animal - open space 5 (2026) 100151

Contents lists available at ScienceDirect

animal - open space

journal homepage: www.elsevier.com/locate/anopes

Method paper

Method: GreenDA – A user-friendly tool for processing and exploring large-scale GreenFeed® data

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ARTICLE INFO

Article history:
Received 13 November 2025
Revised 22 June 2026
Accepted 23 June 2026

Handling editor: Isabel Casasús

Keywords:
Automated head chamber system
Button-based software
Enteric methane
Procedure
Ruminant

ABSTRACT

The GreenFeed® is used worldwide for individual methane (**CH_4**) emission measurement without restricting animal behaviour. It enables a large number of spot gas samples per animal and can simultaneously measure emissions from up to 20–25 animals. However, robust analytical tools that can easily handle large volumes of data generated in real time by this system remain limited. To address this shortcoming, we developed an application that provides user-friendly functionalities (i.e., simple button-based operations) designed for inexperienced users in data analysis programming and large dataset management. This software includes useful features for processing data (e.g., outlier elimination), basic descriptive statistics and calculations (e.g., repeatability; **REP**), as well as data visualisation and reporting at different levels (i.e., herd, animal, treatment) and different time intervals (e.g., hour, day). These descriptive summaries provide valuable insights into which subsequent statistical analyses may be appropriate. To illustrate the functionality of GreenDA, we utilised data collected from 53 cows over a 105-day period using two GreenFeed®. Animals were assigned to a 2 × 2 factorial design with two factors, including diet (Treatment 1) and breed (Treatment 2). After preprocessing the dataset using the default settings of GreenDA, 124 out of 19 749 records were identified as outliers and subsequently removed. The CH_4 emission data followed a normal distribution, and REP reached a plateau in 7 days per subgroup (REP = 0.62). The CH_4 emission kinetics closely mirrored the intake pattern, which was not affected by treatment. The total number of visits peaked at 0100 h and reached its lowest point at 0200 h; however, this daily pattern differed between treatments. All of these analyses were conducted according to the analysis guidelines provided with GreenDA. GreenDA not only analyses large data sets collected by the GreenFeed® but also provides the scientific community with comprehensive guidance for optimising analyses.

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Implications

Quantifying individual enteric methane emissions from a large number of animals simultaneously requires high-throughput data acquisition tools. GreenDA is a free software designed to facilitate the analysis of a large volume of data generated by automated-head systems such as GreenFeed®. GreenDA is a user-friendly tool with a low barrier to entry in terms of programming skills. In addition, GreenDA provides the scientific community with comprehensive guidelines designed to optimise the analysis of large datasets collected with GreenFeed®.

Specifications table

Subject	Physiology and Functional Biology
Specific subject area	Massive data analysis of enteric methane emissions from ruminants
Type of data	Table
How data were acquired	Data were acquired using GreenFeed®.

(*continued on next page*)

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https://doi.org/10.1016/j.anopes.2026.100151
2772-6940/

Data format	Data are presented in Excel files from C-Lock, including a ReadMe sheet which describes the different variables and a sheet with the animal's treatment information.
Parameters for data collection	GreenFeed® data were collected in an experimental farm. The variables were animal identification, machine identification, visit time, visit duration, hour of day, gas fluxes, airflow, treatment 1, and treatment 2.
Description of data collection	GreenFeed® data were collected in real time with two machines from 53 cows during 105 days. Animals were used in a 2 × 2 factorial design with two levels in each factor, including diet (Treatment 1) and breed (Treatment 2).
Data source location	INRAE UE Herbipôle, 63820 Laqueuille, France 45.637672, 2.745514 https://doi.org/10.15454/1.5572318050509348E12
Data accessibility	Repository name: Data.gouv URL: https://www.data.gouv.fr/datasets/greenfeed-result-data-set-generated-from-bovine-experiment/
Related research article	There is no related research article.

