CarbonSECO for Livestock: A Service Suite to Help in Carbon Emission Decisions

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Abstract: Global concerns about agriculture's impact, mainly related to the livestock enteric fermentation producing methane Greenhouse Gas (GHG) emissions, demand solutions to mitigate these impacts. The CarbonSECO platform, tailored for carbon credit generation in Brazilian rural areas, responds to the popularity of carbon credits to offset GHG emissions. However, additional solutions related to GHG need to be conceived. This article extends the CarbonSECO platform, focusing on quantifying, monitoring, and controlling carbon emissions from livestock enteric fermentation. Intelligent techniques, including ontologies and machine learning, provide emissions management solutions for assessing and managing the environmental impact of livestock farming. These techniques address the research question of mitigating carbon emissions from Brazilian dairy farming. The article explores strategies, reviews related works, and proposes platform extensions. A feasibility study using data from an intelligent farm showcases the platform's ability to predict and assess changes for carbon emission reduction. As a result, this work enhances the CarbonSECO platform, offering emissions management for dairy farming. Integrating ontologies and machine learning can promote standardization, aiding property owners in better planning.

1 INTRODUCTION

Global warming and its possible consequences on life on earth have gained more and more space and importance in society, transforming the mitigation of Greenhouse Gas (GHG) emissions into the main focus of environmental debates and policies. In the Brazilian context, agriculture plays a significant role in greenhouse gas (GHG) emissions, representing 33.6% of the total, with 19% originating from enteric fermentation (Embrapa, 2023b).

Enteric fermentation is a natural process in ruminant herbivorous animals, the result of converting vegetable carbohydrates into fatty acids used as a source of energy by the animal that ingested the food. During this conversion, gases such as methane are produced, which is exhaled into the atmosphere during the rumen. These gases are responsible for worsening the greenhouse effect, resulting in accelerated climate change (Siqueira and Caviglioni, 2021). Livestock farming is responsible for 97% of methane emissions, divided between 86% from beef cattle and 11% dairy cattle. Notably, methane from enteric fermentation is one of the main sources of emissions in milk production, contributing 40 to 58% of the total, followed by waste management (Embrapa, 2023a).

Carbon credits represent a way to measure and offset greenhouse gas (GHG) emissions associated with specific activities, like dairy farming. A carbon credit is generated for each ton of carbon that is no longer emitted or captured from the atmosphere. Using selected and validated rules and methodologies, whether projects are reducing emissions is analyzed. To generate credits, actions must be taken to replace an activity that would generate greenhouse gas emissions with another solution that would reduce or eliminate these emissions (WayCarbon, 2022).

The "baseline" (Vale Fund, 2022) is a key aspect to be addressed by a carbon project. Every project needs to determine what its emissions would have been if the project had not been implemented. These

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are called "baseline emissions" (Vale Fund, 2022). The number of credits a project receives is then calculated by subtracting the project's emissions from the baseline emissions. The definition of the baseline will depend on the project activity and the sector, to determine which elements and parameters should be considered for the project.

The Federal University of Juiz de Fora, in partnership with EMBRAPA (an acronym for Brazilian Agricultural Research Corporation) and the Federal University of Goiás, develop projects in the domain of dairy farming (Gomes et al., 2023; Ambrósio et al., 2021; Soares et al., 2021; Magaldi et al., 2017) to seek computational solutions to support dairy production activities. With this partnership, a software ecosystem platform was proposed, called E-SECO (Ambrósio et al., 2021), an evolution of the collaborative E-Science project, to support the development of solutions for agribusiness.

E-SECO encompasses several functionalities to facilitate the development of this type of application, considering the use of scientific workflows and the process of scientific experimentation. In E-SECO, data analysis is an important component (Gomes et al., 2023). This platform offers a suitable environment for carrying out various stages of experiments involving data related to dairy farming, ranging from problem investigation, prototyping, planning, conduction/analysis, packaging of results, and preparation of reports (Ambrósio et al., 2021).

Based on the evolution of the group's research (Gomes et al., 2023), we extended the E-SECO platform to CarbonSECO (Santos et al., 2023). CarbonSECO aims to enable the development of applications related to generating carbon credits on rural properties in Brazil. CarbonSECO prioritizes mechanisms that offer analysis, reliability, and traceability of data and processes in carbon certification projects (Santos et al., 2023).

Considering the importance of this topic today, the relevance of Brazil in the global carbon emission scenario, and specific decisions of COP 28[1], this article presents specific extensions made on CarbonSECO to quantify, monitor, and control carbon emissions from enteric fermentation. Specific services were developed, expanding the CarbonSECO support on carbon emissions in dairy farming, considering intelligent techniques. These new services use ontologies and ML techniques to provide intelligent solutions for managing greenhouse gas emissions from livestock farming. The main goal is to offer these services to be used in developing applications for evaluation and managing the environmental contributions of livestock farming. Specifically, these services can assist in developing decision-making applications, based on predictions about specific features related to the production process of milk and its derivatives. In this regard, a feasibility study was conducted, with data from the smart farm maintained by EMBRAPA- Gado de Leite. It was possible to predict planned changes to reduce carbon emissions using ontological processing and ML.

