' field does not allways disapear once the simulation is completed.

The result table 'Enteric Emission Factors' can be accessed by clicking the respective tab (

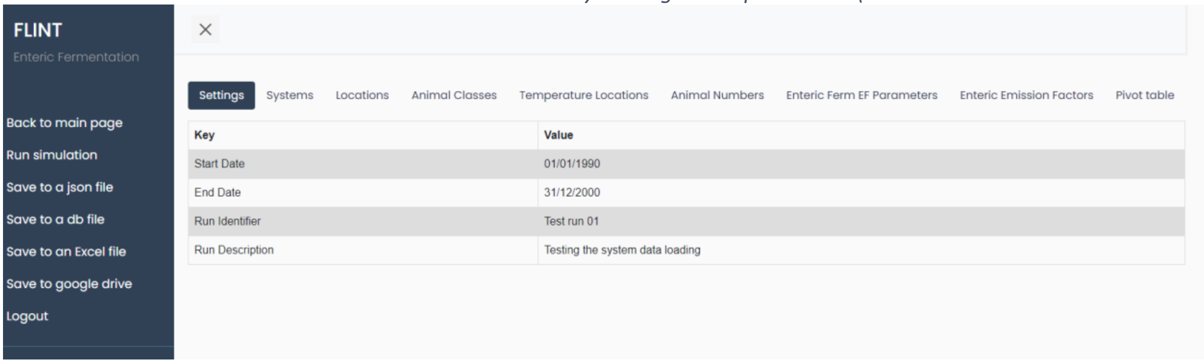


Figure 38).

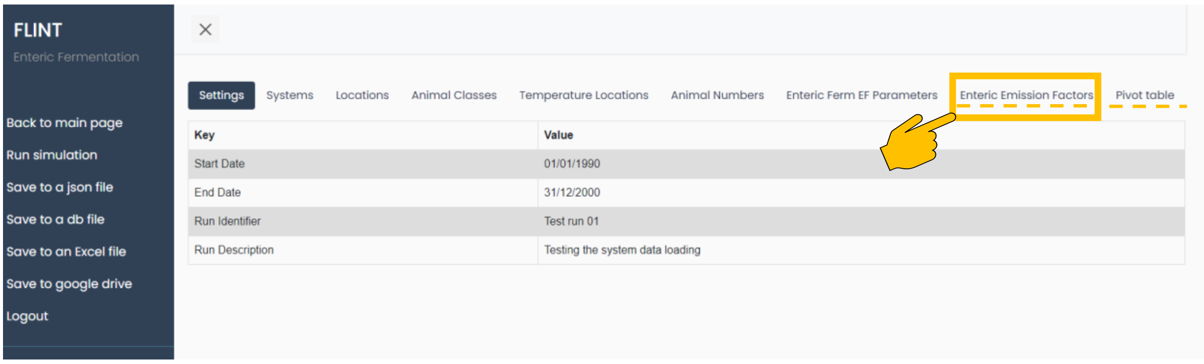
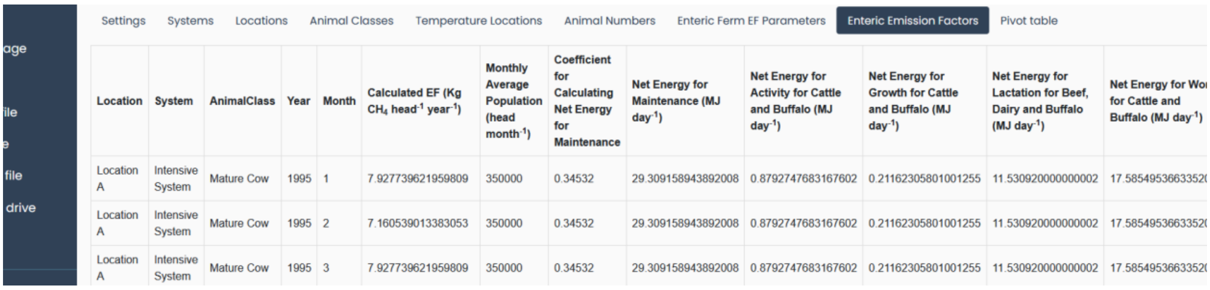


Figure 38 FLINT Enteric Fermentation Interface with finished simulation.

The 'Enteric Emission Factors' table (Figure 39) contains 18 fields which are shown and described in

Table 17. The Calculated Emissions for each animal class in a specific location of a specific system in a defined month of a specific year can be found in field 18 'Enteric Fermentation Emissions from a Livestock Category' on the far right of the table.



Location	System	AnimalClass	Year	Month	Calculated EF (Kg CH_4 head^{-1} year^{-1})	Monthly Average Population (head month^{-1})	Coefficient for Calculating Net Energy for Maintenance	Net Energy for Maintenance (MJ day^{-1})	Net Energy for Activity for Cattle and Buffalo (MJ day^{-1})	Net Energy for Growth for Cattle and Buffalo (MJ day^{-1})	Net Energy for Lactation for Beef, Dairy and Buffalo (MJ day^{-1})	Net Energy for Wo[r]k for Cattle and Buffalo (MJ day^{-1})
Location A	Intensive System	Mature Cow	1995	1	7.927739621959809	350000	0.34532	29.309158943892008	0.8792747683167602	0.21162305801001255	11.530920000000002	17.58549536633520
Location A	Intensive System	Mature Cow	1995	2	7.160539013383053	350000	0.34532	29.309158943892008	0.8792747683167602	0.21162305801001255	11.530920000000002	17.58549536633520
Location A	Intensive System	Mature Cow	1995	3	7.927739621959809	350000	0.34532	29.309158943892008	0.8792747683167602	0.21162305801001255	11.530920000000002	17.58549536633520

Figure 39 The result table 'Enteric Emission Factors'.

