VetAgro Sup

Master's Thesis

Analysis of the environmental performance of a network of PDO dairy farms in the Jura Mountains

What contributions and solutions to greenhouse gas emissions for the farms studied?

JOERG Marie

Master Global Quality in European Livestock Production

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ANCOVA : Analysis of covariance
ANOVA : Analysis of variance
AOC: Controlled Designation of Origin
CAP: Common Agricultural Policy
CAP2ER: Calcul Automatisé des Performances Environnementales en Élevage de Ruminants
CH4: Methane
CIGC: Comité Interprofessionnel de Gestion du Comté
CO2: Carbon dioxyde
FNAOP: Fédération Nationale des AOP laitières
FPA : Fodder production area
GHG: Greenhouse Gas
Ha: Hectare
HAC: Hierarchical ascendant classification
INAO : National Institute of Origin and Quality
IPCC: Intergovernmental Panel on Climate Change
LCA: Life Cycle Assessment
LU: Livestock Unit
N2O: Nitrous oxide
OA: organic agriculture
PCA: Principal Component Analysis
PDO: Protected Designation of Origin
SNBC: Stratégie Nationale Bas Carbone
STH: Areas still under grass
UAA: Useful Agricultural Area
UL : unit of labor
URFAC: Union Régionale Des Fromages d’Appellation d'Origine Comtois

Introduction

« It's obvious that earth's climate is changing since decades, and human activity incidence on climatic system is not to prove anymore » said Valérie Masson-Delmotte *Intergovernmental Panel on Climate Change* (IPCC) 2021 I workgroup vice-president. Tough, population, politics and every activity sectors have to react in order to reduce this incidence. Dairy cattle breeding is often targeted when talking about environment, on right purpose because it is responsible of 6.4% of greenhouse gas emissions (Dollé *et al.*, 2015). Second biggest agribusiness branch with 29.8 billion of euros, just after meat subsidiary (CNIEL, 2019). However, its economic health is becoming more and more unstable. Because of quality and origins identification systems, some productions like Jura mountains Protected designation of origin (PDO) managed to stand out. Now they must keep this quality while facing environmental challenges.

The Jura mountains PDO milk subsidiary must adapt itself to the climate change which causes extreme weather conditions (dryness and rain) with important consequences. The surface productivity limitation described in the Comté PDO specifications, concentrates and mineral nitrogen fertilizers limitation take part in this adaption yet. Fédération Nationale des Appellations d'Origine Protégée (FNAOP) works showed that the average greenhouse gas emissions (GHG) into the Jura mountains PDO is about 0.48 kilograms of CO2 equivalent per liter of corrected milk (kg CO2 eq/L of milk) (Michaud, 2016) when the national average is 0.83 kg CO2 eq/L of milk (Idele, 2021). However, the best actions must still be improved in order to reach the Jura mountains PDO goals: a 18% emissions reduction by 2030 (fixed by the National Low Carbon Strategy (SNBC) for the agricultural branch).

In this context, a group engaged into the peasant agricultural and/or biological process introduced the Clim'AOP Jura project. Their objective is to confront their practical methods with scientist data, in order to strengthen or improve the way they answer to the climate change. In fact, into the Comté PDO, they are not a lot of biological agricultural data which is a production mode highly involved in the environment cause. This leads to ask the following questions: What are the environmental performances of the Jura mountains PDO dairy farms? More particularly, what are those of the biological ones? Which technical parameters could explain the environment performance differences between these farms? What are the most efficient ways to fight against the climate change? To answer these questions, a study was put in place into forty-six farms of the Comté PDO zone. The diagnostics and results of this study, made with the multicriteria evaluation tool CAP2ER, are presented in this report.

The first part of the report will present the context of the Clim'AOP Jura study, including the current state of knowledge on climate change and the environmental impacts of livestock farming, the place of livestock farming in Bourgogne-Franche-Comté, and the current state of political and sectoral strategies for dealing with climate change. Then, we will present the problematic and the working hypotheses. After a second part explaining the materials and methods, we will present the results through a descriptive analysis of the data, a classification of the farms according to their GHG emissions and then, an analysis of covariance to try to identify significant action levers. The results will be discussed as we go along thanks to the bibliographic contributions enriched by expert opinion. Finally, after noting the limitations of this work, perspectives for the continuation of the Clim'AOP Jura project will be proposed.

Table 1 - The origins of the different GHG emissions in livestock farming. Source: personal.

CO2 emissions	Direct energy consumption: fuel consumption on the farm
	Indirect energy consumption: during the manufacture and transport of inputs (fertilizers and feed)
CH4 emissions	Enteric fermentation from the rumination phenomenon
	Fermentation of livestock manure during storage
N2O emissions	Direct emissions: during the application of mineral or organic nitrogen
	Indirect emissions: due to nitrification/denitrification processes via soil microorganisms, ammonia volatilization and nitrate leaching
	Storage of animal waste

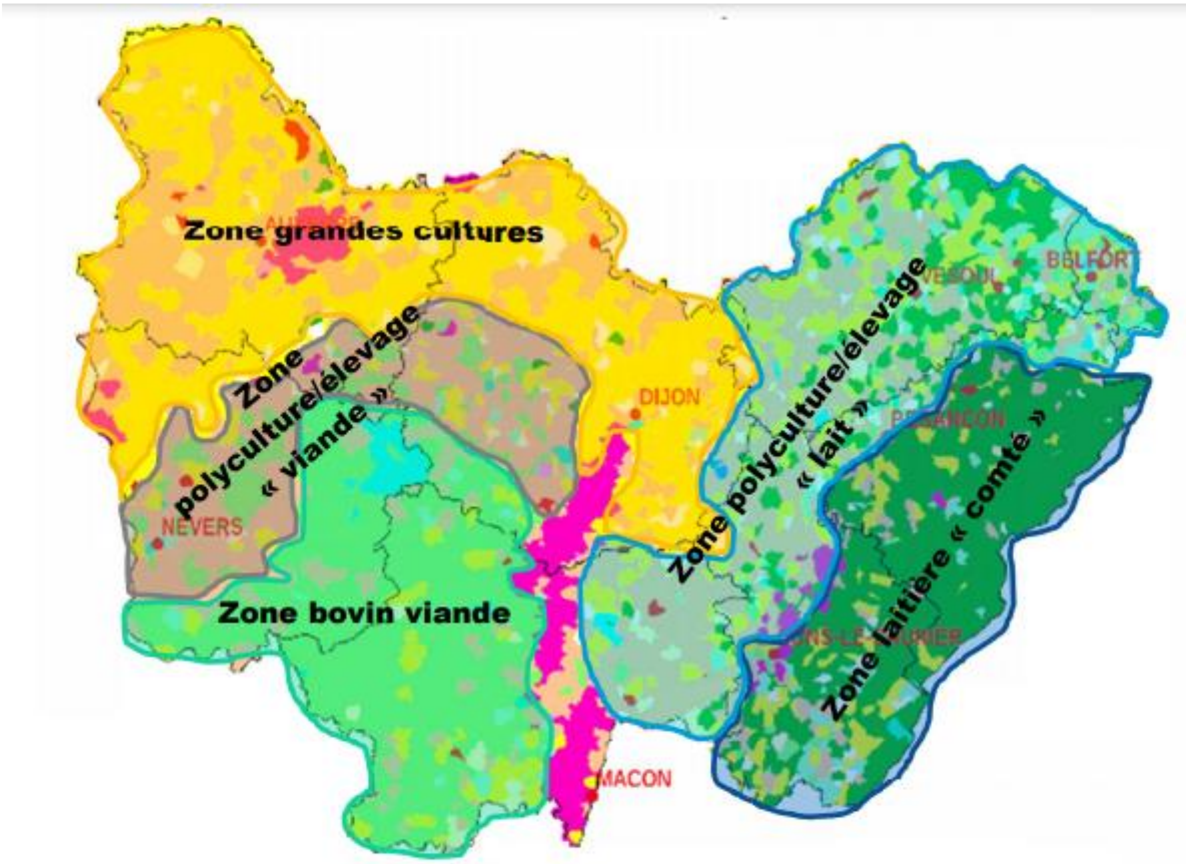


Figure 1 - Map of the main agricultural production areas in Bourgogne-Franche-Comté. Source: ADEME Bourgogne-Franche-Comté, map base: annual agricultural statistics 2010.

Zone de grandes cultures : Field crop zone - Zone de polyculture/élevage "viande" : Polyculture/meat breeding zone - Zone bovin viande : meat cattle zone - Zone polyculture/élevage "lait" : Polyculture/dairy farming area - Zone laitière "comté" : « Comté" dairy zone

I. Clim'AOP Jura: study background

1. Climate change

1.1 Climate change inventory

Nowadays, climate change is becoming a major cause of concern to human population and in numerous sectors. Internationally, between 1850 and 1900, according to reference data, global temperature has increased by 1.1°C until 2019. Worldwide emissions of carbon dioxide (CO2) have been dramatically increased by 67% between 1990 and 2018 while global sea level rose about 9 centimetres 1993 et 2019. In Metropolitan France, temperature has risen about 1.8°C between temperature relative to 1961 from 1990 and 2019. In Europe and in France, in contrast, GHG decreased between 1990 and 2018 (from 23% to 19% respectively) (Ministère de la transition écologique, 2020). The unusual rapid increase in Earth's average surface temperature or the average sea level rise are good indicators to demonstrate that climate has changed over the last century.

Global warming is caused by the emissions of GHG that modify the greenhouse effect, the consequences of this climate imbalance are multiple: tempests, droughts, floods, rise of the sea level, impacts on agricultural production, and so on.

Human activities, amongst others, have an impact on the climate equilibrium. By releasing high concentrations of GHG, those activities contribute to an increase of global average surface temperatures, it's the enhanced greenhouse effect.

In 2018, 31% of the emissions of GHG are linked to the transport sector, 19% to agriculture, 19% to residential and tertiary sector, 18% to manufacturing and construction, 10% to the energy industry, and 3% to waste (Citepa, June 2020).

In France, currently, if no climate policies are implemented, global surface temperature could rise up to 3.9°C by the end of this century. However, with climate policies focusing on stabilizing CO2 concentration, global surface temperature should be limited to a rise of 2.2°C (Météo France, 2020).

1.2 Environmental impact of agriculture and ruminant breeding

The agriculture sector comes in second and accounts for 19% of GHG emissions. In 2018, emissions linked to energy consumption in this sector represented only 12.2% of the total, most of it being made up of methane (CH4 - 45%) mainly due to livestock and nitrous oxide (N2O - 42%), because of crop fertilization (Citepa, 2020).

However, according to the official documents of the SNCB, the agricultural sector must face and meet many challenging expectations which do not facilitate change in the actual practice: "feeding the populations, providing energy and materials, ensuring the sustainability of landscapes and biodiversity, meet growing demands in terms of sanitary and environmental quality of production, cope with pressure on land, while reducing emissions of GHGs and atmospheric pollutants, and do so in economic and satisfactory social policies " (Ministère de la transition écologique et solidaire, 2020).

Ruminant breeding in particular contributes at 14.7% to GHG emissions, of which 12.6% are attributed to bovines (Dollé *et al.*, 2015). These GHG emissions have different origins (**Table 1**), however, depending on the land use (permanent pastures, hedges, etc.) it can be partially counterbalanced by carbon storage. Whether positive or negative, livestock farming also has other impacts on the environment, like the quality of water and air, consumption of fossil resources as well as landscape and biodiversity maintenance.

We are now going to focus on a more local scale, the Bourgogne-Franche-Comté area since ruminant breeding occupies a significant part of this region (**Figure 1**), which also faces the climate change like the rest of the globe.

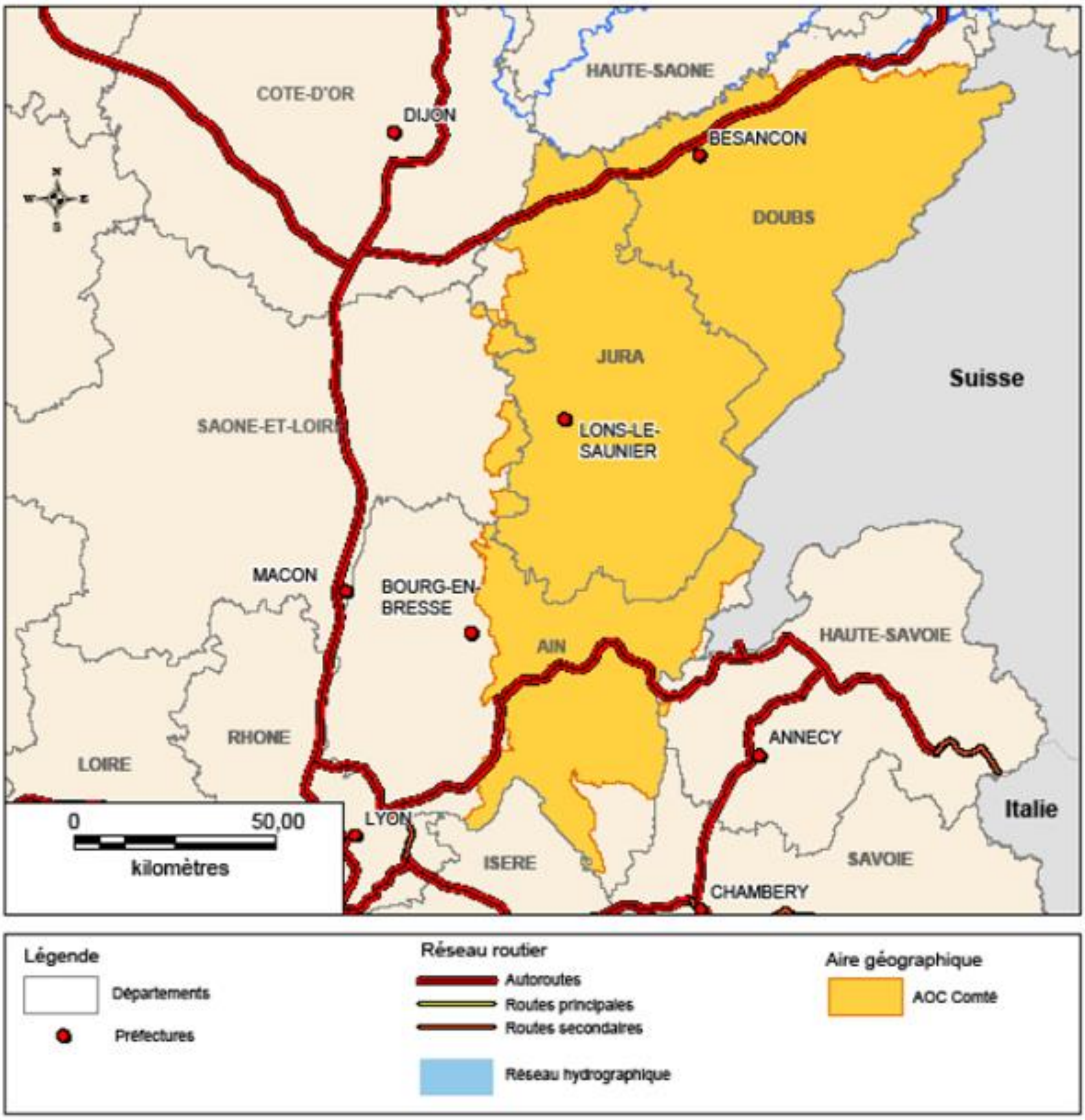


Figure 2 - Geographical area of the Comté PDO. Source: BD-CARTO-IGN, MAPINFO, INAO, February 2010

2. Bourgogne-Franche-Comté : a major agricultural output

1.1. Production systems adapted to the climate

i. Climate evolution in Bourgogne-Franche-Comté

In Bourgogne-Franche-Comté, over the last 50 years, as the annual mean temperatures have increased from 0.7 to 1.6°C, climate has changed. In this region, the mean temperature rise is about 1.3°C with the highest peak in August and December (Tribout *et al.*, June 2019). An increase of summer like days and a decrease of frost days as well as snow cover, have been observed, especially in the Jura massif. Also, between 1991 and 2019, meteorological droughts (more than 15 consecutive days with less than 0.2 mm rainfall) appear every other year. On the other hand, the number of days of heavy rainfall (more than 10mm) increased by 6% between 1961 and 2019. According to the most pessimistic scenarios of the IPCC, in 2100, the city of Lons-le-Saunier could have a climate corresponding to the current climate Narbonne city. (Alterre Bourgogne-Franche-Comté, 2020).