This work's Main Research Question (RQ) is "How to help mitigate carbon emissions from dairy farming, with a focus on Brazilian farms?". To address this specific topic, this article is organized into the following sections, including this introduction. Section 2 discusses Brazilian strategies for dealing with issues related to carbon emissions. In section 3, related work is discussed. Section 4 presents the CarbonSECO extension proposal. In section 5 a feasibility study is detailed. In section 6, conclusions and future work are presented.

2 BACKGROUND

The global reference for quantifying greenhouse gas (GHG) emissions, is the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2021). The IPCC established a standard bottom-up predictive model, which has undergone refinements over time. These models are stratified into different levels of complexity. Tier 1 is the simplest, using standard emission factors based on general literature. Tier 1 does not consider the characterization of regional livestock systems, such as breed types, animal age, and physiological issues (IPCC, 2021). Tier 2 incorporates detailed emission factors, adding specific characterization of food and animals, using estimates based on gross energy consumption (GEI) and CH_4 conversion factor (Ym, expressed as % of GEI converted to CH_4) (IPCC, 2021).

The Verified Carbon Standard (VCS) Program stands out as a global leader in voluntary certification of carbon offsets (Greenfield, 2023). With a background of more than a billion tons of carbon and other greenhouse gas emissions reduced or removed through VCS-certified projects, this program plays an essential role in the ongoing global effort to protect our shared environment (Verra, 2022).

Considering the VCS, the proposal presented in this article is related to Tiers 1 and 2. Emissions in the reference scenario are estimated as the sum of annual emissions from enteric fermentation according to the

[1] https://www.un.org/en/climatechange/cop28

following equation:

$$BE_{Enteric_i} = \sum_{j=1}^{n} \left[EF_{Enteric_{i,j}} \times GWP \times 0.001 \right] \quad (1)$$

Where:

$BE_{Enteric_i}$ = Total CH_4 emissions in the reference scenario from enteric fermentation of cattle on the farm i tCO_2.

$EF_{Enteric_{i,j}}$ = Enteric CH_4 emissions factor for animal group j during the monitoring period $kgCH_4$.

GWP = Global Warming Potential of Methane.

n = Total number of animal group on farm i.

To determine the enteric emission factor, it is possible to use two calculations, the choice depending on the availability of data for each group of animals on the farm. The first option provides procedures to calculate the enteric emission factor for each group of animals, applying an IPCC Tier 2 method, using the following equation:

$$EF_{Enteric_{i,j}} = \sum_{j=1}^{n} \left[\frac{GEI_j \times Y_{m_j} \times N_{i,j} \times Days_{i,j}}{100 \times EC} \right] \quad (2)$$

Where:

$EF_{Enteric_{i,j}}$ = Enteric CH_4 emission factor for group of animals j during the monitoring period ($kgCH_4$).

GEI_j= Average gross energy consumption (GEI) per animal in group j on farm i ($MJhead^{-1}d^{-1}$).

Y_{m_j} = Conversion factor indicating the proportion of GEI converted into enteric CH_4 energy by animal group, CH_4 energy as a percentage of gross (dimensionless) energy.

$Days_{i,j}$ = Number of days spent on farm i by each animal in group j during the monitoring period (d).

$N_{i,j}$ = Average number of heads in group of animals j on farm i in the monitoring period (head).

EC = Energy content of methane ($55.65MJkg^{-1}$)

Average Gross Energy Intake (GEI) is calculated by multiplying Average Dry Matter Intake (DMI) by the energy density of the food, using the following equation:

$$GEI_j = DMI_j \times ED \quad (3)$$

Where:

DMI_j = Average dry mass of food consumed by the group of animals j on a given day (kg head^{-1} d^{-1}).

ED = Average dry matter energy density (MJ kg^{-1}). Standard values of 19.10 MJ kg^{-1} for diets that include oils with a fat content in the range of 4 to 6%, or 18.45 MJ kg^{-1} for diets that include oils with a fat content below 4%, can be utilized.

The second option is applicable in cases where certain data required for the calculations of the first option are unavailable. In this scenario, Tier 1 enteric fermentation emission factors for cattle and buffalo are employed. The enteric emission factor for each group of animals is computed using the formula:

$$EF_{Enteric_{i,j}} = EF_{Production_{i,j}} \times N_{i,j} \times Days_{i,j} \quad (4)$$

Where:

$EF_{Enteric_{i,j}}$ = Enteric CH_4 emission factor for the group of animals j during the monitoring period (kg CH_4).

$EF_{Production_{i,j}}$ = Average enteric CH_4 emission factor for the group of animals j during the monitoring period (specific national or regional factors) (kg CH_4 head^{-1} d^{-1}).

$Days_{i,j}$ = Number of days spent on farm i by each animal in group j during the monitoring period (d).

$N_{i,j}$ = Average number of heads in the group of animals j on farm i in the monitoring period (head).

In this article, we apply these calculations to quantify emissions from enteric fermentation based on the type of information provided by farms. Section 5 presents examples of specific calculations using the proposed equations.