Introduction

In response to growing global concerns about climate change and decarbonisation, research efforts in the livestock sector, particularly in ruminants, have increasingly focused on identifying effective strategies to mitigate enteric methane (**CH_4**) emissions (Beauchemin et al., 2020; Roques et al., 2024). For this purpose, it is essential to quantify enteric CH_4 emissions accurately. The respiration chamber method has long been regarded as the gold standard; however, it presents several limitations related to cost, labour intensity, and the low number of animals that can be measured simultaneously (Bhatta et al., 2007; Hristov et al., 2015; Tedeschi et al., 2022). Thus, alternative methods to quantify individual CH_4 emissions such as the head box chamber (Kelly et al., 1994; Odongo et al., 2008) and sulphur hexafluoride tracer gas (Zimmerman, 1993; Johnson et al., 1994) have been developed. In response to this trend, C-Lock Inc. (Rapid City, SD, USA) developed the GreenFeed® (**GF**), a modified open-circuit respiration chamber and head box system, that collects gases emission (i.e., CH_4, carbon dioxide (**CO_2**), hydrogen (**H_2**)) or consumption (i.e., oxygen (**O_2**)) by animals for 24-h while feed consumption at discrete visits to the unit (Hristov et al., 2015; Jonker et al., 2016; Doreau et al., 2018). This system is one of the powerful tools for measuring individual CH_4 emission in large and small ruminants without restricting animal behaviour; it has been used in various environments, not only in confined systems but also in grazing systems (Waghorn et al., 2016). As a result, more than 900 units have been exported to 48 countries since 2011 (C-Lock, personal communication). However, the GF records in real time different types of data from different sensors (i.e., gas concentrations such as CO_2, CH_4, H_2, O_2, air flow, visit duration, animal identification, etc.) at each individual visit, making it difficult to analyse collected datasets. To address this, Martinez-Boggio et al. (2025) developed an R package called *greenfeedr*, which processes the data and generates reports. This package enables users to load data files directly from the C-Lock server and provides functionalities such as outlier removal, basic report generation, and simple descriptive statistics. Nevertheless, its use assumes familiarity with GF data and basic proficiency in the R statistical environment. Therefore, we aimed to develop a user-friendly analysis program that guides all GF users (experienced or novices) without R programming skills to manage large GF datasets easily.

Material and methods

GreenDA development

GreenDA development was based on the Shiny app framework in R (Cheng, 2012). The standalone program was created using DesktopDeployR (Lee, 2016), which embeds R-portable (R version 4.2; Redd, 2022) within the application along with the required R packages: chron, dplyr, DT, ggplot2, lme4, openxlsx, plotly, psych, readxl, shiny, shinyjs, shinyWidgets, and tibble. As a result, it comes prepackaged with all necessary dependencies, requiring no additional installation steps beyond installing the program itself. Detailed instructions for using all functions are provided within the integrated software manual. The schema of our application is presented in Fig. 1.

Data file preparation

We strongly recommend using the validated final data file from C-Lock®. This step involves removing data from sick animals, malfunctioning machines, and adaptation periods of the animals to the experimental conditions (e.g., diets, GF machines). These data must be deleted from the data file before uploading to GreenDA.

Data processing

Outlier elimination is considered the first step in data analysis (Sauvant et al., 2008).

Outlier elimination based on airflow

If the airflow is below a threshold, the unit may not capture enough of the animal's breath, which can result in an underestimation of gas flux. Therefore, GreenDA incorporates a function to exclude data based on an airflow criterion. Following the method described by Gunter et al. (2017) for large ruminants, the default threshold is set to 26 L/s, and all data recorded below this airflow are removed. This threshold can be adjusted by the user.

Outlier elimination based on visit duration

In the C-Lock algorithm, data recorded for less than 2 min are excluded to ensure the capture of at least one eructation event during the measurement time. Therefore, GreenDA, along with the C-Lock algorithm, defines 2 min (120 s) as the baseline visit duration. This duration can be adjusted to be longer than two minutes, depending on the user.

Outlier elimination according to the statistical approach

There are various methods available to identify and eliminate extreme values. Among these, our application implements three elimination methods: (1) one method based on SD, and (2) two methods based on correlation between CO_2 and CH_4.

The first method for outlier removal based on the SD, assuming normal distribution, considers that any values falling outside the range of the overall mean ± the specified SD threshold are outliers, which are then excluded from the dataset.