Table 17 Fields of the results table 'Enteric Emission Factors'.

No	Column	Description
1	Location	As defined in the input data
2	System	As defined in the input data
3	AnimalClass	As defined in the input data
4	Year	Reference year of the results
5	Month	Reference month of the results
6	Calculated EF	Calculated Emission Factor
7	Monthly Average Population	Monthly Average Population (N)
8	Coefficient for Calculating Net Energy for Maintenance	Coefficient for Calculating Net Energy for Maintenance in cold weather (MJ day^{-1} kg^{-1})
9	Net Energy for Maintenance	Net energy required by the animal for maintenance (MJ day^{-1})
10	Net Energy for Activity for Cattle and Buffalo	Net energy for animal activity (MJ day^{-1})
11	Net Energy for Growth for Cattle and Buffalo	Net energy for animal growth (MJ day^{-1})
12	Net Energy for Lactation for Beef, Dairy and Buffalo	Net energy for lactation (MJ day^{-1})
13	Net Energy for Work for Cattle and Buffalo	Net energy for work (MJ day^{-1})
14	Net Energy for Pregnancy for Cattle, Buffalo and Sheep	Net energy for pregnancy (MJ day^{-1})
15	Ratio of Net Energy Available in a Diet for Maintenance to Digestible Energy Consumed	Ratio of net energy available in a diet for maintenance to digestible energy consumed (REM)
16	Ratio of Net Energy Available for Growth in a Diet to Digestible Energy Consumed	Ratio of Net Energy Available for Growth in a Diet to Digestible Energy Consumed (REG)
17	Gross Energy for Cattle, Buffalo, Sheep	Gross Energy for Cattle, Buffalo, Sheep (MJ day^{-1})
18	Enteric Fermentation Emissions from a Livestock Category	Methane emissions from Enteric Fermentation (Gg CH_4 $month^{-1}$)

6.7. Saving the Results

The results of the simulation can be saved to a Google Sheet ('Save to google drive'), to an MS Excel file ('Save to an Excel file'), to a data base ('Save to db file') or to a Json file ('Save to json file') by clicking the respective button on the left menu bar (Figure 40). When exporting the data, both the original tables (complemented with values for each month of the simulation) and the result tables will be exported to the file or data base.

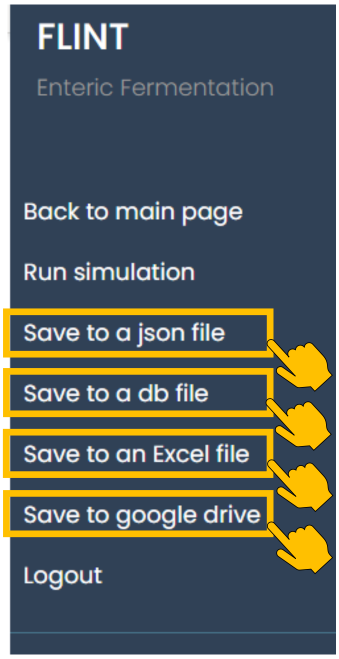


Figure 40 Saving results.

Google Sheets and MS Excel do not support the calculation of very large data sets. If your data set cannot be handled by Google Sheets FLINT Enteric Fermentation will show the following error message:

'Error downloading: googleapi: Error 400: This action would increase the number of cells in the workbook above the limit of 5000000 cells., badRequest'

You might receive a similar error for MS Excel. If this occurs, you will need to export your results to a json file or an SQLite database.

6.8. Visualizing the Results

Clicking on the 'Pivot table' tab of a completed simulation (Figure 41) will open a data visualisation tool (Figure 42).

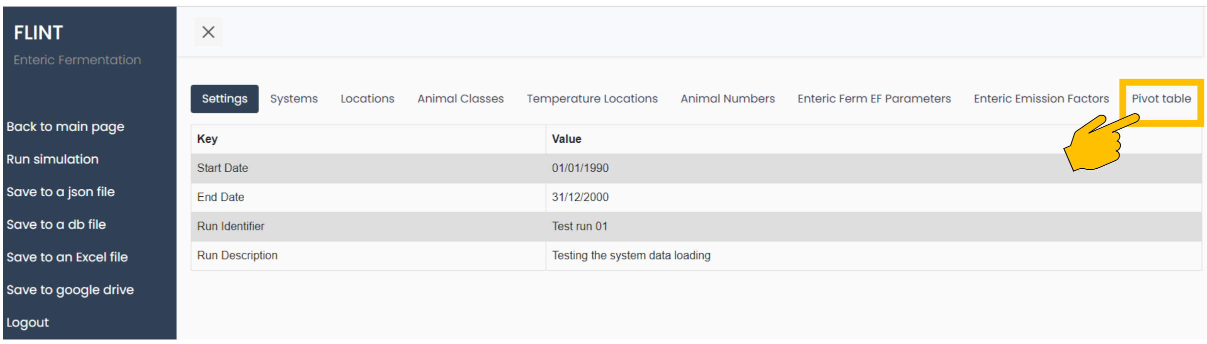


Figure 41 FLINT Enteric Fermentation Interface with finished simulation and the 'Pivot table' tab.

A large variety of tables, graphs and figures can be created by selecting a target variable, pulling variables into the fields that correspond to the Y-Axis/columns or X-Axis/rows and by selecting appropriate display and calculation types (Figure 42).