3 RELATED WORKS

The literature presents few works that deal with carbon emissions to mitigate and assist in decision-making on emissions-related practices. Some works deal with general context, but none effectively propose computational strategies, especially those involving intelligent processing. In this context, we seek to build an architecture with the objective of supporting the development of a software ecosystem platform, called CarbonSECO.

(Tedeschi et al., 2022) reviewed methods for quantifying methane emissions from ruminants and their manure. The study addresses various measurement techniques from classical methodologies, such as breathing chambers, to micrometeorological approaches, and explores the challenges associated with each method. The authors emphasize the need for accurate quantification of greenhouse gas emissions, mainly methane, to ensure adequate reporting in greenhouse gas inventories and to design effective methane emissions mitigation strategies. The review shows the diversity of approaches, including aircraft, drones, and satellites and highlights the importance of addressing knowledge gaps and research requirements in this field. Among the methodologies covered are those for calculating methane emissions using the Tier 1 and Tier 2 approaches proposed by IPCC.

(Mazzetto et al., 2022) investigated the carbon footprint of bovine milk production in several countries, identifying critical factors such as allocation methods and functional units that significantly influence results. The 21 studies analyzed revealed considerable variations in carbon footprint estimates, highlighting the process's complexity. Additionally, the study highlighted mitigation strategies, focusing on the importance of waste management, livestock feed production, and fertilization methods to reduce emissions. The findings provide practical insights for the industry, indicating specific areas for interventions aimed at reducing the environmental impact of bovine milk production, with the caveat that strategies must be adapted to the agricultural conditions of each country.

(Wang et al., 2023) conducted a review on the impact of digital technologies, including the Internet of Things, Big Data, cloud computing, blockchain and AI, on sustainable supply chains. It highlights the application of these technologies in specific practices, such as green procurement, environmentally conscious production, sustainable consumption and ecological logistics. The study emphasizes these technologies' interconnectedness and potential to reduce energy consumption, contributing to greener and more efficient supply chains. It also includes the need to explore pricing on sharing platforms, the design of integrated digital systems, and continued technological innovations.

(O'Brien et al., 2014) investigated the impact of methodological decisions in Life Cycle Evaluation (LCE) on the carbon footprint of milk in dairy production systems. The authors highlighted the influence of greenhouse gas emissions allocation between co-products and the lack of consistency in international LCE standards. Issues related to carbon sequestration and land use change emissions were addressed. The study highlights the need for more specificity in the LCA methodology for accurate comparisons between different dairy production systems.

(Pirlo and Carè, 2013) also address milk production's greenhouse gas (GHG) emissions. They proposed LatteGHG, a tool to estimate the carbon footprint of cow's milk produced under typical conditions in Italy. The study shows the effectiveness of LatteGHG in the environmental evaluation of production systems, revealing the model's sensitivity to variables such as milk production and manure management. Despite the simplicity of some emission factors, the research highlights the continued need to improve the accuracy of estimates of emissions of gases such as methane and nitrous oxide, considering diet composition and animal performance.

(Vogel and Beber, 2022) examine the carbon footprint and mitigation strategies on heterogeneous dairy farms in Paraná, Brazil. Grouping farms into four categories through statistical analysis and life cycle evaluation, the study highlights striking differences in carbon footprint between these groups. Farms with the largest carbon footprint predominate in the region, characterized by less specialized herds and less technical support. To address climate change in the sector, the study highlights the need to promote sustainable practices, integrating them into a broader approach to environmental governance and regional socioeconomic development.

(Desjardins et al., 2012)) analyzed the carbon footprint of cattle in countries such as Canada, the United States, the European Union, Australia, and Brazil, highlighting variations from 8 to 22 kg of CO_2 per kg of live weight. Over the past few decades, improvements in management practices have resulted in significant reductions in greenhouse gas emissions per unit of product. The study addresses the influence of different factors, such as breeding systems, locations and management practices, and discusses the competition for higher-quality land in beef production. It also shows the importance of considering changes in soil carbon due to land management. In general, it considers that the carbon footprint is just one aspect of beef production, and it is essential to consider the impact on services and biodiversity for a complete evaluation of the product's environmental sustainability.

(Singh et al., 2015) propose an integrated cloud-based system to measure and reduce the beef supply chain's carbon footprint. Aimed especially at small and medium-sized farms, the system allows access to carbon calculators through a private cloud, providing crucial information to optimize emissions. Furthermore, the collaborative approach aims to improve stakeholder coordination, identify sustainable practices, and address the consumer demand for transparency and traceability in beef production. The study highlights the relevance of CCT in mitigating carbon emissions, contributing to environmental efficiency and government carbon reduction targets.

(Liu et al., 2023) investigated the impact of implementing digital technology on carbon emission efficiency on dairy farms in China using empirical methods and farm data. The results highlighted a positive influence of digital technology on improving carbon emission efficiency, emphasizing precision feeding technology as the biggest contributor. Farmers' educational experience, technical training, and gov-

Table 1: Comparison of related works.