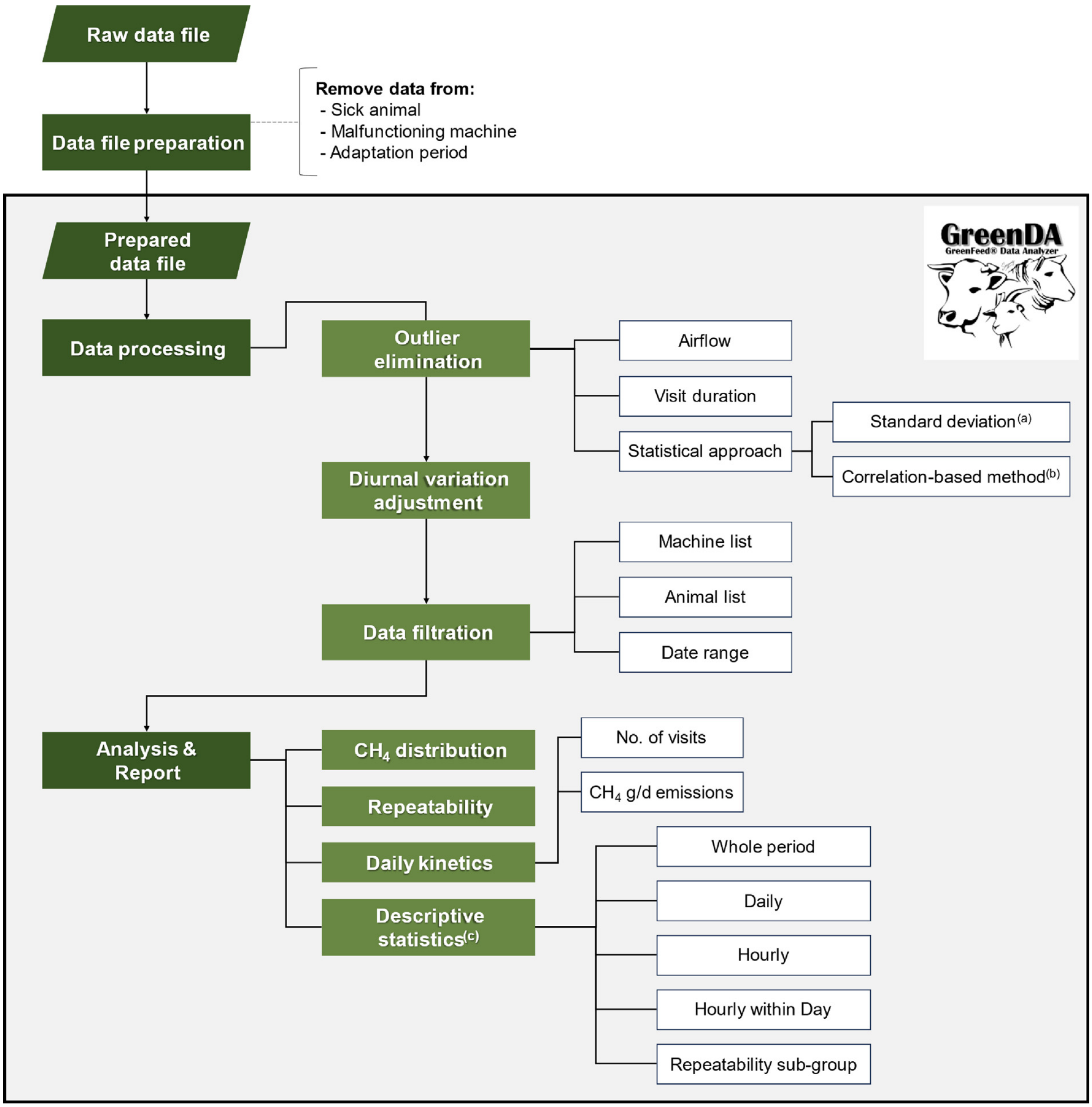

Fig. 1. Workflow of GreenDA for GreenFeed® data analysis. In the statistical approach, (a) the SD-based method, values that deviate from the mean by more than ± SD (default: 3 SD) are considered to be outliers and are removed, (b) The correlation-based method follows the approach of Arbre et al. (2016) and Coppa et al. (2021), where regression equations between carbon dioxide and methane (CH_4) are established, (c) Descriptive statistics include the average and variation of gas flux, as well as the total number of visits, number of animals, and number of visits per animal. Hourly-based statistics additionally include the sum of visit durations.

$$OUT = \{x_i \in X | x_i < \mu - k\sigma \text{ or } x_i > \mu + k\sigma\}$$

where OUT is the set of outliers, x_i denotes the ith measurement of gas flux, X is the set of all observed gas flux points, μ is the arithmetic mean of X, k is the user-defined multiplier for the SD used to determine the threshold (default: 3), and σ is the SD of X.

The second method used for outlier elimination in GreenDA is based on the significant correlation between CO_2 and CH_4 fluxes according to the approach of (1) Arbre et al. (2016) and (2) Coppa et al. (2021). Arbre et al. (2016) proposed a method to remove data points that deviate significantly from the regression line between CO_2 and CH_4. The Pearson correlation coefficient (r) between $CH_4{}^*$ and $CO_2{}^*$ was calculated and used in the outlier detection criterion.

$$\text{dist} = \frac{\text{abs}(CH_4^* - CO_2^*)}{\sqrt{2}}$$

with $CH_4^* = (CH_4 - Mean_{CH_4})/SD_{CH_4}$ and $CO_2^* = (CO_2 - Mean_{CO_2})/SD_{CO_2}$. If dist > 3 × $\sqrt{1-r}$, where r is the correlation coefficient between CH_4^* and CO_2^*, the data points are considered as outliers. Coppa et al. (2021) proposed an outlier detection method based on a simple linear regression equation between CO_2 and CH_4 fluxes. Specifically, regression equations are constructed to predict CO_2 from CH_4 and vice versa using observed data. Based on these equations, predicted values for CO_2 and CH_4 are calculated, and residuals are obtained by subtracting the predicted values from the observed values. The SD of the residuals of both CO_2 and CH_4 is then computed. A data point is considered an outlier if the absolute value of either residual divided by its corresponding SD exceeds 3 ($|\frac{Residual}{SD}| > 3$).

In GreenDA, three of the outlier elimination methods are applicable to CH_4 and CO_2 fluxes, and the entire data line is discarded if an outlier is detected in either CH_4 or CO_2 data. However, for H_2 and O_2 fluxes, only the SD-based outlier removal method can be applied, and if an outlier is found in either of the 2 gases, only the specific outlier value is removed.