In this region, climatic conditions variations can depend on geology, altitude and rainfall. Its soils show a great array due to the diversity of the subsoils. Bourgogne-Franche-Comté offer various climate:

- Altered oceanic climate in the west of the region,
- Towards east (the Morvan and the plateaus in Bourgogne), mid-mountain climate with high rainfall, cold winters and cool summers.
- On the Jura plateaus a low mountain climate is found with cold winters, variable snow cover, and a rainfall that can go up to 1600 mm / year.
- On the high Jura Mountain range, there is a mountain climate: heavy snowfall, temperature that decreases quickly with altitude, summers than can be warm or fresh with frequent thunderstorms.

These variations of pedoclimatic conditions are, among other things, one of the reasons why this region have developed its agriculture (Ministère de l'agriculture et de l'alimentation, 2016).

ii. Inventory of the different productions in the region

There are four main productions from regional agriculture in Bourgogne-Franche-Comté: vines with 34,000 hectares (ha) of which 99% PDO, beef with some farms turned to calf breeding, field crops (wheat, barley, corn) mainly concentrated on the plateaus of the Côte d'Or, Yonne, Nièvre and Haute-Saône, and finally, milk which is mainly used in cheeses production (Ministère de l'agriculture et de l'alimentation, 2021).

This region covers 4.8 million hectares, the useful agricultural area (UAA) stretches on more than half of the territory, namely, 2.56 million hectares. In addition, areas still under grass (STH) cover 25% which is higher than the national average. Concerning arable land, they cover more than a quarter of the territory and only 1% concerns the vineyard. In the regional economy, agriculture have an important place since it contributes 4% of added value (against 1.7% on average at the national level).

Breeding plays an important role within the territory. Regarding milk production, there are around 4,700 farms, of which 3,000 possess a quality label. This represents 258,300 dairy cows in 2019 but since 2016, an overall decrease in the dairy herd has been observed in the region, however this does not concern the Doubs and the Jura where the number of dairy cows increased between 2010 and 2019 (9% and 6%) (Draaf, 2021). The majority of these cows are on farms in Doubs, Jura and Haute-Saône. In 2019, 1.5 billion liters of milk were produced by these farms, of which 38% and 20% are respectively allocated to Doubs and Jura. The milk produced in these two departments is mainly intended for the sectors under PDO for the production of Comté, Morbier, Mont d´Or or Bleu de Gex. These farms are adapted to the pedoclimatic conditions since they favor permanent grasslands with a breeding globally extensive. When it comes to Comté, 145 establishments (including 7 outside the region) transform the milk into cheese. In 2019, Comté production was 66,333 tons, it represents

Table 2 - Specificities of the milk production for the Comté PDO and for organic farming. Source: personal

	Comté PDO (INAO, 2018) and (CIGC, 2019)	Organic farming (European Union, 2008)
Appellation area	Spread over the departments of Doubs, Jura, Ain, Saône et Loire 95% of the total herd is born and raised in the area	
Breed	Montbéliarde, French Simmental, cross between the two breeds	
Milk production	Limited to 4600 liters/year/ha of SFP Milking done twice a day (morning and evening) and robot milking prohibited 1.2 million liters of milk per dairy year 50 dairy cows for 1 farmer 40 additional dairy cows for each additional farmer Maximum 8500 liters/dairy cow on average	
Fertilization	Maximum 50 units of mineral nitrogenous manure / ha of SFP Authorized organic matter: compost, manure, liquid manure and slurry from the PDO area Spreading on short grass and a maximum of 3 spreadings per year on the same parcel Maximum total nitrogen input: 120 units/ha/year Maximum 50 units/ha/year of synthetic nitrogen fertilization If a parcel receives liquid effluents, the total nitrogen ceiling is 100 units/ha/year	Ban on the use of synthetic chemicals Maximum 170 units of nitrogen/ha of UAA/year for organic amendments Obligation to spread organic effluents on organic land
Herd management	Grazing: after the snow melts and as long as climatic conditions, soil bearing capacity and presence of grass allow it Ration: - Prohibition of transgenic feed - At least 70% of the daily ration in fodder from the PDO area - Maximum 1800 kg/dairy cow/year of complementary feed - Maximum 500 kg/livestock unit (LU) heifer/year of supplementary feed At least 80% of the daily ration of fodder from the PDO area	100% of feed from organic farming Prohibition to give milk powder At least 60% of the annual ration is made up of feed produced on the farm. Forage: at least 60% of the daily ration in dry matter
Surface and load	1 ha minimum of grassland/dairy cow 1.3 LU/ha of SFP. Maximum 15% of the SFP in grassland sown for less than 5 years with a pure legume or associated with a single graminaceous plant At least 50% permanent grassland in the SFP Minimum of 1.3 ha of grassland per dairy cow	Seeds from organic farming

the first cheese PDO in France in terms of volume. (Chambre d'agriculture Bourgogne-Franche-Comté *et al.*, 2020).

A part of the region's dairy farms is organic, in 2018, 8.3% of national organic milk is delivered by Bourgogne-Franche-Comté region. 6.4% of Bourgogne-Franche-Comté dairy farms are organically farmed, which represents 4.4% of milk from this region. The majority of this milk (80%) is intended for the cheese productions, non-PDO cheeses represent the largest part (Emmental and Gruyère IGP). If we only consider the former Franche-Comté region, in 2018, 34% of organic milk was intended for PDO cheeses and the portion of this milk which is transformed into Comté is 37.9%, i.e. 3% of regional production (Interbio Franche-Comté, 2019).

As we have seen through the figures, milk transformation into Comté in the region is a well-established and relatively important production. The Comté sector is organized in a way that sets it apart from the others and is ruled by a quite strict specification.

1.2. PDO Comté: a bond between the product and its land of origin

i. Organisation of the Comté sector

Historically, milk transformation into cheese allowed conservation, people were able to consume it during the long winters in the Jura massif, season when the cows were not producing milk. In order to improve conservation, cheese wheels had to be large and therefore it was necessary for the breeders to pool their milk together, this is where the "fructeries" were born, nowadays they are called "fruitières" (that is "the fruit of common work").

It is therefore from history that the Comté sector holds its particular and unique structure, based on a cooperative system thanks to numerous "fruitières" which bring together several producers. This allows milk producers to have a preponderant impact in decision-making for the sector. The governance of the sector is organized around the "Comité Interprofessionnel de Gestion du Comté" (CIGC) which is the largest member of "Union Régionale des Fromages d'Appellation d'Origine Comtois" (URFAC). The CIGC has several functions within the sector, it is at the same time the organization that defend the management (ODG) and the inter-professionalization. The ODG, is in charge of writing the specifications for the PDO and monitors its implementation, it is also responsible for opening the rights to be produced. As an interprofessional organization, it acts and defends the common interests of the industry and ensures its sustainability. The CIGC is organized into four colleges which participate to the decision-making: milk producers, processors, first and second processors and refiners / packers. By virtue of its status, the CIGC has a certain legitimacy and the means to provide answers to environmental questions and to support its members.

ii. Comté specifications

The current production models in Franche Comté are based on historical models that have evolved with current challenges and constraints. That is to say that these are agro-pastoral models that shape Franche-Comté landscapes, enough fodder is needed to ensure the herd's wintering, so this requires careful territory maintenance and conservation of meadows biodiversity. Grazing on parcels that cannot be mowed makes it possible to shape emblematic environments such as wooded pastures. Based on what was made in the past, Comté was awarded with a Controlled Designation of Origin (AOC) in 1958 and then a PDO in 1996. Thus, Comté specification is strict and was created in order to define the designation area (**Figure 2**), to preserve the cheese identity based on the taste, naturalness, environment, expertise within a single social organization.

Comté specifications cover the different stages in order to get to the finished product, the Comté: milk production, processing into cheese and then maturing. However, we will only be interested in milk production since this report focuses on husbandry practices, and in particular those that have a link with the environment. It is also possible to produce Comté milk in organic agriculture (OA), which adds certain constraints during production but also allows better financial maximization. In **table 2**, the main measures to be respected in order to produce Comté PDO cheese and in organic

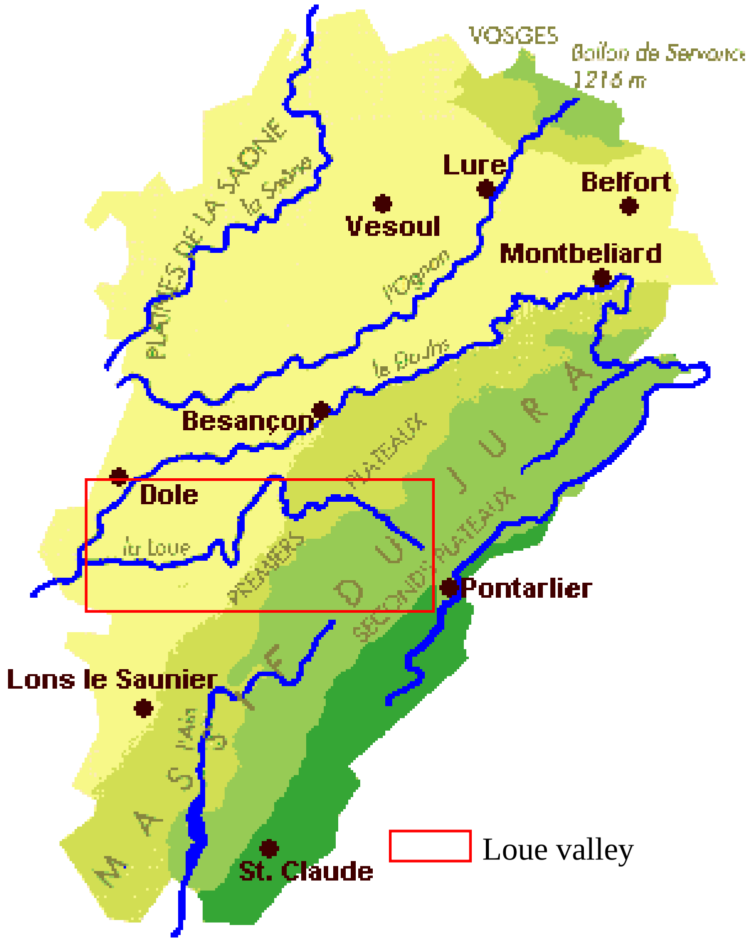


Figure 3 - Map of some rivers in Franche Comté. Source: personal, map base: Interfrance

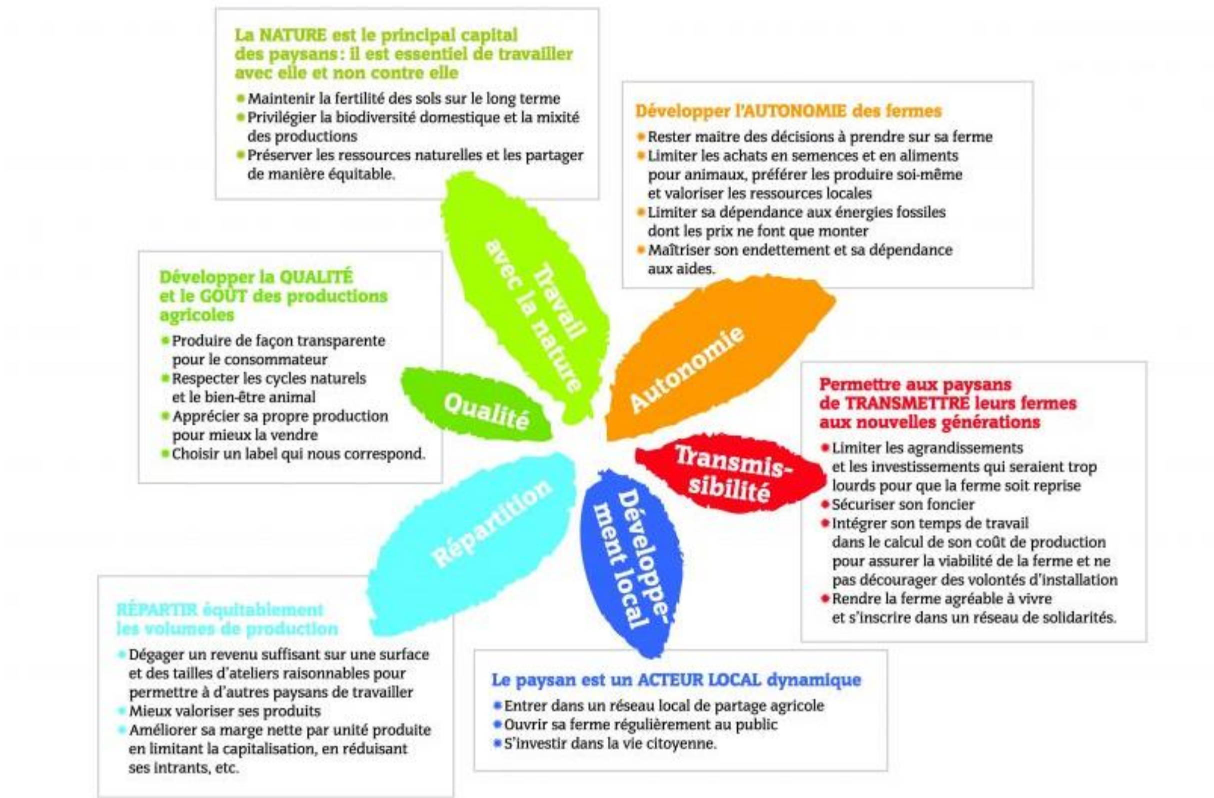


Figure 4 - Diagram representing the 6 themes of Peasant Agriculture. Source: FADEAR

agriculture are gathered, which also specifies the future measures that are being validated by the National Institute of Origin and Quality (INAO) for the Comté PDO.

iii. Advantages and limitations

The Comté sector is a strong sector both in terms of organization and economics. The specifications are quite restrictive but lead to a good valuation of the product. The production of Comté helps structure the Jura massif economy, in particular thanks to the "fruitières". However, there is some limits and threats in the sector, especially with the new production which disrupt traditional agro-pastoral systems to move towards a milk production logic. The standardization and loss of uniqueness of the cheese is also a risk, due to the pressure on the specifications and the expansion of farms (Michaud, 2020). Indeed, some members of the sector want some changes in the sector such as: the authorization to feed green fodder, milking robots and mixers-distributors, or the cancellation of the ceiling on concentrates.