Authors	Architecture and SECO	Intelligent Processing	Enteric Methane Emissions	Decision Support
(O'Brien et al., 2014)			✓	
(Pirlo and Carè, 2013)			✓	
(Vogel and Beber, 2022)			✓	✓
(Desjardins et al., 2012)			✓	
(Singh et al., 2015)	✓		✓	✓
(Liu et al., 2023)			✓	✓
(Berhe et al., 2020)			✓	✓
(Santos et al., 2023)	✓	✓		✓
(Gomes et al., 2023)	✓	✓		✓

ernment incentives contributed to carbon efficiency. It was observed that the application of digital technology had a more pronounced effect on farms with lower initial emission efficiency, highlighting the importance of environmental regulation as a positive moderator in this process. The findings provide insights for strategies for transitioning to low-carbon, digital dairy production systems.

(Berhe et al., 2020) analyzed the impacts of different interventions on greenhouse gas (GHG) emissions in livestock production systems in Ethiopia. A reduction in total GHG emissions was observed by improving livestock feed, implementing improved manure management practices, and optimizing herd production and reproductive parameters. Dietary supplementation with corn grains resulted in a decrease in enteric methane emissions. Furthermore, the joint implementation of these interventions demonstrated an overall reduction in emissions, highlighting the importance of integrated management to promote environmental efficiency in livestock production systems.

These results contribute to understanding the factors influencing GHG emissions in different production systems, providing insights for environmentally sustainable mitigation strategies. (Gomes et al., 2023) present the evolution of the E-SECO platform to address automation in livestock farming, highlighting the e-Livestock architecture to improve animal production. Two case studies at the Compost Barn system demonstrate the platform's effectiveness. The importance of self-adaptation, AI, and IoT is highlighted to face dynamic challenges in agriculture, promoting efficiency and preventing losses in animal production. The article points to the rise of Livestock IoT (LIoT) as a new area of research, emphasizing the need to study specific requirements and technologies for livestock farming with the widespread adoption of IoT. (Santos et al., 2023) propose the CarbonSECO platform for the Control of Carbon Credits, addressing the growing concern about climate change. Focusing on changing land use as Brazil's main source of emissions in 2021, the CarbonSECO platform is presented as support for developing applications related to controlling emissions/carbon credits on rural properties. The aim is to generate knowledge to offer alternatives for cultivating land and mitigating greenhouse gas emissions. The platform incorporates intelligent data analysis, highlighting its potential positive impact on the Brazilian agricultural sector. Preliminary results demonstrate the platform's viability, with an analysis of carbon stocks on a rural property, highlighting its potential to provide insights into sustainable agricultural practices and reducing greenhouse gas emissions. The contribution of our work in the group lies in introducing a service that deals with managing carbon emissions while incorporating intelligent data analysis to provide alternative solutions in the livestock sector. Our approach seeks to reduce emissions and promote sustainable livestock practices.

Table 1 highlights the main features of each work presented in this section. These studies reflect the complexity and diversity of approaches needed to address greenhouse gas emissions in livestock farming, indicating the importance of quantification methods, mitigation strategies, and technological solutions. As we can see, no works propose a suite of intelligent services to support decision-making related to greenhouse gas emissions using intelligent processing as we do in our work. In this regard, our work presents a proposal encompassing services for quantifying, monitoring, and controlling emissions from enteric fermentation while at the same time offering support for evaluating management in livestock farming, extending the functionalities of the CarbonSECO platform proposed in (Santos et al., 2023). The focus

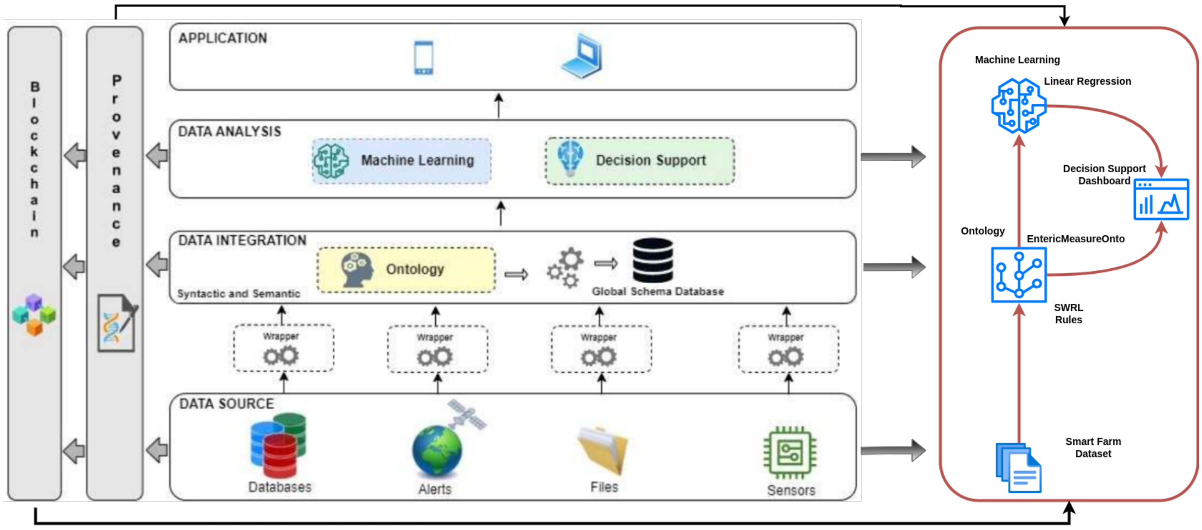

Figure 1: CarbonSECO Main Services with Enhanced Livestock Carbon Emissions and Control Services (Santos et al., 2023).

is to provide specific services that allow rural producers to quantify methane emissions from ruminants and make decisions based on strategic analyses provided by the platform, such as estimates of the impact of a new diet strategy. These services reinforce the support of the CarbonSECO platform in controlling greenhouse gas emissions in agriculture in general, adding specific services for evaluating and managing environmental contributions in ruminant farming.