Diurnal variation adjustment

Individual CH_4 emission is depending on the timing of each animal's visit to the GF. To prevent potential under- or over-estimation of individual CH_4 emissions, we applied the method proposed by Fresco et al. (2023) that accounts for the overall hourly emission pattern.

$$y_{hij} = \mu + H_h + a_i + e_{ij}$$

where y_{hij} is the measured raw CH_4 emission for the ith animal at the hth hour on the jth observation, μ is the overall mean of CH_4 emissions of the herd, H_h is the fixed effect of the hour of the day (0 to 23 h, 1-h intervals) to account for diurnal variation, a_i is the random effect of ith animal, and e_{ij} is the residual error term, assumed to be normally distributed. The reference time for estimating the effects of hour of the day was set to the time closest to the overall herd average. The adjusted CH_4 measurement was calculated as:

$$adjCH_{4_{hij}} = y_{hij} - H_h$$

where $adjCH4_{4_{hij}}$ is the adjusted CH_4 emission for the ith animal at the hth hour on the jth observation.

Data filtration

Once data cleaning is completed, users can select the specific datasets for subsequent analysis. This selection includes the animal list, the GF machine list, and the date range, all of which are automatically generated based on the uploaded file. Users may exclude specific animals or machines, and they can also define a continuous date range to be included in the analysis. However, any problematic data should have been processed before this step. This step is intended for cases where the data itself are valid, but filtering is desired (e.g., analysis by specific GF machines). In particular, when selecting the date range, users can check both the total duration of data and the number of days per subgroup used for repeatability (**REP**) calculation (i.e., divider). If REP estimation is desired, the selected date range should be adjusted to ensure that the number of dividers is at least two.

Analysis and report

Enteric methane data distribution

The user can check the distribution graph of enteric methane data. The distribution graph is available for the entire dataset as well as for each treatment.

Repeatability calculation of enteric methane data

To calculate the REP of CH_4, the total duration of the experiment will be regrouped into multiple subgroups of equal length of day (Fig. 2). GreenDA automatically computes all feasible subgroups based on the user-defined date range by grouping together the lines corresponding to consecutive days. For example, if the total experimental duration is 10 days, the possible subgroup lengths include 1 day/subgroup (ten subgroups), 2 days/subgroup (five subgroups), and 5 days/subgroup (two subgroups).

In GreenDA, we estimated the REP for each subgroup using the following model with the lme4 package in R (Bates et al., 2015):

$$y_{ikj} = \mu + P_k + a_i + e_{ij}$$

where y_{ikj} is the average CH_4 emission for animal i in subgroup k at replicate j, μ the overall mean, $P_k \sim N(0, \sigma_P^2)$ the random subgroup effect of the subgroup k with σ_P^2 the subgroup variance, $a_i \sim N(0, \sigma_a^2)$ the random animal effect with σ_a^2 the animal variance, $e_{ij} \sim N(0, \sigma_e^2)$ the random residual effect and σ_e^2 the residual variance.

If the inclusion of an additional fixed effect in the REP estimation is desired, this can be achieved by defining the contemporary group within the application. The contemporary group is defined as the subset of the herd subject to the same treatment or environmental conditions. Accordingly, when the objective is to account for treatment effects in the calculation of REP, the treatment should be specified as the contemporary group. So, when an additional fixed effect is included in Bates et al. (2015) model, the equation is as follows:

$$y_{ikj} = \mu + T_l + P_k + a_i + e_{ij}$$

where T_l is the fixed effect of the contemporary group l.

The REP was estimated according to the following formula:

$$repeatability = \frac{\sigma_a^2}{\sigma_a^2 + \sigma_P^2 + \sigma_e^2}$$

Daily kinetic analysis (herd, animal, and treatment level)

GreenDA allows daily kinetic analysis for the number of visits and daily CH_4 emissions. The total number of visits is calculated for each 1-h interval of the day between 0 and 23 h. Average CH_4 emissions and their variation (SD or SEM) across the day can also be calculated. If the user performed diurnal variation adjustment, the user can check the smoothed CH_4 kinetic results through the adjusted graph.

Descriptive statistics (herd, animal, and treatment level)

GreenDA provides basic descriptive statistics to support further analyses. Data can be aggregated by whole experimental period, day, hour, hour within each day, or REP subgroup. For each analysis, the average and SD of gas fluxes (i.e., CO_2, CH_4, $adjCH_4$, H_2, and O_2), along with the number of visits, number of animals, and number of visits per animal, are provided. Additionally, visit duration is included in the hourly analysis and hourly within-the-day analysis.