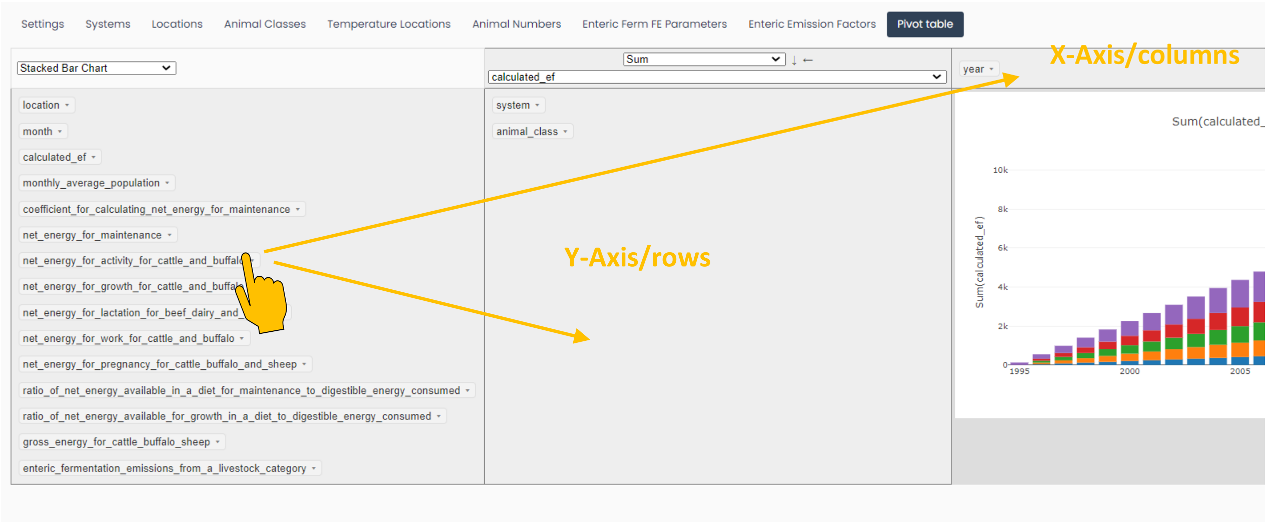


Figure 42 The data visulisation tool of FLINT Enteric Fermentation under the 'Pivot table' tab.

The variable for which the results are calculated can be selected with the lower drop-down menu in the centre panel (Figure 43). The display type can be selected with the drop-down menu on the top of the left panel (Figure 44). The calculation type of the result values can be selected with the upper drop-down menu in the centre panel (Figure 45). Data can be filtered by clicking the grey triangle to the right of each attribute name and unticking/ticking the check marks (Figure 46). Figure 47 shows an example of a stack bar chart displaying Enteric Fermentation Emissions per animal class and year. A tool panel on the upper right of the graph, figure or table facilitates the export or modification of the respective item (Figure 48).

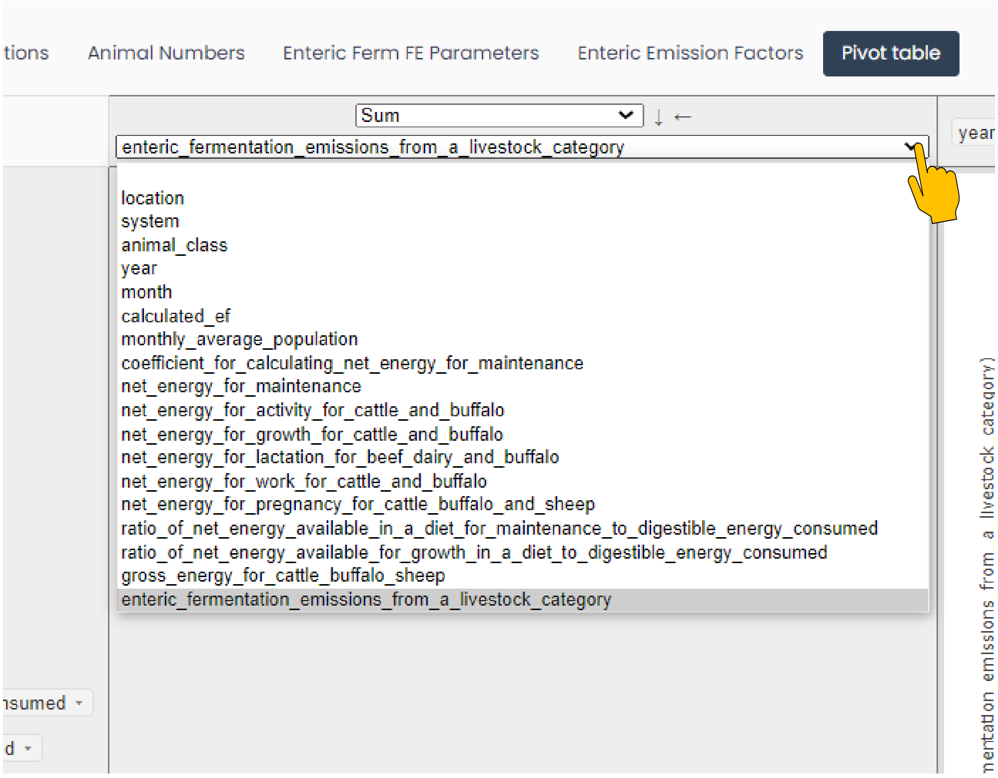


Figure 43 Selection of variables to be displayed as results.