4 CARBONSECO FOR LIVESTOCK

As stated before, the CarbonSECOfor Livestock is an evolution of our previous platform CarbonSECO (Santos et al., 2023) to provide a suite of services related to managing carbon emission/credits in the livestock domain. CarbonSECO emphasizes mechanisms that bring intelligent analysis to Carbon certification projects. Figure 1 presents CarbonSECO's main services enhanced with new services (left of the figure) related to livestock carbon emissions and control, the article's focus.

It is not our objective to detail the CarbonSECO previous services. They are detailed in (Santos et al., 2023). The new service components are discussed below.

4.1 Smart Farm Dataset

In addition to the databases related to rural properties and crops, new data sources, primarily associated with livestock, were added to CarbonSECO. The data comes from various sources, whether data from sensors attached to the animals, such as necklaces and earrings, or platforms for weighing and feeders with intake control. In addition, specific measurements of milk production and animal registration data, including their traceability, are part of the data from Smart Datasets' data sources. However, to guarantee the reliability of the carbon measurement process, it must be based on international guidelines and methodologies, such as the IPCC, used by CarbonSECO (IPCC, 2021).

4.2 Ontology Processing

The EntericMeasureOnto ontology was developed to identify semantic relationships between data, resulting in the discovery of specific features that must be observed in the carbon measurement process. For example, based on semantic relationships, we can identify a feeding protocol that explicitly does not present an increase in carbon emissions but which, based on the relationships identified in the ontology can be an indirect source of increased carbon emissions. This type of relationship can only be discovered by processing inferences and semantic rules defined in the ontology. Consequently, optimizing livestock management on a specific rural property can improve the carbon credits associated with that property.

For this, classes and different types of relationships were defined in EntericMeasureOnto Figure 2, using the OWL language (World Wide Web Consortium, 2004), SWRL rules (SWRL, 2004), and the Pellet reasoner (Sirin et al., 2007). The main ontological classes are: **RuralProperty**, which represents a rural property, **BaselineEmissons**, which represents

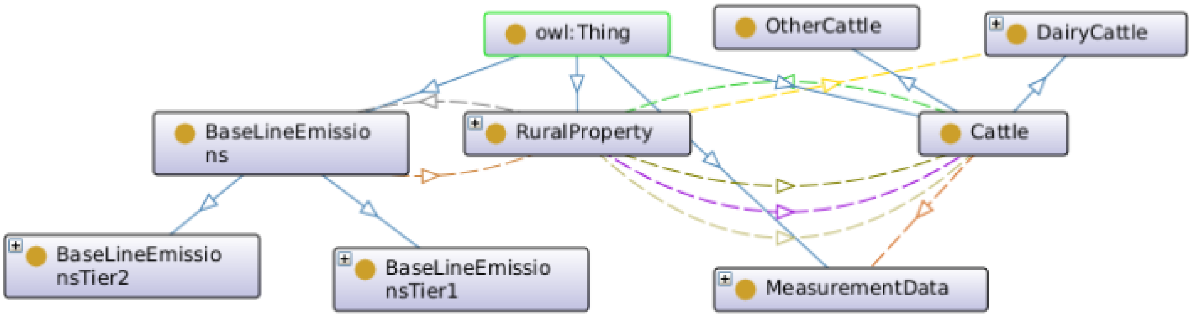

Figure 2: Main ontological classes.

Table 2: SWRL rules.

Tag	Rule
S1	Cattle(?cattle) ˆ milkProduction(?cattle, ?production) -> DairyCattle(?cattle)
S2	Cattle(?cattle) ˆ DairyCattle(?cattle) ˆ emissionFactorTier1(?cattle, ?e) ˆ daysOnFarm(?cattle, ?d) ˆ multiply(?result, ?e, ?d) ˆ -> individualEntericEmissionFactorTier1(?cattle, ?result)
S3	Cattle(?cattle) ˆ individualEntericEmissionFactorTier1(?cattle, ?eeft1) ˆ gwp(?cattle, ?gwp) ˆ multiply(?result, ?eeft1, ?gwp, 0.001) ˆ -> individualEntericEmissionTier1(?cattle, ?finalResult)
S4	DairyCattle(?cattle) ˆ energyDensity(?cattle, ?e) ˆ dryMatterIntake(?cattle, ?d) ˆ multiply(?result, ?e, ?d) ˆ -> grossEnergyIntake(?cattle, ?result)
S5	Cattle(?cattle) ˆ grossEnergyIntake(?cattle, ?gei) ˆ daysOnFarm(?cattle, ?d) ˆ emissionFactorTier2(?cattle, ?ef) ˆ multiply(?result, ?gei, ?d, ?ef, 0.01) ˆ divide(?finalResult, ?result, 55.65) ˆ -> individualEntericEmissionFactorTier2(?cattle, ?finalResult)
S6	Cattle(?cattle) ˆ individualEntericEmissionFactorTier2(?cattle, ?eeft2) ˆ gwp(?cattle, ?gwp) ˆ multiply(?result, ?eeft2, ?gwp, 0.001) ˆ -> individualEntericEmissionTier2(?cattle, ?finalResult)