Concerning the environment, threats exist, water pollution and climate change must then be taken into account. Indeed, despite the supervision of milk production and processing practices, environmental associations accuse the Comté sector of having a negative impact on rivers and in particular on the Loue (**Figure 3**). Even if there are multiple causes, scientific studies show the preponderance of the impact of agriculture on nitrogen contaminations in the Loue (Frossard *et al.*, 2020). This can be explained by the milk production intensification in the PDO zone for several years even if it remains restrained thanks to the specifications (Draaf, 2016). Despite the industry's efforts to improve surface water quality, rivers are still deteriorated and polluted by pesticide, nitrates and phosphorus. Comté specifications set a limit on milk productivity per hectare and thus limit production intensification. Finally, a loss in the diversity of the meadow's flora has been observed since the 1990s, due to the enlargement of herds as well as the intensification of some agricultural practices (management of mineral nitrogen in slurry) (Rossi *et al.*, 2017).

Apart from the strict specifications concerning the PDO and organic farming, another agricultural approach exists to limit the impacts on the environment: the peasant farming.

1.3. Peasant agriculture in Comté PDO

Peasant agriculture is defined as an approach which allows a maximum of peasants spread over the whole territory to make a decent living from their profession, by producing healthy and quality food in a human-sized farm, accessible to all, without challenging tomorrow natural resources. This agriculture participates together with the citizens to make the rural environment alive and in preserving a living environment appreciated by all (FADEAR) (**Figure 4**).

The "Confédération Paysanne" is the political project supporting peasant agriculture, proposition to the CIGC are made through it. From its definition and the 10 principles that frame this approach, peasant agriculture may have an interest in preserving the environment. However, it remains complicated to define the farms that are in peasant agriculture and those that are not since there are no defined specifications but only a diagnosis of peasant agriculture allowing to position in relation to an approach integrating different components.

The interests for the environment are to reduce GHG emissions, since returning to peasant breeding is a major lever. In fact, peasant agriculture is "the maintenance and redeployment of livestock farming that maintains the territory, produces less but better, in line with food needs" (Confédération Paysanne, 2018). This induces the reduction of herds which allows the reduction of methane emissions. In addition, feeding herds with meadow grass reduces protein needs and possibly reduces food imports. Carbon can be stored in soils and biodiversity favored by peasant breeding, which stimulate conservation and maintenance of permanent grasslands and hedges. Peasant agriculture also aims to limit the use of synthetic fertilizers that can be responsible for GHGs emission, soil fertility reduction, and air and water pollution.

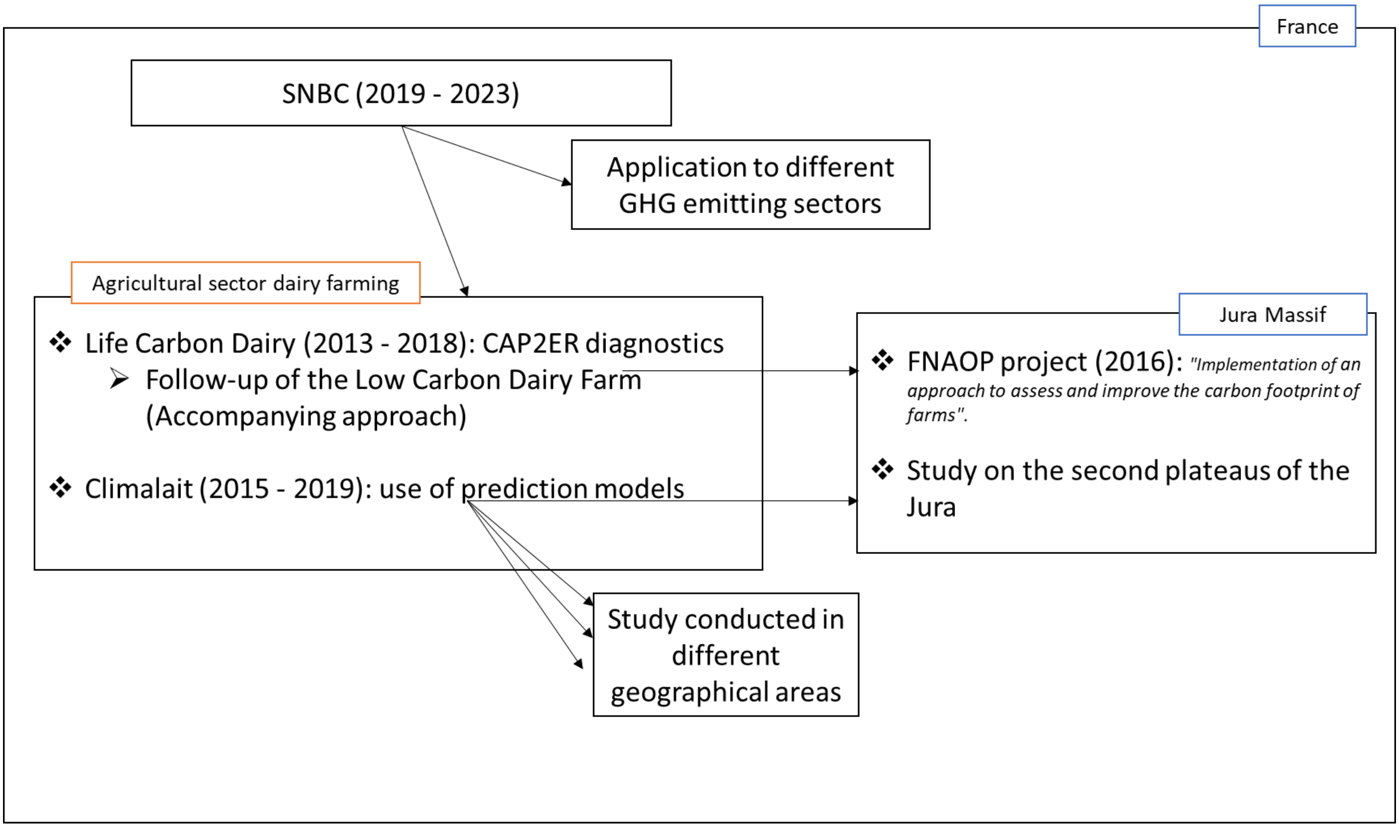


Figure 5 - Non-exhaustive diagram of approaches to face climate change at different scales. Source: personal

1. Strategies and projects facing climate change at different scales

The different strategies and projects to deal with climate change have been represented in **Figure 5**.

1.1. At the national level

i. National Low-Carbon Strategy

The SNBC was established by the energy transition law for green growth in 2015. It sets France's climate objectives and describes the roadmap for driving the climate change reduction policy. The two objectives of this strategy are: to achieve carbon neutrality by 2050 and reduce French population carbon footprint. Thus, for each four-year period, GHG emissions must not exceed a "carbon budget" given on average over the period. For the period 2019-2023, the "carbon budget" amounts to 422 MtCO2eq / year, so for that "budget" to be respected, in the years to come emissions will have to fall by nearly 10 MtCO2eq per year (CITEPA, 2020).

The SNBC is implemented mainly by 10 ministries covering major sectors in terms of GHG emissions. It is the Ecological Defense Council which monitors the implementation of the climate action plan each year. Concerning the agricultural sector, the SNBC aims to reduce emissions by 18% by 2030 compared to 2015 and by 46% by 2050. For this, technical and systemic guidelines are defined:

- Reduce direct and indirect emissions of N_2O and CH_4, by relying on agroecology and precision agriculture;
- Reduce CO_2 emissions from the fossil energy and develop the use of renewable energies
- Develop carbon-free energy production and the bioeconomy to contribute in the reduction French CO_2 emissions, and strengthen the added value of the agricultural sector;
- Stop the current carbon destocking of agricultural soils and reverse the trend;
- Influence the demand and consumption in agri-food chains. (Ministère de la transition écologique et solidaire, 2020)

It is within this framework that projects have been developed at different scales in an attempt to limit the impacts of livestock on climate change and the environment, or to adapt to these new conditions.

ii. Life Carbon Dairy project monitoring of the Ferme Laitière Bas Carbone

The Life Carbon Dairy project led by 14 partners (Chambers of Agriculture, livestock consulting companies, National Interprofessional Center for Dairy Economics (Cniel) and the Livestock Institute (Idele)) took place from 2013 to 2018 in 6 French regions: Bretagne, Pays de la Loire, Normandie, Hauts de France, Lorraine et Rhône-Alpes. The main objective of this project was to raise the awareness of all stakeholders and promote an approach allowing dairy production to reduce its GHG emissions by 20% within 10 years. In order to achieve this objective, a mass assessment of the carbon impact of 4,870 farms was carried out using the CAP2ER diagnostic which stands for "Calcul Automatisé des Performances Environnementales en Élevage de Ruminants". The aim was to develop the climate roadmap for dairy production. The main results of the study are the following:

- Gross GHG emissions regarding the forage system: from 1.01 (corn plain) to 1.09 kg CO_2 eq/ L (grassland mountain and corn mountain), so finally a little variation between major types of system but significant variations were observed within the same forage system;
- Net GHG emissions depending on the forage system: from 0.58 to 0.91 kg CO_2 eq/ L, grassland systems are those that offset their emissions the most and have the lowest net carbon footprint;
- The systems with the lowest GHG emissions have better technical efficiency (milk production, consumption of concentrates, breeding rate, nitrogen inputs);
- The most efficient systems are not necessarily those with the greatest carbon storage, because the productivity per hectare is higher;

- A strong link exists between the environmental and the economic aspect (with regard to the brute margin and operational charges).

Finally, a decrease of 3% was observed over the 3 years, thanks to: better management of inputs (less concentrates, less nitrogen fertilization, increase in milk production / ha of fodder production area (FPA) associated with lower organic nitrogen consumption and a better yield of valued grass). (Brocas *et al.*, 2020)

Following on from the Life Carbon Dairy project, the Low-carbon dairy farm approach was launched by the CNIEL, the objective is to reduce GHGs by 20% between 2015 and 2025. The stated objective is that each farmer involved benefits from support and a tailor-made solution, adapted to their farm and their ambitions. This support is provided on a daily basis thanks to advisers from the Agriculture Chambers, consulting companies or even dairy farms trained to the carbon diagnostic tool. (CNIEL, 2021).

1.2. At the regional level

i. Climalait for the second Jura plateaus

Climalait program objective is to evaluate the impacts of climate change, in the medium and/or long term (horizon 2050), on the various French dairy farming systems, to inform and prepare farmers for climate change on the long term, and finally to suggest possible ways of adaptation. The principle of the study is to work on a limited number of Dairy Units (geographical area defined for the purposes of the study which has pedoclimatic homogeneity in terms of fodder potential, breeding systems and climate change), describe climate changes in the recent past and in the future (using outputs from climate models), then assess the impacts of climate change on crops and suggest adaptations.
This project was initiated by CNIEL and led by the Institut de l'Elevage in partnership with Arvalis, Technical Office for Dairy Promotion, Agriculture Chambers, INRA and Météo-France. To date, results have already been published for several geographic areas, but here we will only be interested in the "Jura second plateaus" area results, which is the closest one to the study. The results of the study show that temperatures have slightly increased over the past decades (+ 0.4 ° C in 30 years), and they tend to increase even more in the incoming year, especially in summer. Precipitation remains variable from one year to the next, but we still notice a decrease in precipitation (- 170 mm) and an increase in evapotranspiration (+ 60 mm) over the last 30 years, which is favor drought.

Predictions have also been made, showing that temperatures could rise from 1.5 ° C to 2 ° C in the near future and up to 4 ° C by the end of the century. There will be frost but way less than in the past and heatwave will multiply. These heavy temperatures may have consequences for animals as the number of days and the intensity of heat stress will increase in the near future, even more towards the end of the century. Simulations show the increase in grassland productivity, accompanied by a change in the distribution of available grass over the year. In early spring, grass production tends to increase while it slows down in summer. Finally, fall conditions allow the grass to regrowth.

Following these observations, we think about some adaptations

- Amass fodder stocks to face bad weather years;
- Trying to grow cereals to gain autonomy (concentrates and straw);
- De-intensify production systems (raise more less productive cows to reduce inputs;
- During fall, use excess grass to fatten cull cows or to breed grass heifers;
- In the case of a year with climatic hazards: anticipate reforms without prior fattening, reduce food needs (and therefore milk production) or reduce the number of heifers.