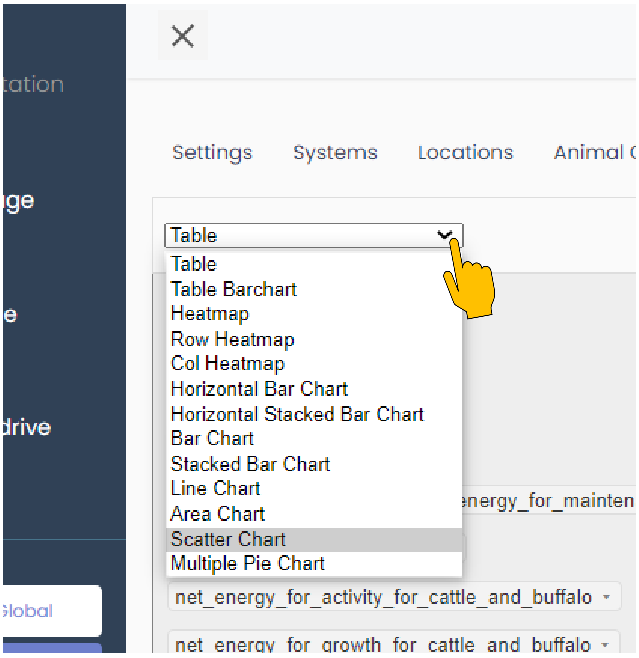


Figure 44 Display types of the data visulisation tool under the 'Pivot table' tab.

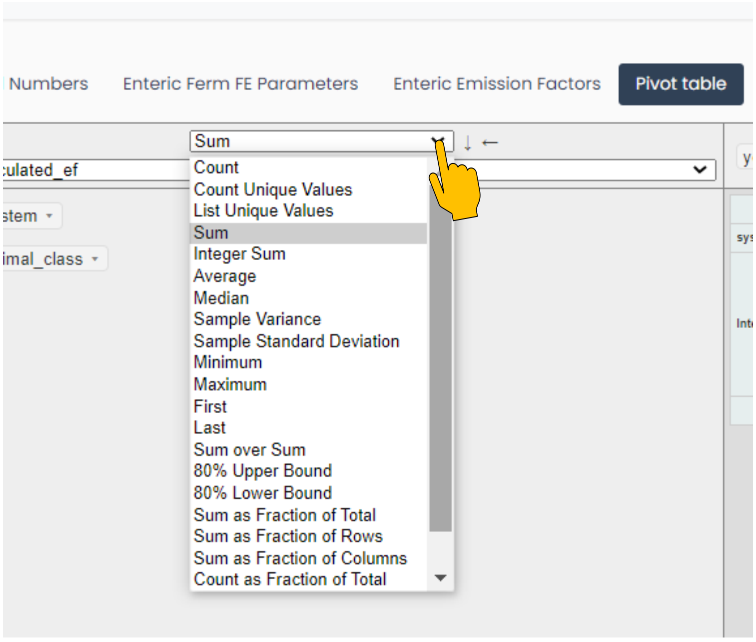


Figure 45 Calculation types of the data visulisation tool under the 'Pivot table' tab.

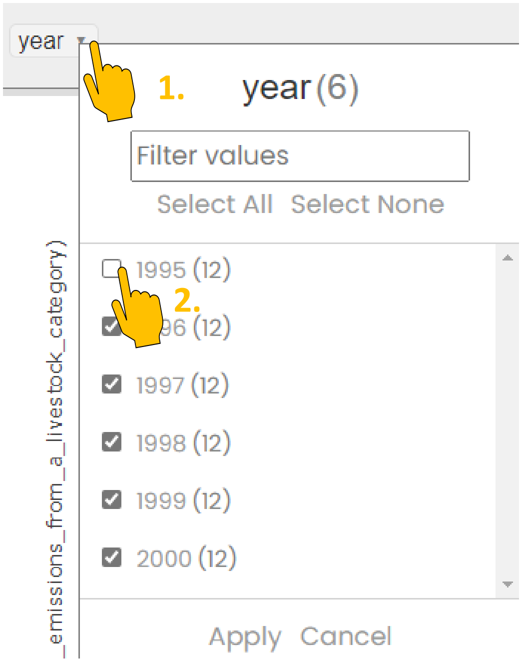


Figure 46 Filtering data under the 'Pivot table' tab.

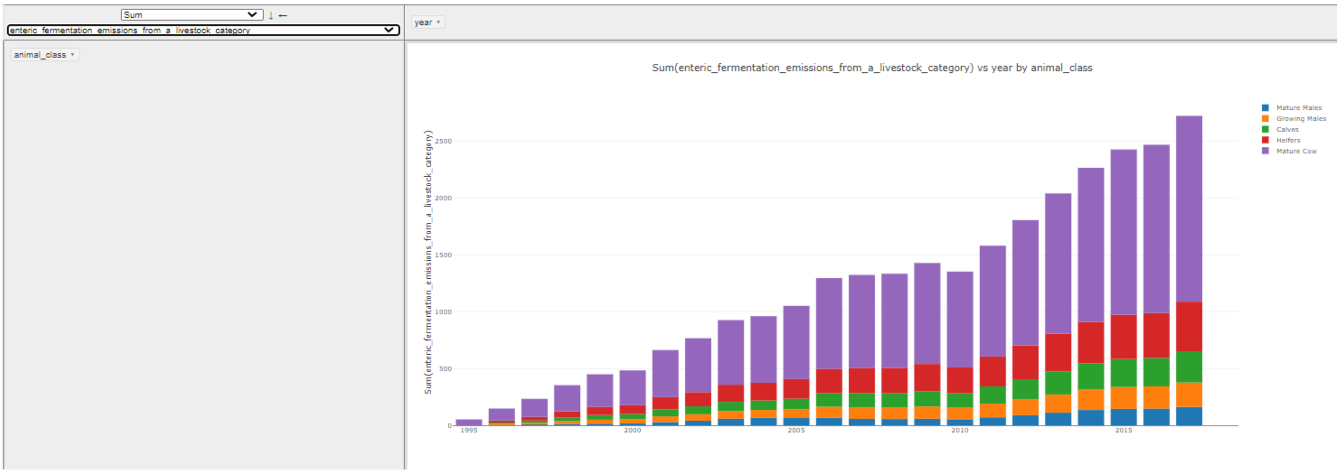


Figure 47 Example Stack Bar Chart showing Enteric Fermentation Emissions per animal class and year.