the baseline methane emissions from the enteric fermentation of animals, **BaselineEmissonsTier1** and **BaselineEmissonsTier2**, which represents the baseline methane emissions from the enteric fermentation of animals from the Tier 1 and 2 calculation methods respectively, **Cattle**, which represents the cows for which enteric emissions are estimated, **DairyCattle** and **OtherCattle**, which represent the cows that are producing milk or not, respectively, **MeasurementData**, which represents the data measurements associated with a Cattle instance. ObjectProperties were also specified to implement the relationships and specific rules in SWRL (SWRL, 2004) to process carbon emissions. As stated before, the rules were specified according to Tier 1 and 2 calculations.

As a result, using the declared model (explicit knowledge) with the addition of specific SWRL rules and inference mechanism (Pellet reasoner), the ontology infers, from the instantiated data, new relationships under the actions on the rural property. As specific examples, in Table 2, **Rule S1** infers that if an animal has milk production, it is a DairyCattle instance. **Rule S2** infers the enteric CH_4 emission factor for the animal during the monitoring period according to Tier 1. **Rule S3** infers the enteric CO_2 emission for the animal during the monitoring period according to Tier 1. **Rule S4** infers the average gross energy consumption for the animal. **Rule S5** infers the enteric CH_4 emission factor for the animal during the monitoring period according to Tier 2. **Rule S6** infers the enteric CO_2 emission for the animal during the monitoring period according to Tier 2.

4.3 Decision Support

Data analysis on a rural property can potentially discover insights that help manage and plan emissions related to livestock practices. Furthermore, they provide support in the adoption of sustainable practices. To assist in decision support related to carbon emissions, in addition to the ontology, which allows the discovery of new relationships between data, we use ML techniques to predict specific actions to improve practices related to carbon emissions. To do this, we

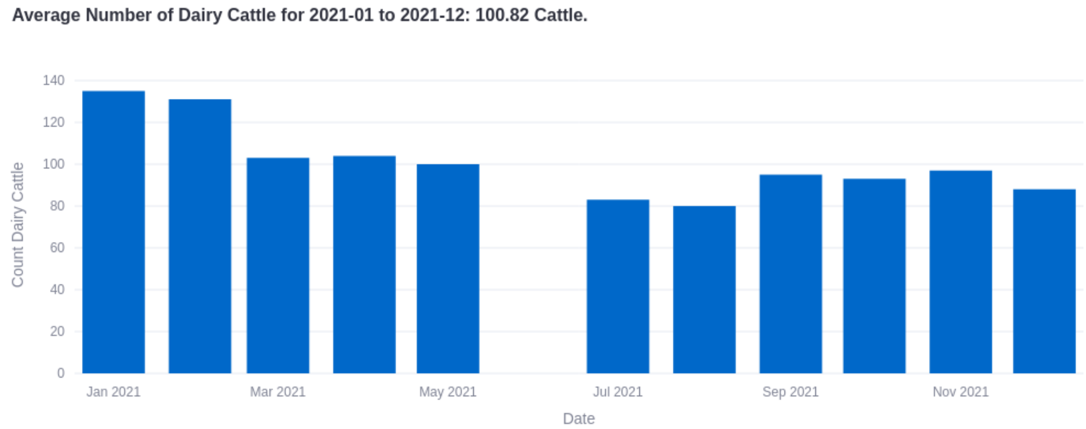

Figure 3: Number of Dairy Cattle Over Time.

use linear regression to analyze and predict emissions linked to practices carried out on the farm. A dataset was used with data captured by sensors and specific measurements on the farm, plus specific data generated from information delivered by experts, including the average daily consumption of dry matter, the energy density of the feed, and the average number of cattle in a specific period. These variables were used as training data for the linear regression model. Throughout the training process, the algorithm adjusted the coefficients to optimize the model's ability to predict emissions based on changes in the variables considered.

In this context, the use of ML techniques aims to assist in predictive analysis of the carbon emissions of a rural property, taking into account expectations of changes in diets and the number of animals over a specific period. This predictability helps in planning farm activities and anticipating specific actions related to carbon emissions by the property, such as sharing knowledge and allowing more informed choices about the best conditions for using animal diet inputs.

This data analysis is presented on a dashboard to assist in decision-making. It uses graphs and specific variables, allowing an integrative view of carbon management on the property, offering insights into the environmental performance of its practices, and enabling strategic adjustments to achieve sustainable goals. For example, Figure 3 depicts a graph illustrating the number of dairy cattle on the property throughout 2021 in Embrapa's Smart Farm.