(Moreau *et al.*, 2018)

ii. Implementation of a process to assess and improve the carbon balance of farms

As we have seen, several initiatives have been taken to deal with global warming and in particular for dairy systems. In this dynamic, the FNAOP has chosen to take part in the "Ferme

Table 3 - Non-exhaustive list of existing environmental impact assessment tools. Source: personal

Name of the tool	Objectives	Scope of use
CAP2ER	Assessing environmental performance	Farm and detail by workshop (milk/meat), for ruminants
IDEA	Moving towards sustainable agriculture in the service of the agro-ecological transition	Majority of production systems in metropolitan France
DIALECTE	Describe the production systems and allow an evaluation of the impact of agricultural practices on the environment	Mixed crop-livestock and field crop systems
ACTA	Familiarize with the notion of agroecology, identify ways to improve	Any production
ClimAgri	To put in relation the energy consumption of agriculture, greenhouse gas and pollutant emissions and the production of agricultural raw materials	Territory

Table 4 - Comparison of different tools to evaluate livestock systems. Source: personnal

Objective	Awareness	Awareness raising / creation of an observatory	Decision support
Level	SelfCO2	CAP2ER Level 1	CAP2ER Level 2
Public	Breeders	Advisors, technicians	Advisors, technicians
Scale of analysis	Workshop/products	Workshop/products	Farm/Workshop/Products
Number of data collected	30	30	150
Data collection time	30 minutes	30 minutes	3 hours
Creation of a database	Only if an online account is created	Yes	Yes
Certification of results	No	Yes (Ecocert)	Yes (Ecocert)

Laitière Low Carbone" project carried out at the national level in order to deal with PDO cow's milk from the Jura massif. The problematic with this project was to set up a process to assess and improve the carbon footprint of farms in the Jura massif. This study was one of the starting points of the Clim'AOP Jura project since it focused, among other things, on the assessment of the carbon footprint and the action to improve the footprint. It was carried out on 55 farms in the PDO area of the Jura massif for which the average net carbon footprint was 0.48 kg CO_2 eq/L of milk. Net carbon footprint was lower than the national average of 0.73 kg CO_2 eq/L of milk and gross carbon footprint was around 0.97 kg CO_2 eq/L of milk on farms in the Jura mountains. The difference with the net is explained by the compensation from permanent meadows and hedges which are great assets for these PDO farms. The two main levers have been highlighted: limitation of inputs (concentrates and fertilizers) via the enhancement of local resources, as well as the limitation of the renewal and breeding rate of the dairy herd which limits unproductive animals in the farms. To carry out these carbon assessments, the CAP2ER tool was used, the same tool was chosen for the Clim'AOP Jura project (Michaud, 2016).

Regarding this dynamic and these results, the peasants of the “Commission Comté de la Confédération paysanne” wish to confront their practices with scientific knowledge to consolidate or improve their response to climate change. The best levers must be further refined so that the PDO milk sector in the Jura massif contributes to the national effort to reduce GHG emission coming from agriculture. This is how the Clim'AOP Jura project was launched.

1.3. Focus on the CAP2ER tool

In order to implement these approaches, multi-criteria evaluation tools are needed. There are many such tools to assess the environmental impact, including those listed in **Table 3**. For the Clim'AOP Jura project, the CAP2ER tool was selected because it is the one most widely used in France for ruminant livestock production and therefore provides the best reference for positioning. It is used, for example, in the Carbon Agri method, which is used to obtain the Low Carbon Label set up by the Ministry of Ecological and Solidarity Transition (Vignau, 2020).

IDELE developed this tool to calculate the environmental performance of ruminant farms. There are three formats of this tool, which are more or less precise (**Table 4**). For level 2, the objectives are to raise awareness of environmental issues among farmers and advisors, and to evaluate the main positive and negative impacts of farms. The CAP2ER tool is based on life cycle analysis (LCA), which "identifies and quantifies, throughout the life of products, the physical flows of matter and energy associated with human activities. It evaluates the potential impacts and then interprets the results obtained according to its initial objectives" (ADEME). The scope of CAP2ER is limited to the farm and the manufacturing and transport stages of the inputs, which represents 90% of the total impact on the life cycle. The carbon weight of imported feed and fertilizers used to make milk is taken into account. On the other hand, if there is a processing workshop, it is not taken into account either, it is the remaining 10%. The study of dairy systems is particular because there are two products for a workshop, the principle of allocations aims to distribute the impacts between milk and meat according to the energy required for the different phases of life of the animals. On average, they are 74% for milk and 26% for meat.

2. Clim’AOP Jura project: problematics and working hypotheses

1.1. Origin and objectives of the project

The Clim'AOP Jura project “La filière lait AOP du massif du Jura face à l’urgence climatique”, in which this internship take part, was launched in response to a call for projects from the Bourgogne-Franche-Comté Region: “Réponses des filières régionales à l’enjeu du changement climatique”. This is a 3 years project, and this internship only concerns year 1, it is funded by the Region at 80% and by external funding at 20%. Part of year 1 missions will be carried out by two agronomist students. This mission will focus on one hand, on a sociological aspect with sociological

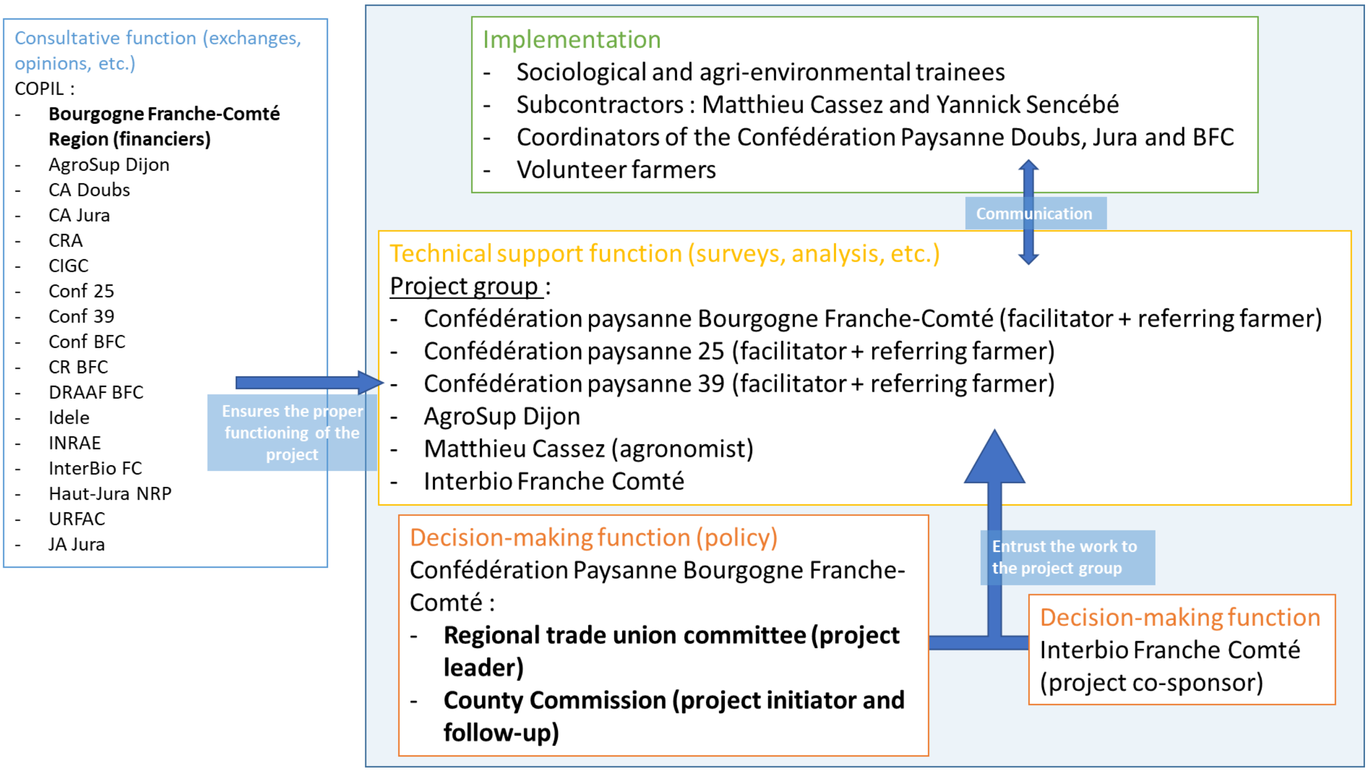


Figure 6 - Governance scheme of the ClimAOP Jura project. Source: personal

CA: Chamber of Agriculture ; Conf: « Confédération paysanne » ; CRA: Regional Chamber of Agriculture ; CR: Regional Committee ; BFC: Bourgogne Franche Comté ; Draaf: Regional Directorate of Food, Agriculture and Forestry ; Inrae: National Institute for Agricultural Research ; NRP: Regional Natural Park ; JA: Young farmers surveys and on the other hand, on an agro-environmental aspect with CAP2ER diagnostics. The agro-environmental component will be the subject of this report, the missions for year 1 of the project are to collect technical data on a network of 50 dairy farms in the PDO zone of the Jura massif using the CAP2ER tool, to compile the results and carry out a statistical analysis. The objective is to identify technical levers to deal with climate change by reducing GHGs emissions and the impacts of livestock on the climate and the environment. The main idea is to focus mainly on organic farms as little is known and few data on this type of system in the area exist and that the practices of these specifications are likely to provide answers to the problems on how to reduce GHGs emissions. In addition, other agricultural organizations also have the ambition to carry out CAP2ER diagnostics, but rather on farms in conventional agriculture, which would allow comparisons in the future.

1.2. Project Governance

The project is supported by the “Comité syndical régional de la Confédération Paysanne Bourgogne-Franche-Comté” and in partnership with “Interbio Franche-Comté”. “Commission Comté” members are the originators of the project and responsible for it monitoring. In addition, technical and scientific support is provided by Yannick Sencébé and Hédi Ben Chedly of AgroSup Dijon as well as Matthieu Cassez (independent agronomist). Leaders of the “Confédérations Paysannes du Doubs, du Jura et de la Bourgogne Franche-Comté” and volunteer farmers participate in the implementation of the project. Also, a project group was set up to allow regular exchanges on more technical aspects such as the conduct of surveys, data analysis, … (**Figure 6**)

1.3. Problematics

Hence, important questions stand out from the construction of this project: What are the environmental performances of dairy farms in the PDO zone of the Jura massif? Particularly those of organic farms? Which practices influence the environmental performance of these farms? Which of these practices are the most effective to fight against climate change?

1.4. Working hypotheses

In this report, in order to address these questions, several hypotheses will be tested using the database created during the CAP2ER diagnostics:

- 1st Hypothesis: The higher the load is, the higher the GHG emissions there are.
    - Practices allowing limitation of the number of animals (turnover rate, lifespan of dairy cows, number and duration of lactation of dairy cows, age at first calving) are favourable to the diminution of GHG emissions.
    - animals (quantity of concentrates distributed) increase GHGs emissions.
    - Intensive practices on term of surface increase emissions (replacement of permanent pasture with temporary pasture, high consumption of organic and mineral fertilization).
- 2nd Hypothesis: The larger the size of the farms, the more GHG emissions there are, since this can impact the management of the farm. And the more labour productivity increases (milk production / unit of labor (UMO)), the more GHG emissions there are.
    - A large-sized UAA can promote the splitting up of land parcels and limit autonomy possibilities regarding the inputs.
    - High labour productivity and herds and / or large areas can lead to poorer control of the work as well as risks of waste.
- 3rd Hypothesis: Hedges is the agroecological element that has the highest impact on carbon storage and therefore allows a significant reduction in net emissions (almost reaching neutrality).
- 4th Hypothesis: The results of nitrogen excess correlate with GHG emissions.
    - The more nitrogen there is, the more there is a risk of leakage and thus the risk of pollution increase.
    - Fighting against nitrogen pollution risks come down to fight against GHG emissions.

Table 5 - Documents needed for data collection. Source: Personal

Information	Documents
Animal inventories	Synel software, cattle book
Crop rotation and agro-ecological elements	Common Agricultural Policy (CAP) statement
Quantity of feed and fertilizer purchased, stock Grain sales	Ledger
Milk sold Meat production	Annual dairy summary Ledger, animal inventories
Milk quality and reproduction data	Milk recording document, Boviclic software
Electricity consumption and animal weights	Invoices

To assess the environmental performance of these farms, we will focus on GHG emissions. Indeed, GHG emissions are correlated with environmental impacts such as acidification, eutrophication and energy consumption. Moreover, climate disruption is one of the most pressing challenges of the 21st century (Guerci et al., 2013).

To test these hypotheses and respond to these questions, a study will be carried out on a sample of farms in the PDO area of the Jura massif. The objective is to identify potential levers of actions to reduce GHG emissions at the farm level.

II. Materials and methods

1. Conducting surveys

In order to build a database, 46 farms were selected thanks to partners network of the project and volunteers. The initial criteria were organic farming and / or in peasant agriculture farms (that is to say, by simplification, members or supporters of the "confédération paysanne" (peasant confederation)). With the aim to cover in the best way possible the PDO zone of the Jura massif, geographical criteria were also taken into consideration. For the purpose of having a representative sample of the area, we tried to have a diversity of farms, in terms of area size, of herds with a variable level of intensification (in terms of feeding and production of milk).
To out the CAP2ER diagnostics, farmers were contacted to arrange an appointment date between April 15 and July 15, 2021. Various documents have been requested to compile data of interest (**Table 5**) for the 2019 campaign. We choose the year 2019 so that all accounting periods would be closed and accessible.

2. Use of the CAP2ER Level 2 tool

To collect the data the CAP2ER level 2 version 6.0.3 was used. The information gathered during the interviews allow to connect breeding practice, environmental impact, and socio-economic indicators. Thus, advisers and breeders can work together to realize an action plan to improve both environmental, technical and economic performance.

In CAP2ER level 2, a large number of indicators are taken into account:
- Environmental indicators: climate change, air quality, water quality, depletion of fossil resources.
- The positive contributions of livestock are also studied using the tool: nutritive performance, carbon storage and biodiversity conservation.
- Sustainability indicators (production cost, satisfaction of working conditions, …) can be provided but remains optional, as they concern economic performance as well as working conditions.

Several units are used depending on the indicators:
- For surface indicators (carbon storage, biodiversity maintenance, feeding performance, permanent grassland, nitrogen application, fuel consumption) the results are expressed to the hectare of UAA.
- For product indicators (GHG emissions, carbon storage, energy consumption), the results are expressed as a production unit (corrected litre of milk sold or kilogram of live meat produced). The corrected liters of milk correspond to an adjustment to 40 g/kg of fat and 33 g/kg of protein.

When collecting data, there are 7 tabs to complete (**Appendix 1**):
- General data: basic data on the farm (type of production, labour, etc.);
- Herds: in our study only dairy cattle farm, information on animal numbers, animal purchases and sales, herd production and management;

- Housing and effluents: time spent inside, type of animal housing, effluents management;
- Surfaces: data on surfaces usage (size, rotation, mineral and organic fertilization), rotations involving meadows, straw and agroecological elements;
- Feeding: there is two possibilities, either a simplified unit where the farmer needs to specify for each food, the part which goes to the dairy meat cattle production (including the part which goes to the dairy cows), or a detailed unit for which it is necessary to specify the ration for each category of animals. In our case, we have chosen detailed units, the data collected is the available food (purchased and produced on the farm) and the food for the herd (ration in kg / day);
- Energy: information on electricity and fuel consumption, and work carried out by or for third parties;
- Other: entry of economic data for the farm and production, as well as questionnaire on the work.