Demonstration of GreenDA functioning with a bovine case study

A total of 56 bovines from an experimental farm were phenotyped indoors for their CH_4 emissions over a 105-day period during

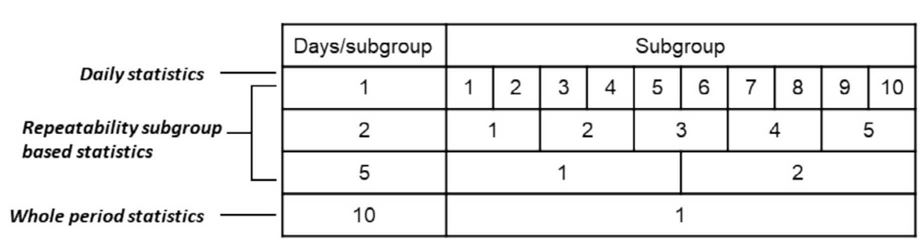

Fig. 2. Time scale for repeatability calculation and descriptive statistics.

the winter of 2024 using two GF. The study was conducted according to a 2 × 2 factorial design comprising two diets without additives (A and B; treatment 1) and two suckling cow breeds (C and D; Treatment 2). Animals were raised in free-stall and fed forage-based diets distributed once daily at 0830 h as *ad libitum*. Three animals exhibiting feed intake problems were excluded from the example dataset analysis (n = 53).

Two GF machines (GF 111 and GF 112) provided bait to attract animals to visit GF and were calibrated to distribute 6 drops of 40 g every 30 s per animal and per visit at minimum 3-h intervals (i.e., 1 920 g maximum of concentrate delivered per day and per cow). In total, 19 749 measurements were obtained, with an average of 3.5 ± 1.18 visits per day per animal. The animals stayed at the machine for an average of 3 min 11 s (± 41 s).

The dataset used in this article to demonstrate the functionality of GreenDA did not influence the development of its functions. Therefore, GreenDA can be applied to analyse other datasets without limitation, including those generated from experimental designs different from the one used in this study.

Results

Data processing

In our dataset, a total of 33 records (0.17%) were obtained at an airflow below 26 L/s, with no significant differences in CO_2 and CH_4 fluxes between measurements recorded below and above this threshold (Table 1). But with an airflow below 27 L/s, 131 records (0.66%) were recorded, and significant differences were observed in CO_2 and CH_4 fluxes (Table 1). The three methods of outlier elimination according to the statistical approach, included in GreenDA, were applied to our dataset cleaned with airflow (26 L/s) and visit duration (2 min). A total of 91 records (0.5%) were removed based on the 3 SD criterion, 104 records (0.5%) according to the Arbre et al. (2016) method, and 170 records (0.9%) according to the Coppa et al. (2021) method. In our dataset, the R^2 between CO_2 and CH_4 fluxes was 0.47 ($P < 0.01$). The results of the completed diurnal correction can be found in the adjusted CH_4 results of CH_4 kinetics (Fig. 3).

Analysis and reports

Both graphs from the entire dataset and from each treatment showed a normal enteric CH_4 distribution shape (Fig. 4). The dataset collected over a 105-day period was subdivided into subgroups of 1, 3, 5, 7, 15, 21, and 35 days to calculate REP. As the number of days per period increases, variation among subgroups decreases, resulting in a tendency for REP to increase until reaching a plateau (Fig. 5; 0.62 at 7 days/subgroup). The kinetics of the total number of visits enables a visual assessment of temporal patterns in animal visit behaviour, revealing periods of high and low activity (Fig. 6; Supplementary Figure S1). In our dataset, the CH_4 emission pattern showed a sharp increase at 0900 and 1600 h (Fig. 3). Additionally, this daily pattern, unlike the visit pattern, did not show differences according to treatments (Supplementary Figure S2). Descriptive statistics were provided for the entire dataset across five-time scales (i.e., whole period, daily, hourly, hourly within the day, and REP subgroup periodically) and five grouping criteria (entire, by animal, by treatment 1, by treatment 2, and by treatment 1 × treatment 2). The corresponding output files can be found in Supplementary Material S1.

Author's points of view

Data processing

Outlier elimination based on airflow

Data collected at an airflow of 20 L/s or less for large ruminants are excluded during C-Lock's data preprocessing procedure (C-Lock, personal communication). Gunter et al. (2017) reported that CO_2 and CH_4 emission estimates decreased as airflow rate decreased below 26 L/s for large ruminants in a GF. In contrast, McGinn et al. (2021) and Christodoulou et al. (2025) proposed exclusion of data recorded at airflow rates below 27 L/s. So, although the default airflow threshold of GreenDA is set at 26 L/s, it can be adjusted to other values (e.g., 27 L/s) depending on the user's dataset.