5 FEASIBILITY STUDY

This section details a feasibility study to evaluate CarbonSECO livestock's new services. This evaluation considers using CarbonSECO to deal with quantifying, monitoring, and controlling carbon emissions from enteric fermentation. The scope of the study was defined as "Analyze the use of the CarbonSECO Livestock services from the point of view of Farmers in the context of data extracted from Dairy Smart Farm".

From this scope, we derived the RQ: "How to help mitigate carbon emissions from dairy farming, with a focus on Brazilian farms?". The data extracted can be reached at GitHub [2]. This data set encompasses 162 animals, including sensor data and production system-related details, with 3,381 observations collected from January 2021 to December 2021, encompassing monthly data collection that occurred during three milking sessions. The dataset includes key features such as Tag (serving as a unique identifier), Weight (measured in kilograms), Milk Production (indicating the quantity of milk produced), and Date (recording the month of the measurement). For this analysis, the monitored cow remained on the property throughout the month. It's important to note that no measurements were recorded in June. To process this data, we used the EntericMeasureOnto ontology.

To find out existing ontologies that can be reused in this evaluation, a search was conducted. Unfortunately, no one that fits our purposes was found, therefore, the domain ontology was specified, considering the steps specified in (Verra, 2020; Nicola and Missikoff, 2016; Feilmayr and Wöb, 2016), and the data extracted from the Smart Farm related to EMBRAPA's research projects.

Using the CarbonSECO new services, we seek to make predictions on calculating emissions in a future scenario. These predictions can help choose strate-

[2]https://github.com/PedroAssisDev/Measuring_Enteric_Fermentation_Emissions/blob/main/data/pesoXleite.csv

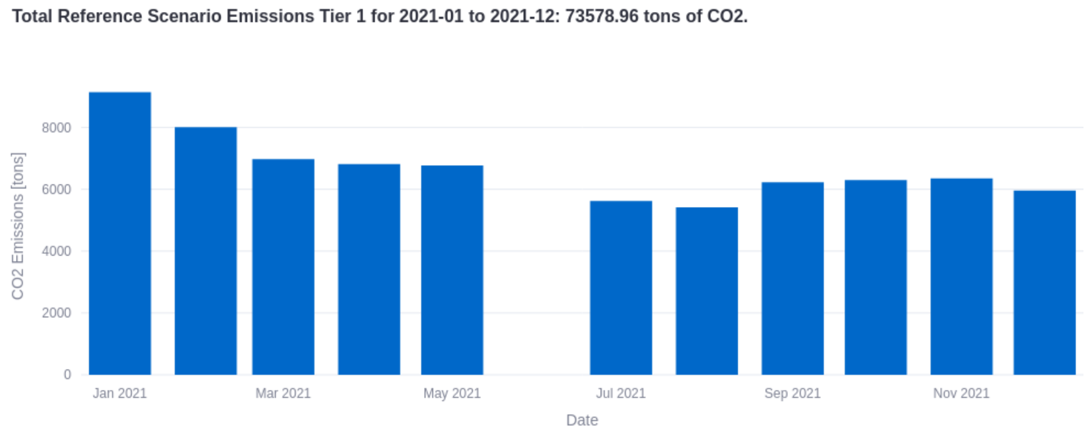

Figure 4: Monthly Carbon Emissions using Tier 1 Methodology.

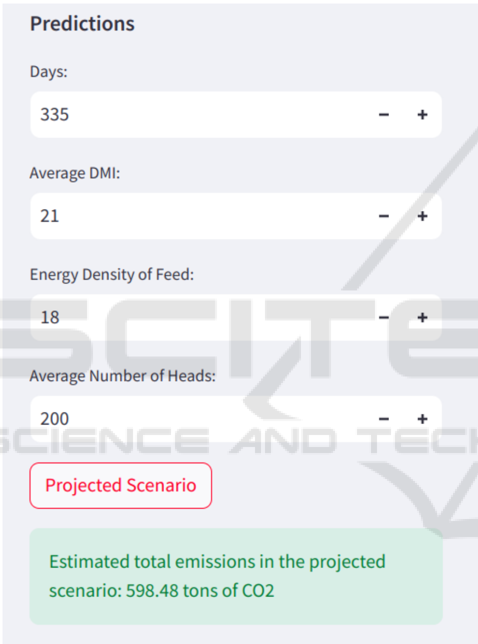

Figure 5: Projected Total Carbon Emissions using CarbonSECO Service.

gies for mitigating carbon emissions from livestock farming. Therefore, based on the available data, it was possible to carry out emission calculations using the EntericMeasureOnto ontology, following the Tier 1 method. These calculations imply that the analysis of carbon emissions in dairy farming benefited from the ontology's structuring and organization, improving the results' precision and reliability. Figure 4 illustrates the carbon emissions trends over the months, emphasizing the total emissions for the period.

To verify the calculation module utilizing the Tier 2 method, we added values into the dataset related to the diet of animals. In this context, the Average Energy Density and Average Dry Matter Intake were 25 kg per head daily and 18 MJ/kg, respectively. The emissions were subsequently computed using the EntericMeasureOnto ontology, following the Tier 2 method. Figure 6 presents the monthly progression of carbon emissions, detailing both the individual monthly values and the cumulative total for the specified period.