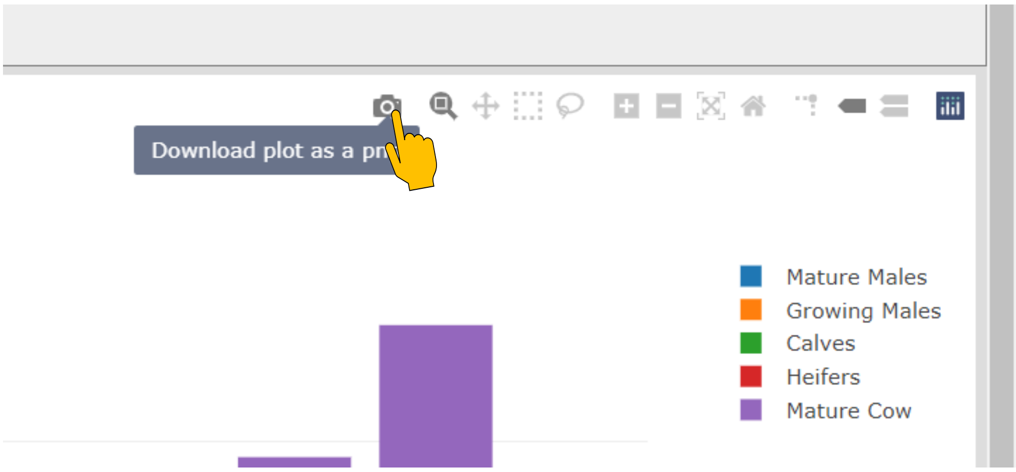


Figure 48 Tool bar for exporting and modifying the result tables and graphs.

6.9. Error Messages

Error messages will be displayed in the lower area of the left menu panel (Figure 49).

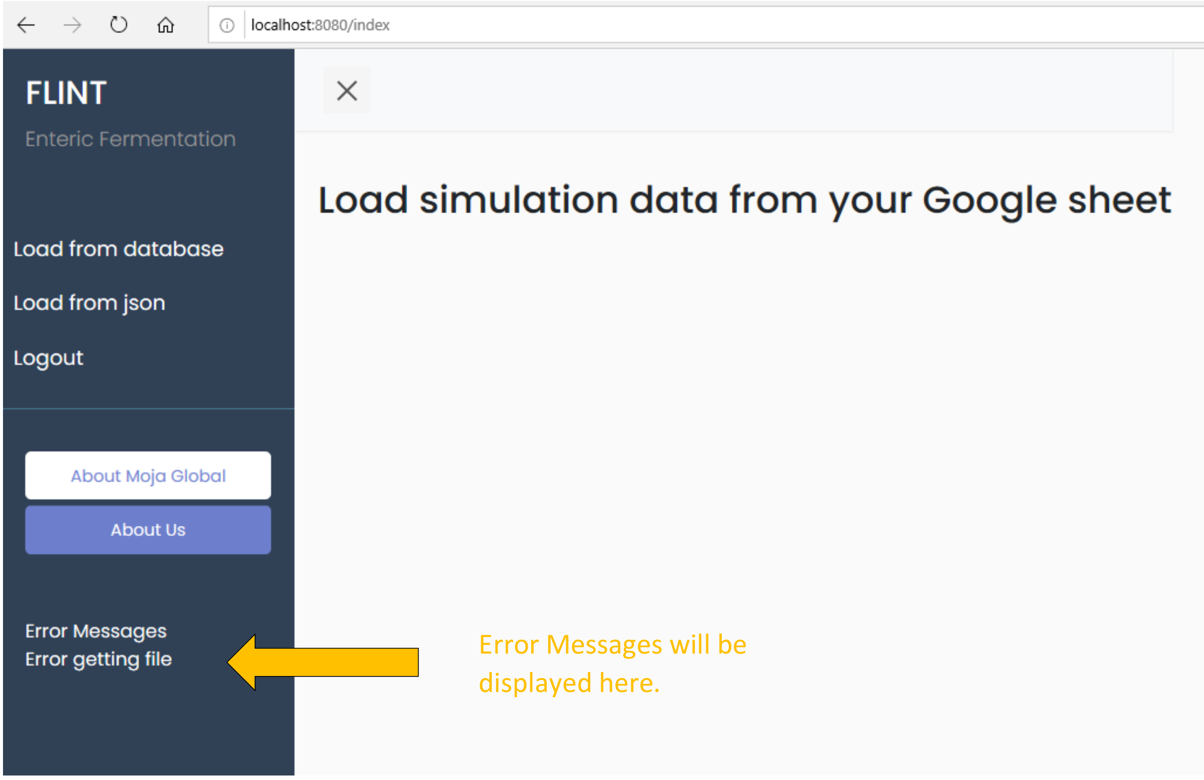


Figure 49 Error Messages displayed in FLINT Enteric Fermentation.

6.9.1. Error downloading: googleapi: Error 400

Google Sheets and MS Excle not support the calculation of very large data sets. If your data set cannot be handled by Google Sheets FLINT Enteric Fermentation will show the following error message:

> Error downloading: googleapi: Error 400: This action would increase the number of cells in the workbook above the limit of 5000000 cells., badRequest

You might receive a similar error for MS Excel. As a solution, an SQLite data base or Json file can be used as data input instead of Google Sheets.

7. Equations and Calculation Flow

FLINT Enteric Fermentation uses Equation 1 to 14 to generate the total CH_4 emissions related to enteric fermentation. All equations are based on equations published in Chapter 10 of the IPCC 2006 guidelines[7]. The calculation flow is shown in Figure 50.