A final "validation" tab appears and is automatically completed by the tool, it allows to check data consistency at the end of the interview using a certain number of indicators.

We will now touch on calculation methods and references allowing the CAP2ER tool to provide results and indicators.

GHG emissions:

Methane emissions related to enteric fermentation and manure management are calculated from the organic matter (OM) composition of the ration according to an equation that we will not detail here.
CO_2 emissions are a result of electricity and fuel consumption in the farm, these energies consumed are multiplied by a corresponding emission factor. These emissions are linked to the purchase of inputs (food and fertilizers), each have a specific carbon weight per kilogram of raw material.
N_2O emissions are linked to the excreta management (building and storage), organic and mineral fertilizers spreading and the soils (leaching, soil turning). The emissions are calculated by multiplying the nitrogen inputs at the various stations by the emission factors which vary according to the temperature and building type, or also according to storage methods and the kind of effluent.

Carbon storage in soils:

Carbon storage vary depending on the type of soil. With CAP2ER, we evaluate the additional storage allowed each, thanks to a storage fee per type of surface:

- Permanent or temporary meadow surfaces: 570kg C / ha / year
- Pastoral surfaces: 250kg C / ha / year
- Hedges: 125kg C / 100m linear / year
- Cultivation surfaces without meadow rotation: -170kg C / ha / year
- Cultivation surfaces with meadow rotation: -950kg C / ha / year

(Dollé *et al.* 2013)

Ammonia and water quality:

The excess of apparent nitrogen footprint is calculated based on nitrogen inputs and outputs. Nitrogen, which is not recycled, has three potential fates:

- Soil storage
- Leaching into the soil and losses toward water
- Volatilisation to air (as N_2O or ammonia). Ammonia emissions occur throughout the manure management chain, and the more manure is in contact with open air, the more ammonia volatilizes.

Biodiversity:

This tool accounts for the various agroecological infrastructures (wet meadows, hedges, grass strips, ...) and translates them into equivalent hectares of biodiversity using equivalence coefficients defined

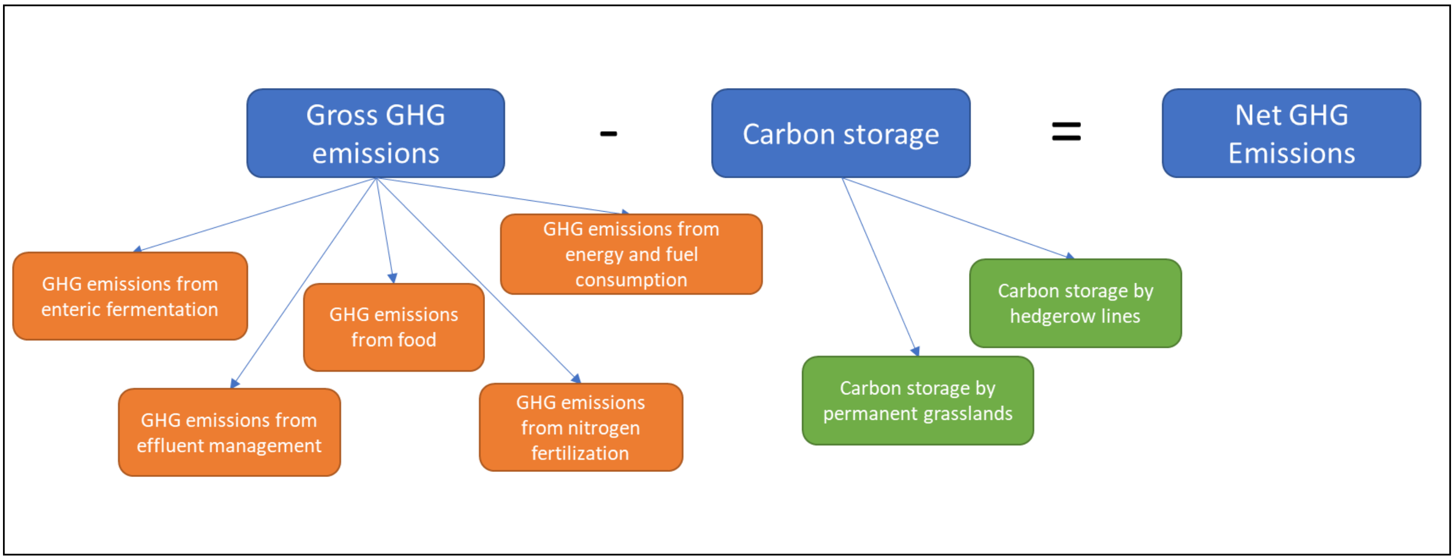


Figure 7 - Diagram of the components of gross and net GHG emissions and carbon storage. Source: personal

Table 6 - GWP of the three main GHGs. Source: personnal

GHG	GWP
CO2	1
CH4	25
N2O	298

by the “Bonnes Conditions Agricoles et Environnementales”. The forest and wood borders are not taken into account as agroecological elements.

Nurturing performance:
It corresponds to the number of people potentially fed by the farm, the indicator is evaluated according to the PerfAlim method (Céréopa) which gives three indicators (energy, proteins, and animal proteins), but only animal proteins are of interest here.

Once this series of calculations has been carried out, the results are summarized in 8 pages for a farm which only has one dairy cattle production (**Appendix 2**). The first three pages concern the results of the farm, and it consist in a farm and production presentation, environmental assessment and nitrogen balance of farming. In following pages, the results are linked to the production level and are compared with references values from the Inosys Livestock Network farms (between 2009 and 2017).

In order to identify the most effective practices or the possible action levers regarding our hypothesis, we then performed a statistical analysis of the results. It is mainly the technical results as well as the results concerning GHG emissions and nitrogen management that were studied.

3. Statistical analysis

1.1. Descriptive analysis

The first stage of the analysis consisted in recovering all the data from the CAP2ER diagnoses in order to constitute a database, then describing them and presenting the relevant results for the rest of the analysis. Then, a global overview of the sample was obtained by characterizing it through a descriptive analysis of the data (average, minimum, maximum, standard deviation, etc.), allowing to study the variability and distribution within the sample. A focus was made on the GHG variables as they are the focus of this study. The sample results were also compared with national or regional values from previous studies. After observing the variability of GHG emissions, we wanted to explain it by classifying the farms according to their GHG emissions.

1.2. Principal component analysis and hierarchical ascending classification

For the rest of the analysis, we implemented a principal component analysis (PCA) and then a hierarchical ascending classification (HAC), which allowed us to form groups of farms according to their gross and net GHG emissions. For this purpose, R Studio version 1.4.1717 was used with the "Factoshiny" and "Factominer" packages. In order to discriminate the GHG results of different farms by identifying groups, the sub-variables that calculate gross and net emissions were also integrated. (**Figure 7**).

This choice of variables was also made because they have the same unit, i.e. "kg CO2 eq/L of corrected milk", which is the unit used when talking about GHG emissions. It is based on the global warming power (GWP) of each GHG. (**Table 6**) The emission of 1g of a GHG with a GWP of X is equivalent to the emission of X g of CO2.

Finally, we performed analyses of variance (ANOVA) on variables relating to structural elements (areas, hedge lines, permanent grasslands, ploughing, production) and practices (herd management, feeding, area management, fuel and electricity consumption). These variables are 32 in number (**Appendix 3**) and were selected according to the hypotheses we wished to test. The ANOVAs carried out allowed us to compare the groups with each other and to know if there were differences between these groups for certain variables.

In order to learn more about the whole sample, we wanted to test the effect of production mode and detect the variables contributing to GHG emissions.

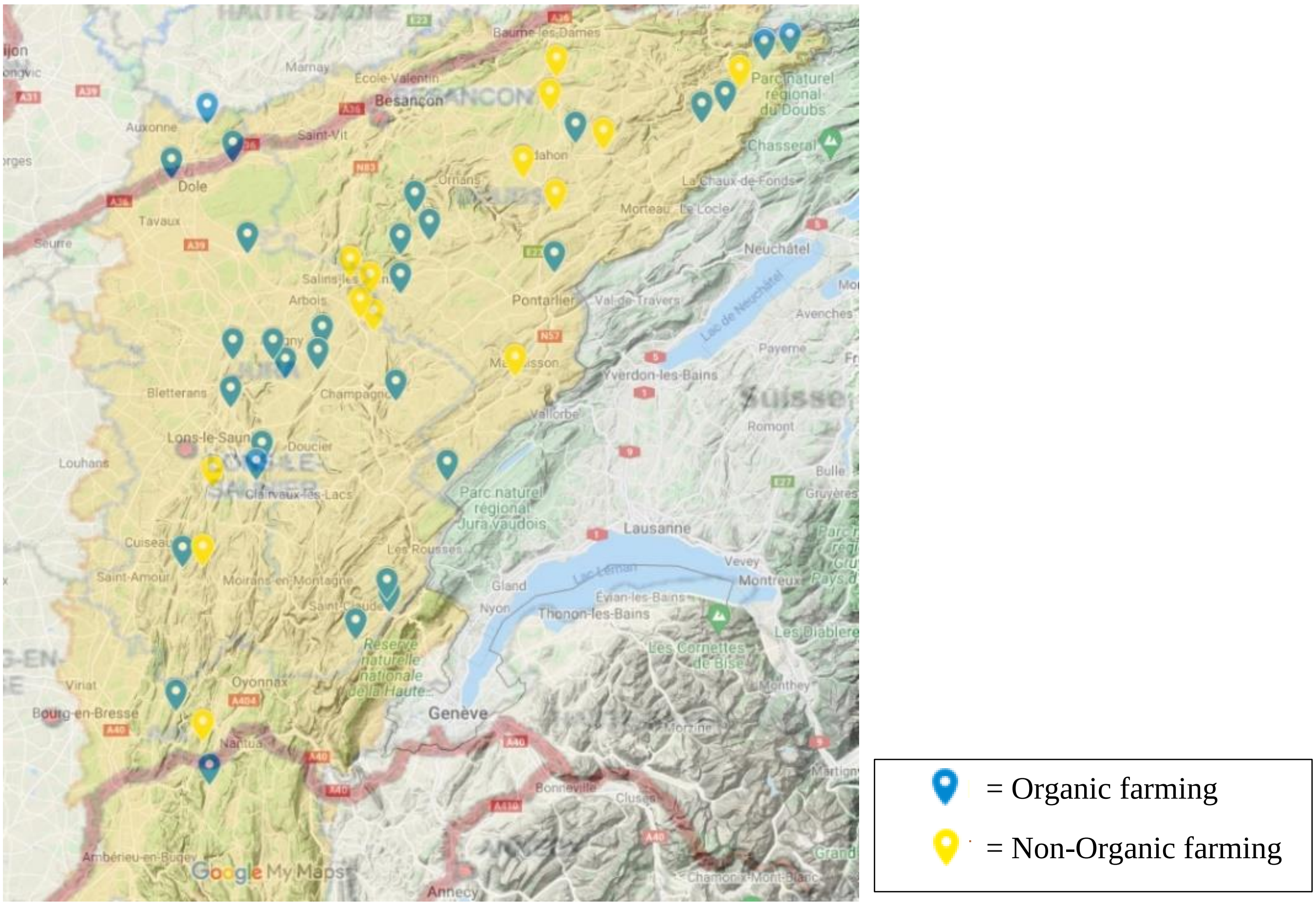
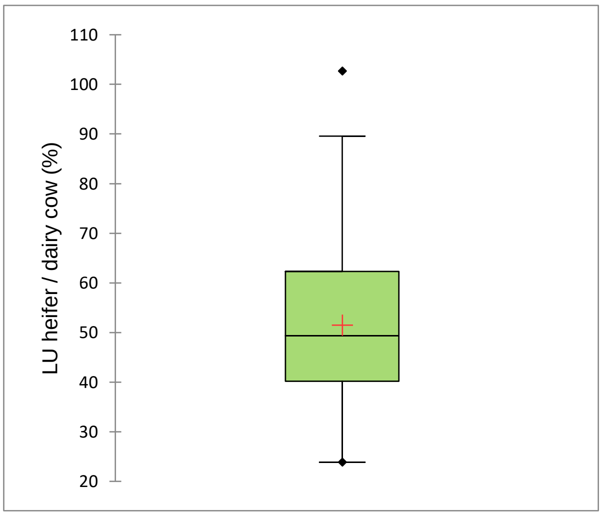
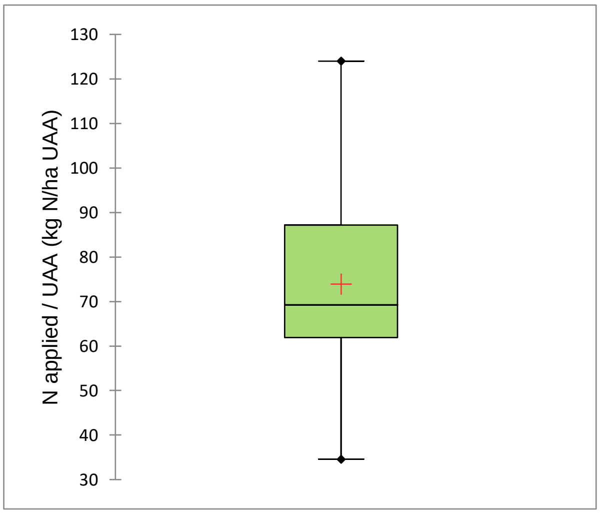


Figure 8 - Map of the distribution of the sample farms in the Comté PDO. Source :personal





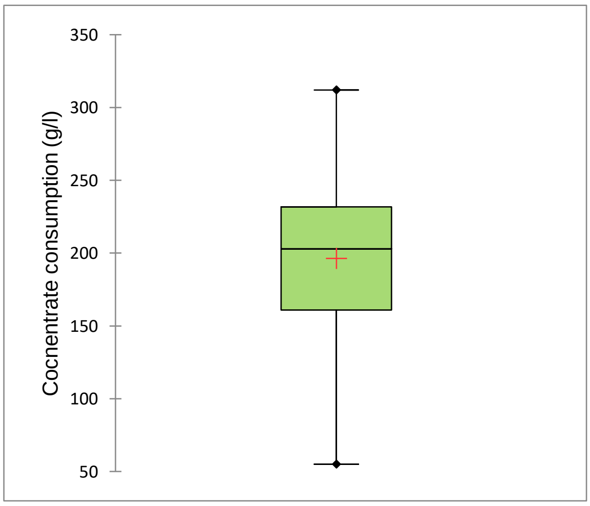


Figure 9 – 3 graphical representations of the data dispersion of the variables: rearing rate (% LU heifer/dairy cow), organic nitrogen applied/ha UAA and concentrate consumption (g/l)

1.3. Analysis of covariance

To investigate the possible effect of production mode (organic farming) on GHGs, an analysis of covariance (ANCOVA) was performed. In the model studied, production method was designated as the main factor and other continuous variables were designated as co-factors. Organic farms were designated as "1" and non-organic farms as "0".