To evaluate the feasibility of the forecasting module, we processed a specific dataset with a fixed duration of 335 days, providing a representative timeframe for the analysis. Key input parameters included the average daily dry matter intake (Average_DMI), 21, representing typical feeding conditions for cattle. The energy density of the feed (Energy_density_of_feed) wwas 18, as a measure of the nutritional characteristics of the diet. The average number of cattle (Average_number_of_heads) in the dataset was 200.

Using the CarbonSECO service in processing this dataset, it became feasible to forecast an estimated emissions total. The results indicate a projected total of 598.48 tons of CO2, offering insights into the anticipated environmental impact within the specific context of the provided conditions and practices. This projection is graphically illustrated in Figure 5 , providing an overview of the evolution of emissions and the total impact over the specified period.

In summary, the feasibility study of CarbonSECO Livestock's new services yielded insights into carbon emissions management in dairy farming. These results help farmers in decisions related to carbon emissions in the farm. Therefore, the CarbonSeco helps in decision support related to caron emissions. Utilizing Tier 1 and Tier 2 methods, and incorporating specific data, we could answer the RQ, "How to help mitigate carbon emissions from dairy farming, with a focus on Brazilian farms?". The Tier 1 method, using actual data from Dairy Smart Farm showcased the efficacy of the EntericMeasureOnto ontology in refining car-

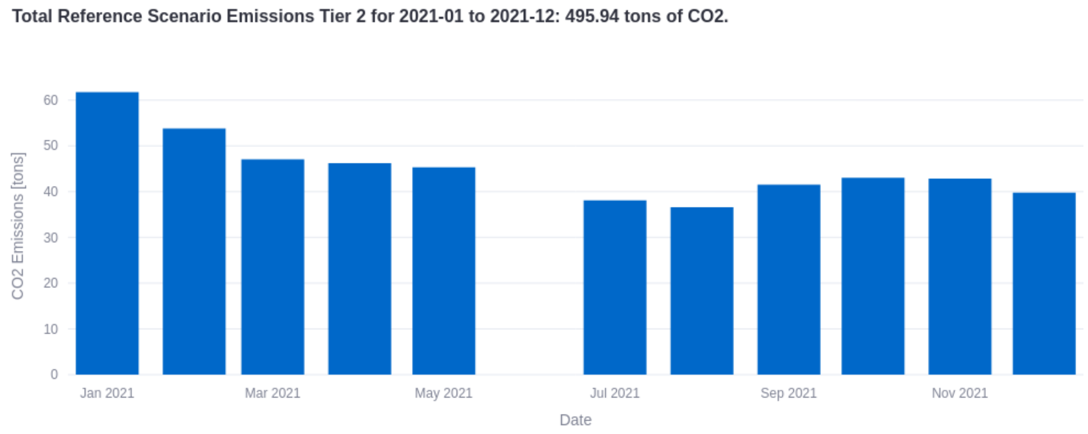

Figure 6: Monthly Carbon Emissions using Tier 2 Methodology.

bon emission calculations, enhancing precision and reliability. Illustrated trends in Figure 4 emphasized monthly evolution and total impact, aiding informed decision-making.

The Tier 2 method, employing specific values, showed CarbonSECO's calculation module capability. The projection of 598.48 tons of CO2 over 335 days offers a predictive tool for farmers, providing proactive mitigation strategies and fostering sustainable livestock management practices.

Therefore, CarbonSECO Livestock has the potential for carbon emission management in dairy farming, providing services for real-world and predictive scenarios. The results and comparisons lay the groundwork for further exploration, fostering environmentally conscious decision-making in the agricultural sector.

6 CONCLUSIONS AND FUTURE WORK

This paper presented services for quantifying, monitoring, and controlling emissions from enteric fermentation that will be integrated into CarbonSECO. This addition expands the platform's capacity to cover specialized services focused on carbon emissions and supports the development of applications related to generating carbon credits on Brazilian rural properties.

The utilization of ontologies and ML algorithms contributed to the standardization and estimation of future emissions, these intelligent technologies empower property owners with better planning capabilities.

The integration of these services supports the CarbonSECO platform with new functionalities, provides the user with social and environmental considerations, promoting sustainable production practices with reduced carbon generation. This, in turn, provides valuable decision support for stakeholders dealing with carbon emissions in the agricultural sector.

In future work, it is essential improve the proposed service with different methods for calculating fermentation emissions arising from enteric fermentation. Additionally, there is a need for continuous improvement of the machine learning module to enhance the system's predictive accuracy. The adaptation and incorporation of new types of input data to enrich the analytical capabilities of the platform further. Lastly, the addition of a new service dedicated to quantifying, monitoring, and controlling animal waste emissions will provide a comprehensive solution, ensuring a more embracing approach to environmental sustainability in livestock farming.

DATA AND CODE AVAILABILITY

The data used in this study and the code implementation are available at https://github.com/PedroAssisDev/Measuring_Enteric_Fermentation_Emissions

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