Monthly livestock numbers:

Based on Equation 10.1 of Chapter 10 of the IPCC 2006 guidelines.

(variable form input table)

$$MAP_j = FMA_j \times DM_j \times \frac{NAPM_j}{DM_j} \qquad \text{Equation 1}$$

MAP_j = average population in month j
FMA_j = fraction of the month j the animals are alive (fraction of month alive / enteric fermentation parameters)
$NAPM_j$ = number of animals produced in month j (animal number / animal numbers)
DM_j = number of days that month j has

Coefficient for calculating net energy for maintenance:

Equal to Equation 10.2 of Chapter 10 of the IPCC 2006 guidelines.

(variable form input table)

$$CF_i(in\ cold) = CF_i + 0.0048 \times (20 - °C) \qquad \text{Equation 2}$$

Cf_i = coefficient which varies for each animal category (CF / enteric fermentation parameters)
$°C$ = mean daily temperature during winter season (mean winter temperature (average temp)/ temperature location)

Net energy for maintenance:

Based on Equation 10.3 of Chapter 10 of the IPCC 2006 guidelines.

(variable form input table)

$$NE_{mj} = CF_i(in\ cold) \times (BW_j)^{0.75} \qquad \text{Equation 3}$$

NE_{mj} = net energy required by the animal for maintenance per day in month j, MJ day^{-1}
$Cf_i(in\ cold)$ = converted coefficient which varies for each animal category (Equation 2)
BW_j = live-weight of animal in month j, kg (body weight/ enteric fermentation parameters)[8]

[7] IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Prepared by the National Greenhouse Gas Inventories Programme, Hayama, Japan, 1 online resource (5 volumes).
[8] This parameter is named 'weight' in the original IPCC 2006 document.

Net energy for activity:
Based on Equation 10.4 of Chapter 10 of the IPCC 2006 guidelines.
(variable form input table; variable form equation)

$$NEa_j = Ca_j \times NE_{mj} \qquad \text{Equation 4}$$

NE_{aj} = net energy for animal activity per day in month j, MJ day^{-1}
C_{aj} = coefficient corresponding to animal's feeding situation (Ca / enteric fermentation parameters)
NE_{mj} = net energy required by the animal for maintenance per day in month j, MJ day^{-1} (Equation 3)

Net energy for growth (for cattle and buffalo)**:**
Based on Equation 10.6 of Chapter 10 of the IPCC 2006 guidelines.
(variable form input table)

$$NE_{gj} = 22.02 \times \left(\frac{BW_j}{C \times MW}\right)^{0.75} \times WG_j^{1.097} \qquad \text{Equation 5}$$

NE_{gj} = net energy needed for growth per day in month j, MJ day^{-1}
BW_j = the average live body weight of the animal in the population in month j, kg
(body weight / enteric fermentation parameters)
C = a coefficient with a value of 0.8 for females, 1.0 for castrates and 1.2 for bulls (C / enteric fermentation parameters)
MW = the mature live body weight of an adult animal in moderate body condition, kg
(mature weight / enteric fermentation parameters)
WG_j = the average daily weight gain of the animal in the population in month j, kg
(daily weight gain / enteric fermentation parameters)

Net energy for lactation (for beef, cattle, dairy cattle, and buffalo)**:**
Based on Equation 10.8 of Chapter 10 of the IPCC 2006 guidelines.
(variable form input table)

$$NE_{lj} = Milk_j \times (1.47 + 0.40) \times Fat_j \qquad \text{Equation 6}$$

NE_{lj} = net energy needed for lactation per day in month j, MJ day^{-1}
$Milk_j$ = amount of milk produced per day in month j, kg of milk day^{-1}
(milk production / enteric fermentation parameters)
Fat_j = fat content of milk in month j, % by weight (fat content / enteric fermentation parameters)

Net energy for work (for cattle and buffalo)**:**
Based on Equation 10.11 of Chapter 10 of the IPCC 2006 guidelines.
(variable form input table; variable form equation)

$$NE_{wj} = 10 \times NE_{mj} \times Hours_j \qquad \text{Equation 7}$$

NE_{wj} = net energy for work per day in month j, MJ day^{-1}
NE_{mj} = net energy required by the animal for maintenance per day in month j, MJ day^{-1} (Equation 3)
$Hours_j$ = number of hours of work per day in month j, (hours worked / enteric fermentation parameters)

Net energy for pregnancy (for cattle/buffalo and sheep)**:**
Based on Equation 10.13 of Chapter 10 of the IPCC 2006 guidelines.
(variable form input table; variable form equation)

$$NE_{pj} = C_p \times NE_{mj}$$ Equation 8

NE_{pj} = net energy required for pregnancy per day in month j, MJ day^{-1}
C_p = pregnancy coefficient (see table 10.7 in the IPCC 2006 guidelines) (Cpregnancy / enteric fermentation parameters)
NE_{mj} = net energy required by the animal for maintenance in month j, MJ day^{-1} (Equation 3)

Ratio of net energy available in a diet for maintenance to digestible energy consumed:
Based on Equation 10.14 of Chapter 10 of the IPCC 2006 guidelines.
(variable form input table)

$$REM = \left[1.123 - (4.092 \times 10^{-3} \times DE\%) + [1.126 \times 10^{-5} \times (DE\%)^2] - \left(\frac{25.4}{DE\%}\right)\right]$$ Equation 9

REM = ratio of net energy available in a diet for maintenance to digestible energy consumed
$DE\%$ = digestible energy expressed as a percentage of gross energy (de / enteric fermentation parameters)