The identification of the co-variables was performed using the best model selection functionality of XLSTAT (version 21.3.1) which is based on the identification of the ANCOVA model structure that best explains the variability of the GHG data. The R^2 value of the ANCOVA model was used to identify the cofactors that best explain the variability of the data.

As these co-variables are continuous variables, they are not directly comparable but only serve to explain part of the GHG emission results. This is why we studied the correlation matrix resulting from the ANCOVA. Indeed, the correlation values closest to 1 and -1 allow us to draw solid conclusions on the potential levers to act on GHG emissions. For correlation values closer to 0, the robustness of the ANCOVA analysis allowed us to observe trends.

The same ANCOVA was performed by exchanging only the dependent variable "GHG emissions/liter of corrected milk" for "GHG emissions/ha of UAA". The estimated means for each variable were then compared to see if the unit chosen to express GHG emissions could impact the interpretation of the results.

At the end of these different stages, we were able to obtain results and then analyse them.

III. Presentation of results and discussion

1. Characterization of the sample and GHG emissions

1.1. Description of the 46 farms audited

The interviews were conducted on 46 dairy PDO farms in the Jura massif. The interviews lasted about 2.5 hours and required time to check the consistency of the information and to complete it if necessary. The fact that the farms were selected on a voluntary basis facilitated access and data collection.

In the sample there are farms with two different production methods: organic and non-organic. The majority of the farms in the sample are in organic farming with 67%, the remaining 33% are not in organic farming. The geographical distribution of farms is rather homogeneous in the PDO area. There are 48% of farms in the Jura against 46% in the Doubs and 6% in the Ain department (**Figure 8**). Moreover, 91% of the farms are located on the "plateau/mountain" areas and are thus considered as "mountain-herbager" systems and 9% are in the plain area.

On the farms surveyed there is an average of 1.94 UMO working on the farm. The milk production per cow is about 5534 liters of corrected milk (in relation to fat and protein). The average herd size is 45 cows with some farms having a minimum of 21 cows and others having a maximum of 118 milking cows. FPA production averages 90 ha and ranges from 43 ha to 255 ha. The average stocking rate is 0.83 LU/ha of FPA. The rearing rate (% of LU heifers/milk cows) is 51% and the average quantity of concentrates consumed by the dairy cows is about 196 g/l. Finally, on these farms, protein autonomy is 78% on average. A strong dispersion of the data is observed for some of these variables, in fact, the range between the minimum and maximum values is quite large and the standard deviations are high (**Appendix 4**). The variables for which the values seem to be the most dispersed are: concentrate consumption, organic nitrogen applied, and rearing rate (**Figures 9**). We also note the presence of some extreme values, much higher than the whole sample, for the variables: number of dairy cows, FPA and UMO.

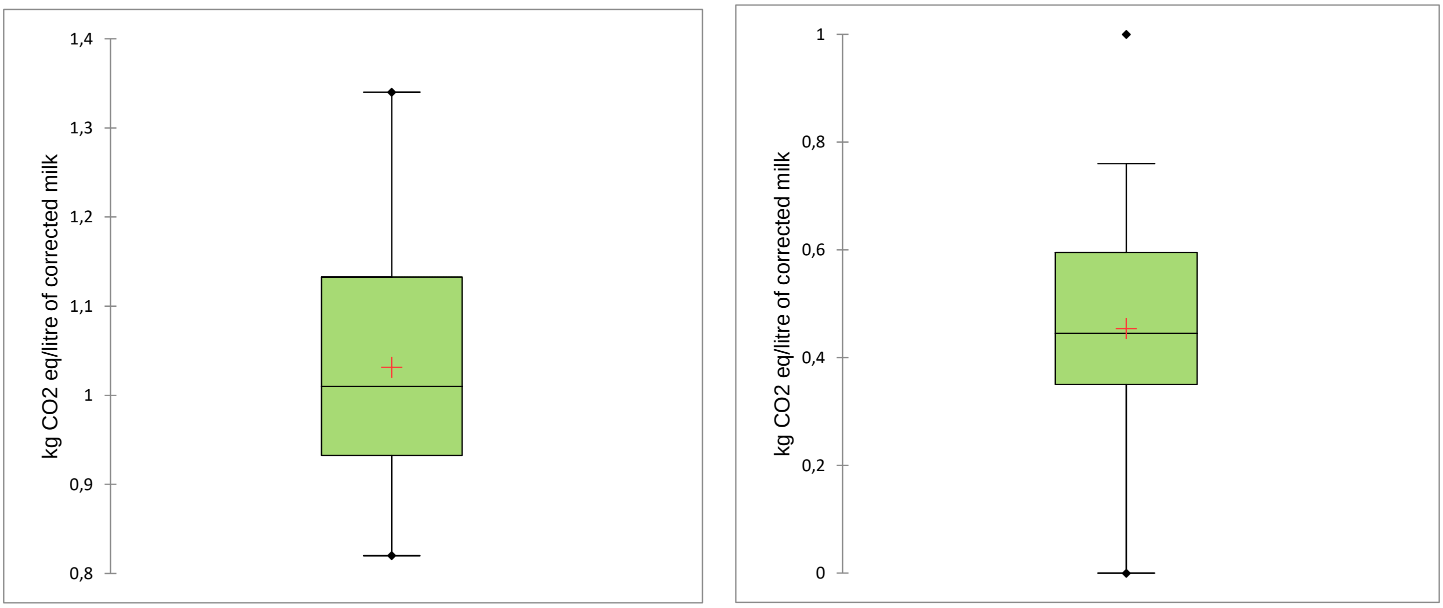


Figure 10 - Graphical representations of the data dispersion of the GHG emissions (gross emissions on the left, net emissions on the right)

Table 7 - Comparison of GHG emissions from our sample with results from other studies. Source: personal

	Gross GHG (kg CO2 eq/litre of corrected milk)	**Net GHG (kg CO2 eq/litre of corrected milk)**
Clim'AOP Jura	1,03	0,45
Study 1 (65 farms in mountainous areas)	1,11	0,56
Study 2 (95 farms in Bourgogne Franche Comté in "mountain pasture" system of which 8% are organic)	0,98	0,52
Study 3 (55 farms in PDO area)	0,97	0,48

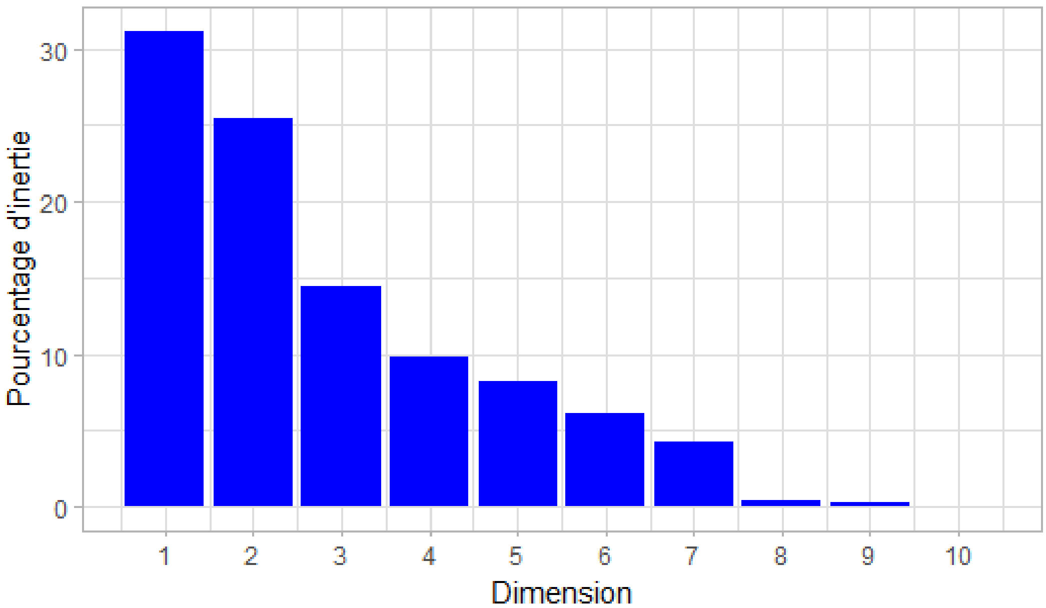


Figure 11 – Total inertia decomposition of the data set. Source: personal

1.2. GHG emissions results

The gross GHG emissions are 1.03 kg CO2 eq/L of milk on average for the sample of farms studied. Carbon storage was 0.58 kg CO2 eq/L of milk. Finally, the net GHG emissions are 0.45 kg CO2 eq/L of milk.

The GHG emissions data are represented graphically in **Figure 10**, which show a high variability of the data. Overall, the dispersion of the data is more important for net GHG emissions. Indeed, the standard deviation is about ½ of the mean and the maximum and minimum values are very far apart (variation of 1 kg CO2 eq/L of milk). For gross GHG emissions, the dispersion is less important, the standard deviation is lower and the difference between maximum and minimum values is smaller, it is 0.52 kg CO2 eq/L. The variability within the sample indicates that it is interesting to go further in the data analysis and understand what may characterize these differences within the sample. Moreover, there is probably room for improvement to reduce the carbon footprint of Comté PDO milk production.

Table 7 aggregates the GHG emission results from our study as well as from three to the studies. The results of the farms in our sample are overall good, as carbon storage is higher than that obtained in other studies (Brocas *et al.*, 2018; IDELE, 2021) with 0.58 kg CO2 eq/L milk compared to 0.55 and 0.46 kg CO2 eq/L milk. Net GHG emissions are lower than in three studies (0.45 kg CO2 eq/L of milk versus 0.56, 0.52 and 0.48 kg CO2 eq/L of milk). On the other hand, gross GHG emissions (1.03 kg CO2 eq/L of milk) are lower than those of the first study (1.11 kg CO2 eq/L of milk) but higher than those of the other two (0.98 and 0.97 kg CO2 eq/L of milk). Finally, the PDO farms of the Jura massif seem to have a net carbon footprint clearly lower than other equivalent mountain pasture systems, even if the comparison remains questionable since the years of study are not the same. The year 2019 is a year of drought in Franche-Comté, in fact, 30 communes in the Doubs have been recognized as a state of natural disaster for damage caused by differential land movements due to drought and soil rehydration (Prefect of the Doubs, 2020). In addition, the Comté specifications induce restrictions (on productivity per hectare, mineral nitrogen applied, consumption of concentrates) that can have an impact on GHG emissions.

In Sweden, a study was conducted on the variation of gross GHG emissions from dairy farms under different management modes, the results were an average of 1.13 kg CO2 eq/L of milk with results ranging from 0.94 to 1.33 kg CO2 eq/L of milk. Thus, the different management methods have an impact on the variability of the carbon footprint (Henriksson, 2011)

Another Italian study was conducted on mountain dairy farms comparing GHG emissions according to the number of LUs on the farm (less than or greater than 30). The gross emissions of the small farms were higher (1.38 vs. 1.10 kg CO2 eq/L of milk), while taking UAA as a unit they were lower (0.22 vs. 0.73 kg eq. CO2/ha UAA). They thus highlighted the importance of grasslands in these small farms (Salvador, 2017)

Overall, the results of these two studies are superior to the results of our study on gross GHG emissions.

2. Classification of farms according to their gross and net GHG emissions

1.1. Characterization of the groups

The results of the PCA and AHC, allowed the farms to be divided into four groups that could be distinguished according to the quantities and origin of GHG emissions, and the quantities and sources of carbon storage.

The PCA results are illustrated by the histogram of inertia (**Figure 11**) and the correlation circles (**Figures 12**). The decomposition of the total inertia shows that the first 3 dimensions of the PCA retain 71% of the information and explain a large part of the spatial distribution of farms. The three dimensions are explained by the correlation circles.

Dimension 1, which has an inertia of 31%, is positively explained by net GHG emissions, GHG emissions from effluents, GHG emissions from fuel and electricity consumption, GHG emissions

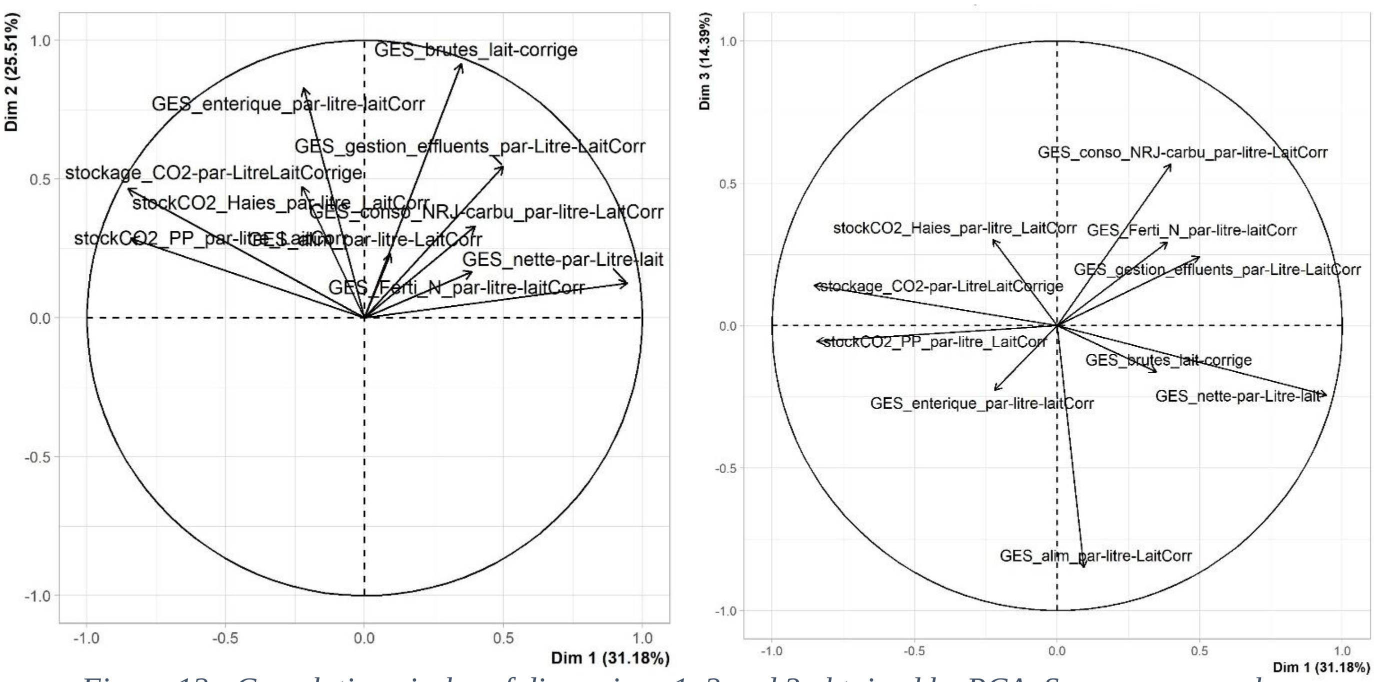


Figure 12 - Correlation circles of dimensions 1, 2 and 3 obtained by PCA. Source: personal