Outlier elimination based on visit duration

Most of the gases emitted through respiration consist of CO_2, whereas CH_4 is primarily released in the form of eructation events occurring at 1- to 2-minute intervals (Van Soest, 1982). Thus, a minimum visit duration is required to ensure that at least one eructation event is captured while the animal is at the machine. In GreenDA, a default threshold of visit duration is 2 min for data cleaning in alignment with C-Lock's algorithm, but this value could be adjusted based on the user's experimental design. The frequency of eructation per minute varies depending on factors such as cattle breed, physiological stage, and diet (Garnsworthy et al., 2012; Velazco et al., 2016; Bell et al., 2018). Nevertheless, it has been reported that setting the visit duration threshold at 3 min, rather than 2 min, generally requires fewer data points to reach the desired level of REP (Arthur et al., 2017; Beck et al., 2024). In our dataset, when we applied 3 min threshold, we deleted 40% of the total records. Thus, this threshold should be determined according to the experimental design and dataset. For instance, in an upland grazing system where the number of data points is limited compared to indoors (Bouchon et al., 2024), discarding visits shorter than 3 min may be problematic, as a considerable proportion of the records could fall below this threshold.

Outlier elimination according to a statistical approach

The removal of outliers based on the 3 SD is a commonly used approach in the processing of ruminant nutrition data (Fischer et al., 2020; Martinez-Boggio et al., 2025). However, the applied SD range may vary depending on the study (Cottle et al., 2015; Renand and Maupetit, 2016). Considering this, a default threshold

Table 1
Differences in carbon dioxide (CO_2, g/day) and methane (CH_4, g/day) fluxes in cattle according to the airflow threshold of the GreenFeed®.

	26 L/s[1]			27 L/s[2]			*P*-value	
	Lower	Higher	SEM	Lower	Higher	SEM	26 L/s	27 L/s
CO_2	11 385	11 834	304.0	11 290	11 837	152.9	0.14	<0.01
CH_4	413	409	22.3	387	409	9.1	0.85	0.01

[1] Average gas flux classified as lower (<26 L/s; n = 33) and higher (≥26 L/s; n = 19 716) when the optimal airflow criterion was set at 26 L/s.
[2] Average gas flux classified as lower (<27 L/s; n = 131) and higher (≥27 L/s; n = 19 618) when the optimal airflow criterion was set at 27 L/s.

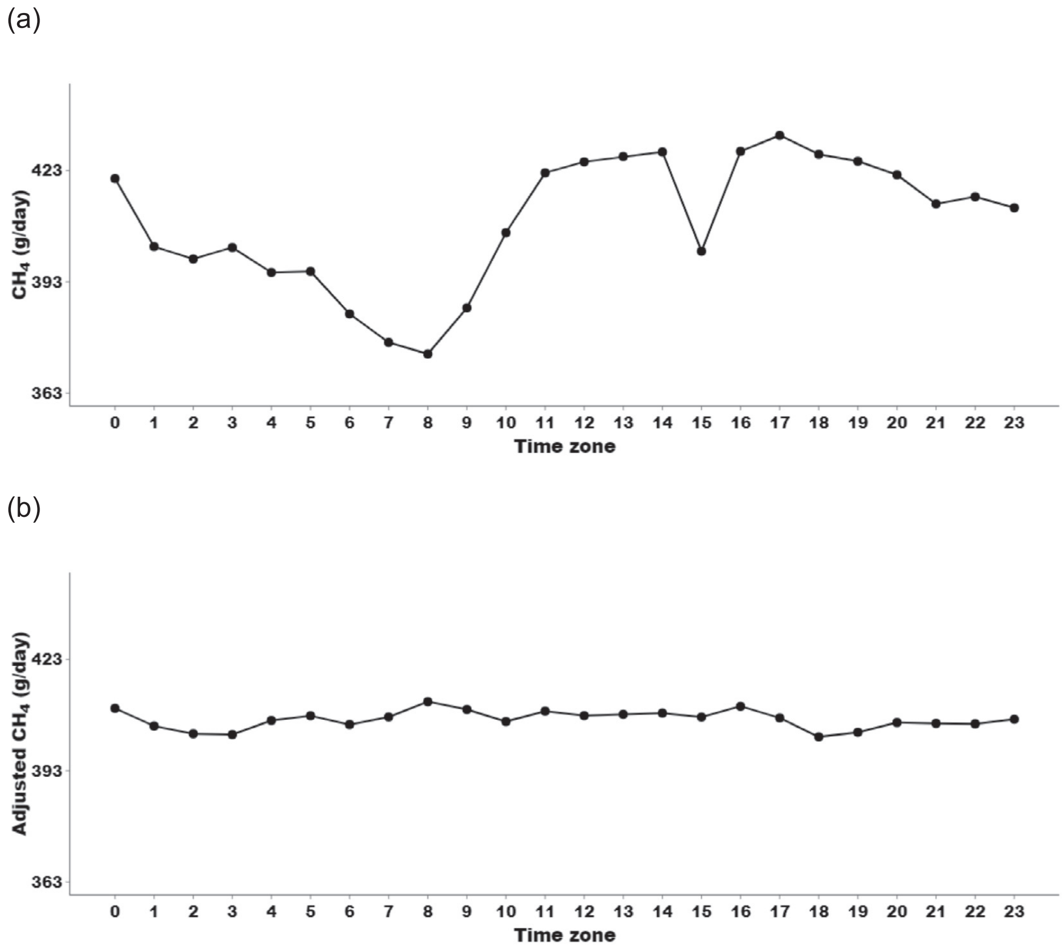

Fig. 3. Average methane (CH_4) emission in cattle across the day: (a) hourly average CH_4 emission for the entire herd, (b) hourly average CH_4 emission for the entire herd adjusted for diurnal variation. Time zone refers to the average of data at 1-h intervals.