Ratio of net energy available in a diet for growth to digestible energy consumed:
Based on Equation 10.15 of Chapter 10 of the IPCC 2006 guidelines.
(variable form input table)

$$REG = \left[1.164 - (5.160 \times 10^{-3} \times DE\%) + [1.308 \times 10^{-5} \times (DE\%)^2] - \left(\frac{37.4}{DE\%}\right)\right]$$ Equation 10

REG = ratio of net energy available in a diet for growth to digestible energy consumed
$DE\%$ = digestible energy expressed as a percentage of gross energy (de / enteric fermentation parameters)

Gross Energy, GE:
Based on Equation 10.16 of Chapter 10 of the IPCC 2006 guidelines.
(variable form input table; variable form equation)

$$GE = \left[\frac{\left(\frac{NE_{mj} + NE_{aj} + NE_{lj} + NE_{wj} + NE_{pj}}{REM}\right) + \left(\frac{NE_{gj}}{REG}\right)}{\frac{DE\%}{100}}\right]$$ Equation 11

GE = gross energy, MJ head^{-1} day^{-1}
NE_{mj} = net energy required by the animal for maintenance per day in month j, MJ day^{-1} (Equation 3)
NE_{aj} = net energy for animal activity per day in month j, MJ day^{-1} (Equation 4)
NE_{lj} = net energy needed for lactation per day in month j, MJ day^{-1} (Equation 6)
NE_{wj} = net energy for work per day in month j, MJ day^{-1} (Equation 7)
NE_{pj} = net energy required for pregnancy per day in month j, MJ day^{-1} (Equation 8)
NE_{gj} = net energy needed for growth per day in month j, MJ day^{-1} (Equation 5)
REM = ratio of net energy available in a diet for maintenance to digestible energy consumed (Equation 9)
REG = ratio of net energy available in a diet for growth to digestible energy consumed (Equation 10)
$DE\%$ = digestible energy expressed as a percentage of gross energy (de / enteric fermentation parameters)

CH_4 emission factor for each animal category:

Based on Equation 10.21 of Chapter 10 of the IPCC 2006 guidelines.

(variable form input table; variable form equation)

$$EF = \left[\frac{GE \times \left(\frac{Y_m}{100}\right) \times Days_j}{55.65}\right] \quad \text{Equation 12}$$

EF = emission factor, kg CH_4 head^{-1} month^{-1}

GE = gross energy, MJ head^{-1} day^{-1} (Equation 11)

Y_m = methane conversion factor, per cent of gross energy in feed converted to methane (Ym / enteric fermentation parameters)

$Days_j$ = number of days of month j

The factor 55.65 (Mj/kg CH_4) is the energy content of methane

Enteric fermentation emissions from a livestock category:

Based on Equation 10.19 of Chapter 10 of the IPCC 2006 guidelines.

(variable form equation)

$$Emissions = EF_{(T)} \times \left(\frac{MAP_{j(T)}}{10^6}\right) \quad \text{Equation 13}$$

$Emissions$ = methane emissions from enteric fermentation, Gg CH_4 month^{-1}

$EF_{(T)}$ = emission factor for the defined livestock population, kg CH_4 head^{-1} month^{-1} (Equation 12)

$MAP_{j(T)}$ = average population of livestock species / category T in the country in month j (Equation 1)

T = species/category of livestock

Total emissions from a livestock enteric fermentation:

Based on Equation 10.20 of Chapter 10 of the IPCC 2006 guidelines.

(variable form input table; variable form equation)

$$Total\ CH_{4Enteric} = \sum_i EF_{(T)i} \quad \text{Equation 14}$$

$Total\ CH_{4Enteric}$ = total methane emissions from enteric fermentation, Gg CH_4 month^{-1}

$EF_{(T)i}$ = emission factor for the defined livestock population, kg CH_4 head^{-1} month^{-1} (Equation 13)