Table 8 - Characterization of the 4 groups obtained with hierarchical ascending classification by the origin of their GHG emissions

	Group 1	Group 2	Group 3	Group 4
Gross GHG emissions	0,96	1,11	0,96	1,24
ANOVA results	B	A	B	A
Carbon storage	0,81	0,75	0,44	0,53
ANOVA results	A	A	B	B
Net GHG emissions	0,18	0,366	0,521	0,71
ANOVA results	C	BC	AB	A
GHG emissions from enteric fermentation	0,60	0,65	0,56	0,62
ANOVA results	AB	A	B	A
GHG emissions from effluent management	0,17	0,19	0,18	0,31
ANOVA results	B	B	B	A
GHG emissions from nitrogen fertilization	0,061	0,057	0,065	0,093
ANOVA results	AB	B	AB	A
GHG emissions from energy and fuel consumption	0,06	0,059	0,055	0,088
ANOVA results	B	B	B	A
GHG emissions from food	0,075	0,099	0,09	0,098
ANOVA results	A	A	A	A
Carbon storage by hedgerows	0,063	0,24	0,083	0,13
ANOVA results	B	A	B	B
Carbon storage by permanent grasslands	0,74	0,5	0,36	0,36
ANOVA results	A	B	C	BC

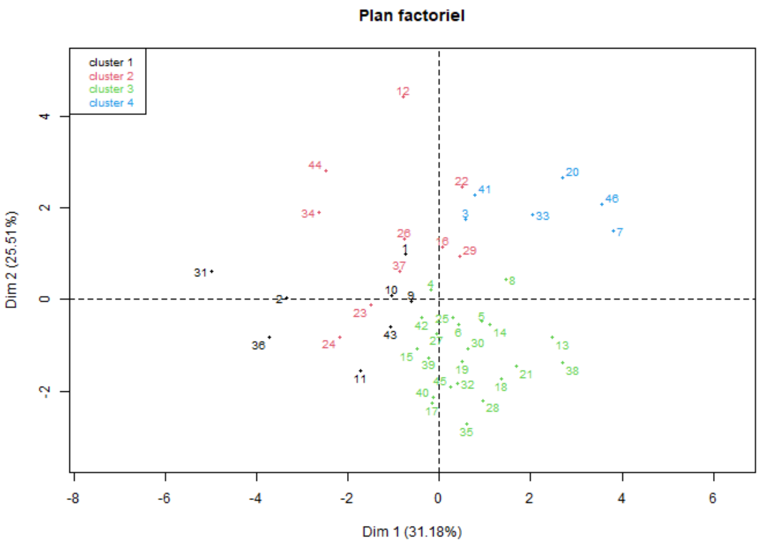


Figure 13 - Hierarchical ascending classification of individuals. Source: personnal

from fertilization and gross GHG emissions. And it is negatively explained by carbon storage by permanent grasslands and total carbon storage.
Dimension 2, which has an inertia of 25%, is positively explained by gross GHG emissions, GHG emissions from enteric fermentation, GHG emissions from manure management, carbon storage by hedgerows, total carbon storage and GHG emissions from fuel and electricity consumption.
Finally, dimension 3, with an inertia of 14%, is positively explained by GHG emissions from fuel and electricity consumption, carbon storage by hedgerows and GHG emissions from manure management. It is also negatively explained by GHG emissions from feed. (**Appendix 5**)

The AHC carried out on 5 dimensions (**Figure 13**) in order to retain the maximum amount of information allowed us to classify them into 4 groups. These groups have significant differences in their GHG emission results.
The four selected groups are characterized as follows (**Table 8**):

- Group 1 "**very low net GHG emissions thanks to grassland (0.18 kg CO2 eq/L of milk)**" (n=8): in this group there are few net GHG emissions because gross emissions are strongly compensated by carbon storage by permanent grassland (0.74 kg CO2 eq/L of milk). Hedgerows, on the other hand, do not compensate much for gross emissions (0.063 kg CO2 eq/L of milk).
- Group 2 "**low net GHG emissions thanks to hedgerows (0.37 kg CO2 eq/L of milk)**" (n=10): in this group there are many gross GHG emissions (1.11 kg CO2 eq/L of milk), which are linked to high enteric methane emissions (0.65 kg CO2 eq/L of milk). Carbon storage by hedgerows is quite high (0.24 kg CO2 eq/L of milk), which lowers net emissions.
- Group 3 "**average net GHG emissions (0.52 kg CO2 eq/L of milk)**" (n=22): in this group there are few gross GHG emissions (0.96 kg CO2 eq/L of milk), this is linked to enteric methane emissions which are low (0.56 kg CO2 eq/L of milk), but there is also a very low compensation of the emissions (as much by the permanent grasslands as by the hedges) (0.44 kg CO2 eq/L of milk), so finally the net GHG emissions are quite high.
- Group 4 "**high net GHG emissions (0.71 kg CO2 eq/L of milk)**" (n=6): in this group there are many gross GHG emissions (1.24 kg CO2 eq/L of milk), they are mainly related to effluent management (0.31 kg CO2 eq/L of milk), moreover, there is little carbon storage to compensate them (0.53 kg CO2 eq/L of milk).

Table 9 shows the ANOVA results for the significantly different variables.

Groups 1 and 4 have the highest proportion of organic farms with 87% and 83% respectively, but they are also the groups with the lowest numbers compared to groups 2 and 3. Group 1 is also the one where the majority of farms (75%) are at an altitude of more than 800 meters, while the majority (83.3%) of those in group 4 are at less than 600 meters.

In group 1 we find farms with a low stocking rate/ha mainly explained by a low number of LUs for a surface raised mainly on permanent grassland. There is also a low consumption of concentrates, low organic nitrogen application and low milk production/ha FPA. This group could be described as rather extensive in terms of surface area, with low milk productivity per hectare, and having an autonomous strategy and good technical control.

Group 2 is characterized by a low UAA, FPA, number of dairy cows and milk production per cow. This results in a high stocking rate. As expected, there is a high level of hedges. This group could be described as intensive in terms of stocking but with low productivity per hectare.

Group 3 is made up of farms with high values for milk production/ha FPA and per dairy cow, concentrate consumption, grass yield, stocking rate and organic nitrogen applied. On the other hand, the age at first calving and the number of hedges are low. This group could be described as rather intensive in terms of input consumption (concentrates) and productivity.

Finally, group 4 is characterized by a high farm size in terms of area and animals, and the load is high. Milk production/ha of FPA, organic nitrogen applied, concentrate and fuel consumption, and

Table 9 - Description of the groups by means calculated for different variables. Source: personnal

	Group 1	Group 2	Group 3	Group 4
Workforce	8	10	22	6
Organic farming	87,5	70,0	54,5	83,3
Milk production/ha SFP (liter/ha SFP)	2063 c	2803 bc	3737 a	3216 ab
Corrected milk production/dairy cow (corrected milk liter/dairy cow)	5466 ab	4730 b	5899 a	5627 ab
Stocking rate (LU/ha SFP)	0,56 b	0,85 a	0,91 a	0,85 a
Organic N applied/ha milk UAA (kg N/ha milk UAA)	54,3 b	69.5 ab	81,0 a	81,2 a
Number of LUs	59,3 b	54,7 b	69.8 ab	104,3 a
Number of dairy cows	38.2 ab	36,6 b	47.1 ab	63,4 a
UAA (hectare)	106.4 ab	70,4 b	89.7 ab	146,4 a
SFP (hectare)	105.8 ab	69,7 b	82.7 ab	132,7 a
Intra crops consumed (hectares)	0,4 b	1,1 b	4.3 ab	7,4 a
Temporary grassland (hectares)	5,0 b	7,8 b	14,6 b	33,5 a
Permanent grassland (%PP/UAA milk)	96,2 a	87.1 ab	78.0 ab	61,6 b
Hedgerows (linear meters)	3836 b	13160 a	6827 b	13038 a
Hedgerows/ha milk UAA (linear meter/ha milk UAA)	38,1 c	193,4 a	83.4 bc	93,9 b

	Group 1	Group 2	Group 3	Group 4
Workforce	8	10	22	6
Organic farming	87,5	70,0	54,5	83,3
Age at first calving (months)	34.8 ab	35.1 ab	33,2 b	36,9 a
Concentrate consumption/liter (g/l)	150 b	195 ab	204 a	230 a
Concentrate consumption/heifer unit (g/heifer unit)	127 b	272 ab	325 ab	435 a
Concentrate consumption/dairy cow/year (Kg/dairy cow/year)	883 b	947 ab	1247 a	1343 a
Yield of grass used (TMS/ha)	2,7 c	3,5 b	4,4 a	3.9 ab
Fuel consumption (liter/ha milk UAA)	48,9 b	63,8 b	71.8 ab	100,0 a
LU/Labor Unit	30,0 b	34,4 b	36,6 b	48,2 a
UAA/Labor Unit	55.8 ab	44,4 b	45,8 b	70,1 a
Altitude (number of individuals)				
<600	1	4	9	5
600 à 800	1	5	7	1
>800	6	1	6	0

age at first calving are also high. This group also differs from the others by the high amount of temporary grassland and intra-crop consumption, while permanent grassland is low. In relation to the work on the farm, the UAA/UL and the LU/UL are high compared to the values observed in the other groups. This group could be qualified as intensive on the means of production.

1.1. Elements of discussion on the differences in practices between the groups

Finally, when the groups are compared, certain variables stand out significantly. Thanks to these statistical tests, it is possible to have an idea of the practices associated with the differences in GHG emissions between the groups and thus provide avenues for action on emissions. groups 1 and 4 are the two extremes with very low net GHG emissions for group 1 and higher emissions for group 4. Groups 3 and 4 have intermediate results, but these are not due to the same practices.

- Farm size

First of all, groups 1 and 4 differ in their GHG emissions which can be associated with the size of the farms. Indeed, group 4, which emits a lot of GHGs, is characterized by a high UAA and FPA, and a high number of LUs, whereas group 1, which emits less GHGs, also has a high FPA and a high UAA but fewer LUs. Group 2 would be characterized by small areas and Group 3 by intermediate size.

- Stocking rate

Group 1, which has the lowest net GHG emissions, is significantly different from the others with respect to stocking. Since stocking refers to both the number of animals and the amount of land, several elements must be considered to understand its effects.

Limiting stocking consists of seeking a balance between the feeding potential of the land and the number of animals present; this makes it possible to secure food stocks and reduce nitrogen pressure on the soil via manure. In organic farming, the number of dairy cows is on average higher to compensate for a lower level of production, but the number of total LUs is lower (FNAB, 2019).

Regarding soils, intensively managed environments with high stocking grazing favor the degradation of the grass cover and can have significant nitrogen losses (as nitrogen inputs are high and there may be fall/winter grazing practices) (Dollé et al., 2013).

- Milk production and feed management

The main difference between groups 2 and 3 is the milk production per cow, which is lower for Group 2 than for Group 3. Their gross GHG emissions are also different, but they are lowest for group 3. This raises the question of a possible dilution effect of GHG emissions when production is high, provided that concentrate consumption is well controlled. This seems to be the case for group 3, since with 300 kg/concentrate/milk cow/year more and an almost equivalent consumption of concentrate in g/L, the milk production per cow exceeds that of group 2 by about 1100 liters. Finally, group 3 is correct in terms of technical control of feeding, with a moderate productivity of dairy cows. Group 2 has a low productivity with a poor control of concentrates.

For groups 1 and 4, the quantity of milk produced per cow is not significantly different while there is a significant difference between their gross GHG emissions. This could be explained by a poor technical mastery in group 4, especially on herd management. With almost 100 kg/concentrate/milk cow/year compared to group 3, the milk production per cow is 200 liters lower. In addition, in group 4, the LU/manpower values are high, so there is a significant amount of work and a risk of having less time for certain tasks and of being less precise about feed management. This hypothesis could be confirmed since in this group the average consumption of concentrates per LU, per cow and per liter of milk are high. The high quantities of concentrates can be related to the area of crops consumed, which is also the highest for this group. Indeed, according to the field observations

of Matthieu Cassez, agricultural engineer, sometimes when there is a lot of intra consumed crops available on a farm, there can be a slackening of the feed management due to a lower cost, hence higher quantities distributed. This is especially true for group 3, where there are also self-consumed crops and large quantities of concentrates consumed.

However, group 3 has lower gross emissions than group 4, mainly because emissions from enteric fermentation are lower. This could be explained by the fact that the amount of concentrates fed to cows is high in this group, yet increasing concentrates in the ration may result in lower methane emissions (Doreau *et al.*, 2017). The differences in gross emissions between groups 3 and 4 may be associated with better technical control of the herd with a lower age at first calving. Indeed, according to the study conducted by Foray *et al.* (2020), systems with an age at first calving of 24 months have significantly lower gross GHG emissions than those based on calving at 36 months (Foray *et al.*, 2020).

- <u>Effluent management</u>

A significant proportion of the gross GHG emissions of group 4 are due to manure management, yet the amount of organic nitrogen applied per hectare in group 4 is not significantly different from the other groups. It can therefore be assumed that the differences are in the type of effluent, type of building or storage.

- <u>Carbon storage</u>

Groups 1 and 2 have the lowest net emissions, and differ from groups 3 and 4 in their carbon offsets. Carbon storage is associated with permanent grasslands for group 1 and with the hedge line/ha of UAA in group 2. It is proven that carbon storage is very important since it can compensate for up to 30% of GHG emissions (Gac *et al.*, 2010). Regarding hedges, groups 2 and 4 have almost the same amount of hedges, although group 4 compensates less for its emissions because it is related to the size of the farm and group 4 has a much higher UAA.

- <u>Temporary grassland and geographical area</u>

Group 4 is also differentiated by the area of temporary grassland, it is the group with the largest area on average, and it is also the group for which a majority of farms are below 600 meters in altitude. Whereas group 1, which has the largest share of temporary grassland in the UAA, is the one with a majority of farms above 800 meters altitude. This can be explained by the difficulty of producing cereals (climate, soil, etc.) or mechanization in the higher altitude areas. The geographical situation of group 4, strongly marked by a low altitude, can have as consequences lower quality pastures and meadows and a more accentuated sensitivity to drought which provoke a lower availability of the basic ration. This could explain the high complementation in concentrates in this group.