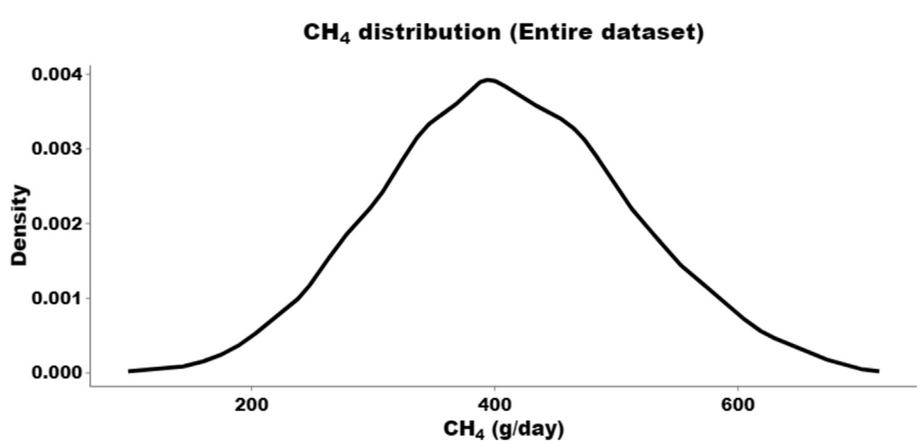

Fig. 4. Distribution of methane (CH_4) emission data for the entire herd of cattle.

of 3 SD is used in GreenDA, but the value can be adjusted according to the user's preference. In addition, particularly when analysing experimental data using a treatment that may affect CH_4 emissions, the user must check the dataset distribution in advance, and if the distribution differs significantly depending on the treatment group, the dataset must be divided for outlier elimination.

The two methods based on correlation are applied under the assumption that CO_2 and CH_4 fluxes exhibit a strong correlation (Aubry and Yan, 2015). These methods are not the most suitable for our dataset given the low correlation between CO_2 and CH_4. Thus, users should be checking the significance of correlation between the two gases before applying correlation-based methods. In addition, certain additives may reduce CH_4 emission without affecting CO_2 flux levels (Kim et al., 2020; Melgar et al., 2020). Therefore, user should select an appropriate elimination method according to their experimental conditions.

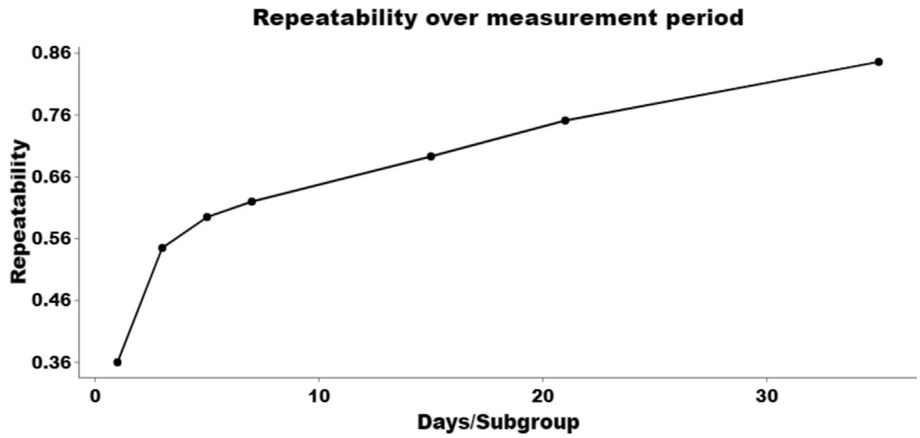

Fig. 5. Repeatability of methane emission in cattle during the experimental period (105 days) divided into several subgroups.

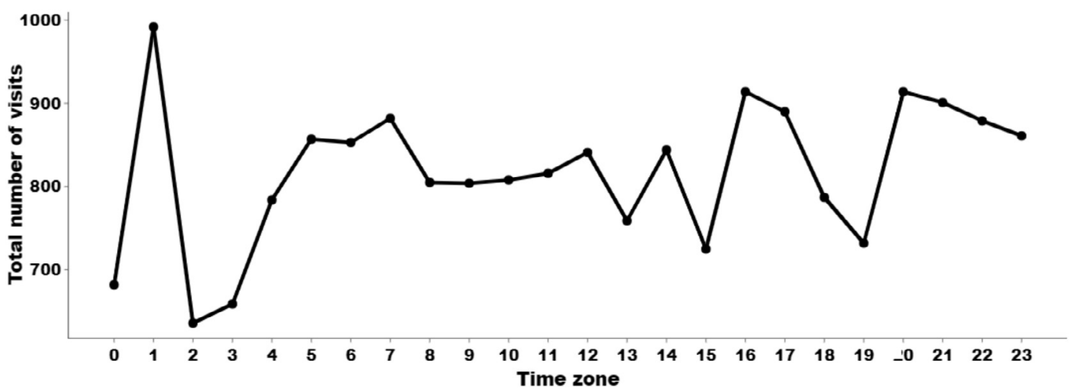

Fig. 6. Total number of visits across the day for the entire herd of cattle. Time zone refers to the average of data at 1-h intervals.