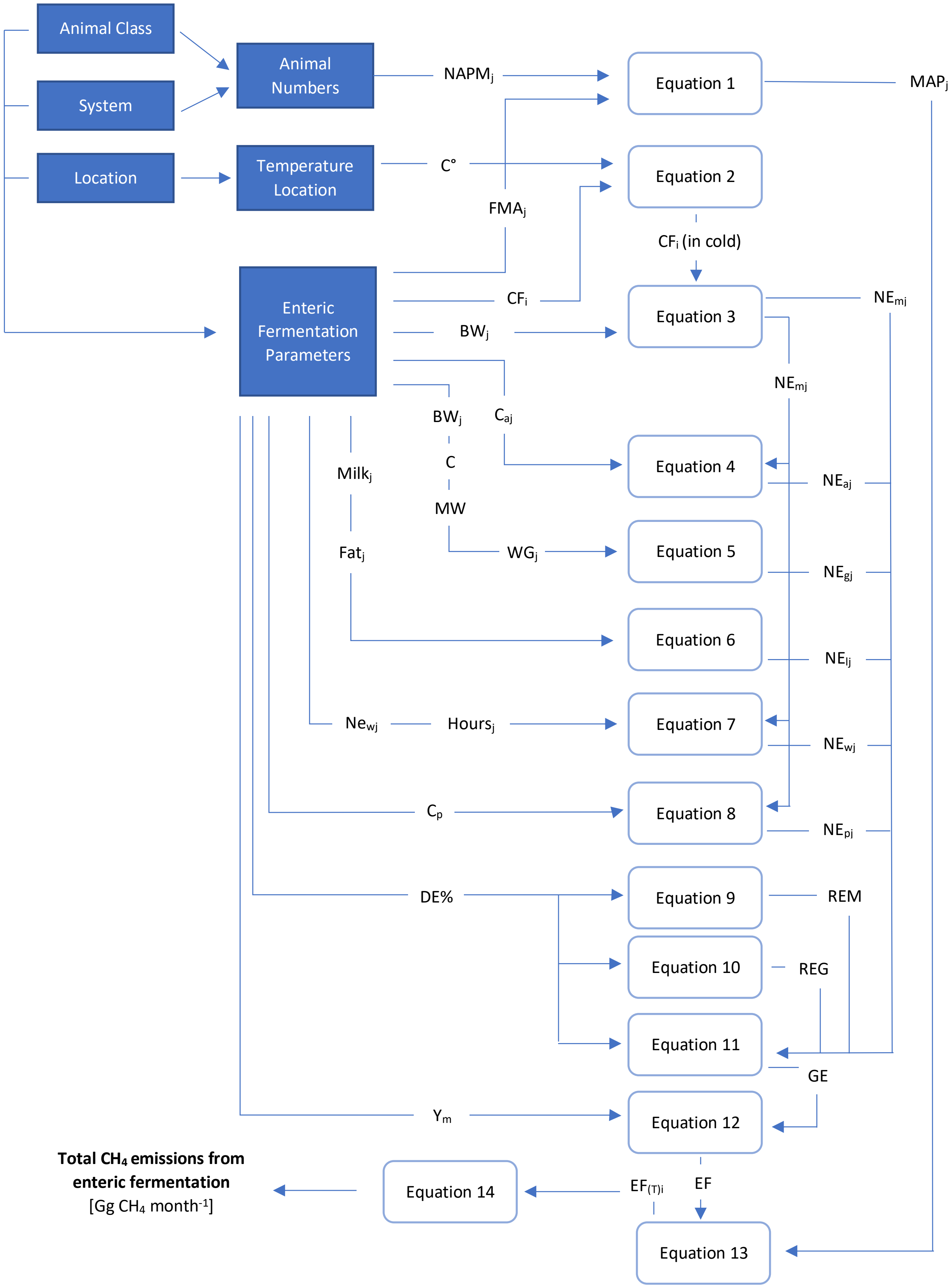


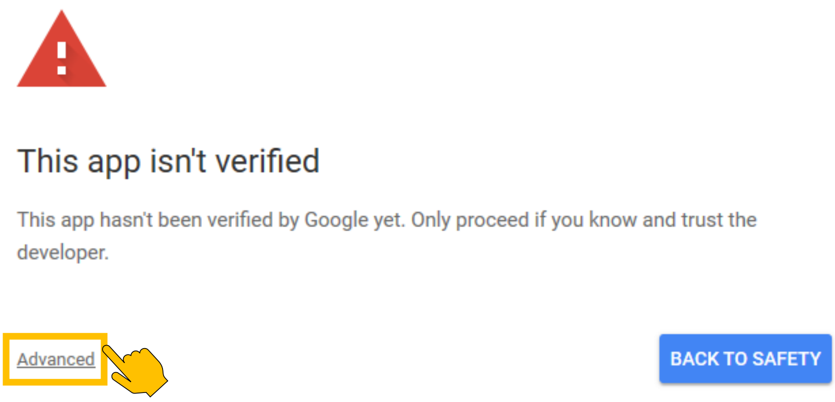
Figure 50 FLINT Enteric Fermentation calculation flow.

8. Appendix

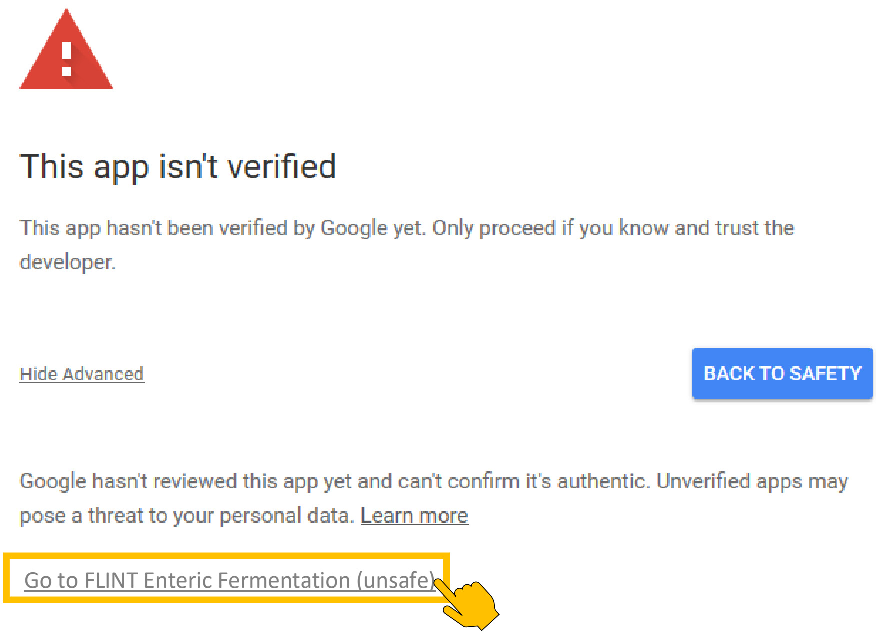
What to do when the 'This app isn't verified' warning appears:

In this case, click 'Advanced'. An extension of the pop-up Window appears. Click on 'Go to FLINT Enteric Fermentation (unsafe)'.

Pop-up window



Pop-up window (Advanced)



Another pop-up window will appear, and you will be asked to grant permission to

- view and manage metadata of files in your Google Drive. (klick 'Allow')
- view and manage metadata of files in your Google Drive files and folders that you have opened or created with this app. (klick 'Allow')
- see, edit, create, and delete your spreadsheets in Google Drive. (klick 'Allow')

Subsequently, your selections will be displayed with some additional information and you are asked to confirm your choice (klick 'Allow')