Diurnal variation adjustment

Recently, several studies have suggested the necessity of considering diurnal variation when analysing gas flux data from the GF (Manafiazar et al., 2017; Fresco et al., 2023; Beck et al., 2024). This diurnal pattern is known to be associated with feeding patterns on the farm. Methane emissions typically increase immediately after feed allocation and then gradually decline until the next allocation (Bell et al., 2018; Fresco et al., 2024). It has been reported that adjusting for such variation can improve model performance in estimating daily CH_4 emissions (Fresco et al., 2024).

But for the diurnal correction to function effectively, it is necessary to have a distribution of visits throughout the day at the herd level. Although more recent models, such as that proposed by Fresco et al. (2024), incorporate farm-level effects, GreenDA assumes that datasets from different farms should be analysed separately. Therefore, GreenDA does not consider farm effect.

Analysis and reports

Repeatability calculation

When animal biological data are collected over multiple days, REP reflects the consistency of repeated measurements within the same animal (Wolak et al., 2012; MacNeil and Waterman, 2025). Thus, in CH_4 data analysis using GF, calculating REP is one of the essential steps to determine the minimum number of days required to ensure robust data. Users can identify the point at which REP reaches a stable plateau through the graphical output, thereby determining when the data become stabilised. However, if there are few visit points during the experimental period or the variation of the data fluctuates greatly, there are cases where a plateau is not reached. High REP does not necessarily prove data accuracy, but if REP is low or unstable, results should be interpreted with caution, taking into account within-animal variation. It is important to note that, for REP calculations, it is also important to have data points for every possible date for each animal. Otherwise, differences in residual variance may occur, which could lead to misinterpretation of the data.

Daily kinetic analysis (herd, animal, and treatment level)

Using the GF, it is important to verify that the daily kinetics of CH_4 emission are related to the intake pattern, as is the case in our dataset (data not shown). Examining the patterns of CH_4 emission and visit frequency is particularly essential in studies using feed additives. In particular, when using GF, evaluating the kinetic patterns is essential in studies involving compounds that specially suppress CH_4 emission following major feeding events (e.g. nitrate and 3-nitrooxypropanol). If the visit patterns do not align with the intake pattern, CH_4 emissions may be over- or under-estimated (Doreau et al., 2018).

Conclusion

We have developed an R-based user-friendly software tool, GreenDA, for analysis of large datasets generated by automated head chamber systems such as GreenFeed®. This software includes different functionalities for preprocessing data, basic descriptive statistics and calculations, as well as data visualisation. In addition, GreenDA provides a useful procedure for the scientific community to analyse datasets collected with the GreenFeed®. GreenDA is freely available and will be continuously improved based on feedback from GreenFeed® users. In addition, although the software was designed to be broadly applicable across all ruminant species, its functionality for small ruminants could not be validated due to the lack of available datasets. Thus, we were unable to test its performance in small ruminants or propose appropriate default parameter values for their use. This will be evaluated once additional data become available.

Peer Review Summary and Supplementary material

Peer Review Summary and Supplementary material for this article (https://doi.org/10.1016/j.anopes.2026.100151) can be found at the foot of the online page, in Appendix A.

Ethics approval

This study was conducted at the INRAE's Herbipôle experimental facility (https://10.15454/1.5572318050509348E12, Laqueuille, France) in accordance with the French Ministry of Agriculture guidelines on animal research and all applicable European guidelines and regulations, with no need for additional authorisation by the local ethics committee for GreenFeed data acquisition.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

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Additional information

The software described in this article is protected by copyright® CeCILL version 2.1 and has been registered with the Inter Deposit Digital Number (IDDN) system under the identifier IDDN.FR.001.300031.000.S.C.2025.000.10000. This registration confirms the originality of the source code and its legal protection.

The development and distribution of this software tool are intended to support all GreenFeed® users. This does not imply that INRAE officially endorses GreenFeed® as the standard method for quantification of enteric CH_4 emission. C-Lock was not involved in the development of this software.

Raw dataset file, supplementary figures, and supplementary material can be found in Data.gouv (https://www.data.gouv.fr/datasets/greenfeed-result-data-set-generated-from-bovine-experiment/).

GreenDA software, including a manual, is available on GitHub (https://github.com/INRAE-UMRH-Dinamic).

Financial support statement

This research was supported by the Methane 2030 program, which is part of the France 2030 national project. The Methane 2030 program was funded by several sectors, including the French government and APIS-GENE.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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