Finally, it can be seen that groups 1 and 4 are very different, yet they are the ones with the highest proportion of organic farms. This shows that practices and GHG emissions can be different even when farms follow the same specifications.

Thus, with this part of the analysis, we were able to highlight the differences between the groups but not make a direct link with GHG emissions. Hence the interest in going further in the analysis in order to be able to compare GHG emissions according to production methods and understand which variables are involved in GHG emissions.

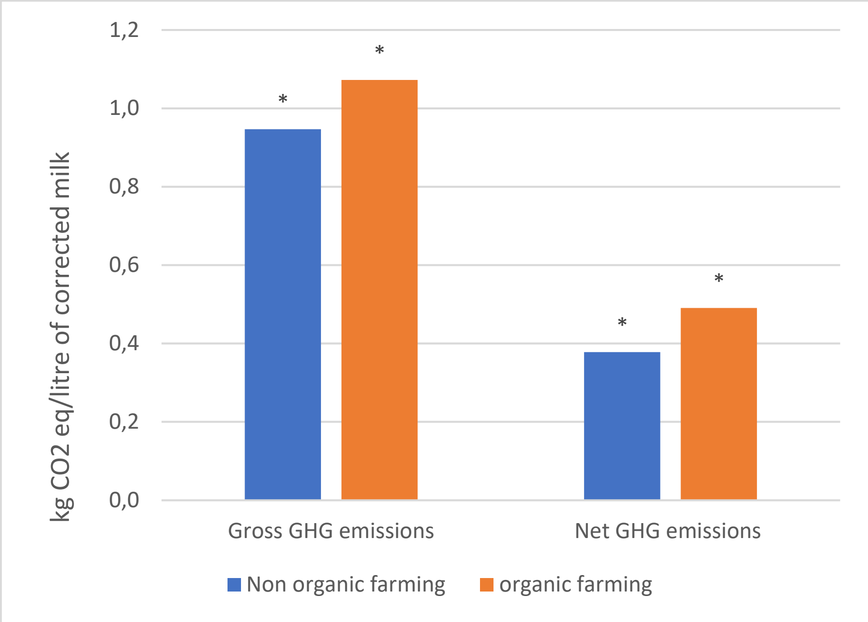


Figure 14 - Estimated average gross and net GHG emissions ***per liter of milk adjusted*** *by production method. Source: personal*

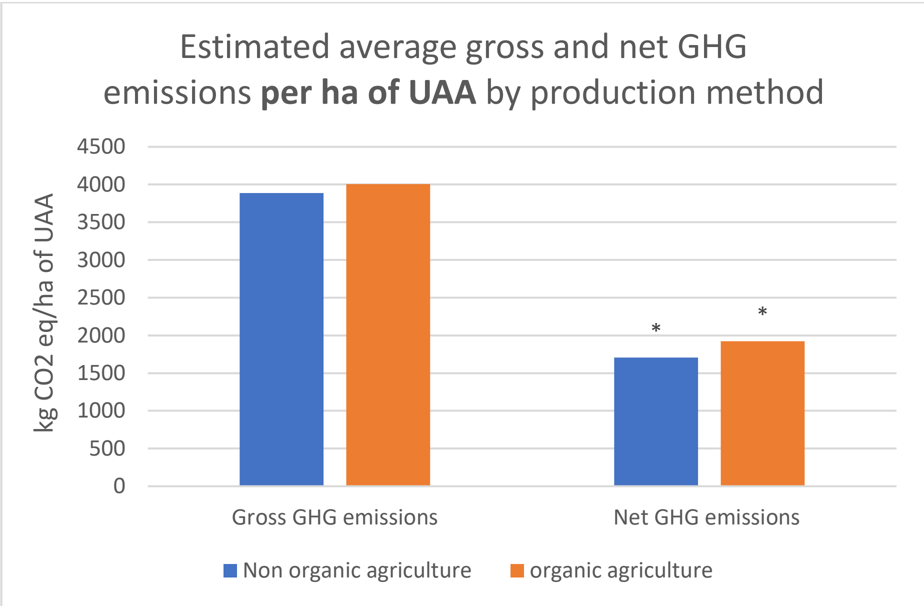


Figure 15 – Estimated average gross and net GHG emissions ***per ha of UAA*** *by production method. Source: personal*

Table 10 - Comparison of estimated averages for net and gross GHG emissions by selected unit and production method. Source: personal

	Production method	Estimated averages	Probability values
Gross GHG emissions/liter of milk adjusted	OA	1.072	0,006
	Non-OA	0.947	
Net GHG emissions/liter of milk adjusted	OA	0.490	0,011
	Non-OA	0.378	
Gross GHG emissions/ha of UAA	OA	4007.9	0,546
	Non-OA	3887.4	
Net GHG emissions/ha of UAA	OA	1922.8	0,33
	Non-OA	1704.7	

3. What practices explain the differences in GHG emissions between farms?

1.1. Comparison of emissions between organic and non-organic farms

Following the ANCOVAs, we were able to obtain adjusted averages of gross and net GHG emissions per corrected liter of milk and per hectare of UAA and according to the "organic farming" and "non-organic farming" modality (**Figure 14 and 15**) The adjusted averages are obtained when applying the model determined by the ANCOVA, they take into account the imbalance of the sample and the effect of the covariates.

It can be seen that the adjusted means of gross and net GHG emissions per corrected liter of milk for the organic group are significantly higher than for the other group, with probability values of less than 1% (**Table 10**). However, when looking at the data, the differences are in the order of about 100 grams CO2eq per liter of corrected milk, which equates to differences of about 11% for gross emissions and 22% for net emissions. For the results per hectare of UAA the results for gross GHG emissions are not significant. And for net GHG emissions they are, with a probability value of 0.330, and it is again the emissions from organic farms that are higher than the others. The differences are quite small, about 3% for gross emissions and 12% for net emissions. These results are different from what one might have expected, and there are several possible explanations. First, the most frequently used unit for GHG emissions is the liter of milk. However, in organic farming, dairy cows tend to be less productive than in conventional farming, and therefore emit more GHG per liter of milk. Furthermore, this result could be due to a sample effect since the individuals in our sample who are not in organic farming are still motivated by environmental initiatives.

Studies conducted in Pays de la Loire showed different results from ours with lower gross GHG emissions in organic farming (0.92 kg CO2 eq/L of milk versus 0.95 kg CO2 eq/L of milk). Net emissions are also lower with 0.75 kg CO2 eq/L of milk in organic farming and 0.88 kg CO2 eq/L of milk in conventional (Julien, 2019).

In order to situate the organic farms in our sample in relation to a larger sample in France, their GHG emissions can be compared to the "Results CAP2ER from 2013 to 2019 for organic farms" (study conducted as part of the Low Carbon Dairy Farm) (Idele, 2021). This study covers 454 dairy farms in France and the results are 0.99 kg CO2 eq/L of milk for gross emissions and 0.67 kg CO2 eq/L of milk for net emissions. For our sample, the adjusted[1] averages for organic farms are slightly higher for gross emissions with 1.07 kg CO2 eq./L of milk and lower for net emissions with 0.49 kg CO2 eq. /L of milk. This means that it is mainly carbon storage that makes the difference, which is confirmed when we look at the proportion of permanent grassland in the milk UAA, which is 76% on average for our sample and 36% for the farms in the study to which we compare our results. This comparison simply allows us to have an idea of how our farms are situated in relation to national averages. Nevertheless, it leads us to believe that the organic farms in our sample are differentiated by their permanent grassland, which allows them to offset their GHG emissions.

1.2. Identification of explanatory variables

XLSTAT tested several models which allowed us to choose the best one with a larger explanation of the variability illustrated by the R^2.

Concerning the model chosen for gross GHG emissions, the R^2 is 0.82, which means that 82% of the variability of this variable is explained by the 18 explanatory variables selected. These explanatory variables selected in the model provide information to explain the variability of GHG emissions. (**Appendix 6**)

[1] It is likely that the data from the study to which our data are compared are not adjusted data but observed data. The observed data for our sample are 1.04 kg CO2eq/L of milk for gross emissions and 0.45 kg CO2eq/L of milk for net emissions.

Table 11 - Explanatory variables of gross GHG emissions with their p-value and correlation coefficient. Source: personnal

Explanatory variables for the gross GHG emissions variable	Probability value	Correlation with gross GHG emissions
Milk production/dairy cow	**<0,0001**	-0,439
Age at first calving	**0,01**	0,298
Concentrates/head of heifers (g)	**0,004**	0,216
% protein autonomy	**0,003**	-0,198
Yield of recovered grass (T dry matter/ha)	**0,03**	0,033
Grazing time/dairy cow/year	**0,001**	0,085
Breeding rate (%)	**0,03**	-0,037

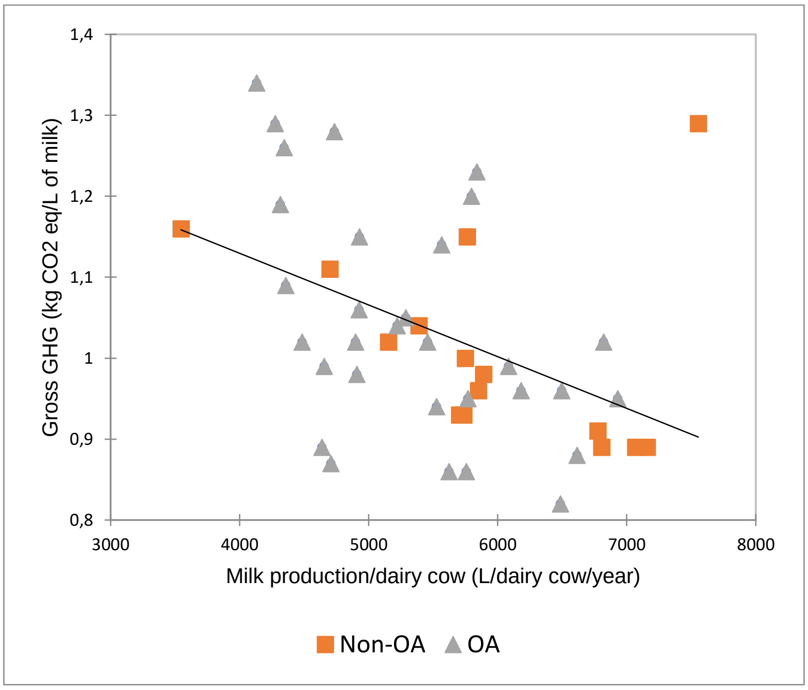


Figure 16 - Relationship between milk production per dairy cow and gross GHG emissions

Those that provide significant information are: **milk production/milk cow, %LBU heifers/milk cows, age at first calving, gr of concentrates/LBU heifers, % of protein autonomy, yield of valued grass, grazing time/dairy cow/year.**

The correlation matrix given by the ANCOVA identifies the variables for which the correlation with gross GHG emissions is the strongest. The variable that stands out from the others and has the highest correlation is: **milk production/dairy cow**. The direction of the regression line indicates that the more milk produced per dairy cow the lower the gross GHG emissions **(Figure 16).** For the other variables, the correlations with gross GHG emissions are less strong, as follows

- Positive correlation: age at first calving, amount of concentrate per LU heifer, grass yield and grazing time
- Negative correlation: protein autonomy and rearing rate (% LU heifer/dairy cow)

Table 11 shows each of the explanatory variables with its probability value and correlations with gross GHG emissions.

Concerning the model chosen for net GHG emissions, the R^2 is 0.95. This model is composed of 19 explanatory variables that explain 95% of the variability of this variable. (**Appendix 7**) These 19 variables were selected because they contribute to providing information, the significant variables are as follows: **number of LUs, UAA, intra-consumed crops, nitrogen balance, eq. ha of biodiversity maintained, milk production/dairy cow, age at first calving, gr. of concentrates/heifer LU, % of protein autonomy, yield of valued grass, %permanent grassland/UAA, linear meters of hedges/ha UAA, grazing time/dairy cow/year, electricity consumption/1000L milk.**

The correlation matrix given by the ANCOVA identifies the variables for which the correlation with net GHG emissions is the strongest. The variables that stand out from the others and have the highest correlation values are: **nitrogen balance**, **eq. ha of biodiversity maintained, grass yields and %permanent grassland/UAA.** Thus, we can conclude several things: net GHG emissions increase when the nitrogen balance and the grass yield increase. Conversely, they decrease when the hectares of biodiversity maintained and the proportion of permanent grassland in the UAA increase. (**Figure 17**)

For the other variables, the correlations with net GHG emissions are less strong, as follows

- Positive correlation: amount of concentrate per LU heifer, number of LUs, UAA, intra crops consumed, milk production/milk cow, age at first calving
- Negative correlation: protein autonomy, electricity consumption, hedge line per hectare of UAA and grazing time

Table 12 shows each of the explanatory variables with its probability value and correlations with net GHG emissions.

The results of these ANCOVAs allow us to validate or not our initial hypotheses:

- Hypothesis 1: "Practices that limit the number of animals (renewal rate, life span of dairy cows, number and length of lactation of dairy cows, age at first calving) are favourable to reducing GHG emissions." Validated for age at 1st calving, but clarified that this applies to gross GHG.
- Hypothesis 1: "Intensive animal management practices (quantity of concentrates distributed) increase GHG emissions. Validated but only on the quantities of concentrates distributed to heifer LUs.
- Hypothesis 2: "The larger the farm size, the more GHG emissions there are, since this can impact farm management." Validated, indeed, UAA is positively correlated with net GHG emissions.
- Hypothesis 3: "The linear of hedgerows is the agroecological element that has the most impact on carbon storage and therefore allows a significant decrease in net emissions (or even the

Table 12 - Explanatory variables of net GHG emissions with their p-value and correlation coefficient. Source: personnal

Explanatory variables for the net GHG emissions variable	Probability value	Correlation with net GHG emissions
Milk production/milk cow	0,002	0,130
Age at first calving	0,04	0,020
Concentrates/head of heifers (gr)	0,001	0,362
% protein autonomy	0,03	-0,227
Yield of recovered grass (T dry matter/ha)	<0,0001	0,655
Grazing time/dairy cow/year	0,008	-0,039
Number of LUs	<0,0001	0,273
UAA	0,009	0,049
Intra-Consumer Crops (ha)	0,007	0,299
Nitrogen balance (kg N/ha)	0,048	0,391
Biodiversity maintenance (Eq. ha/ha of milk UAA)	0,03	-0,253
% of permanent grassland in the milk UAA	<0,0001	-0,443
Lineage of hedges/ha of UAA milk	<0,0001	-0,082
Electricity consumption (KWh/1000litres milk)	0,03	-0,215

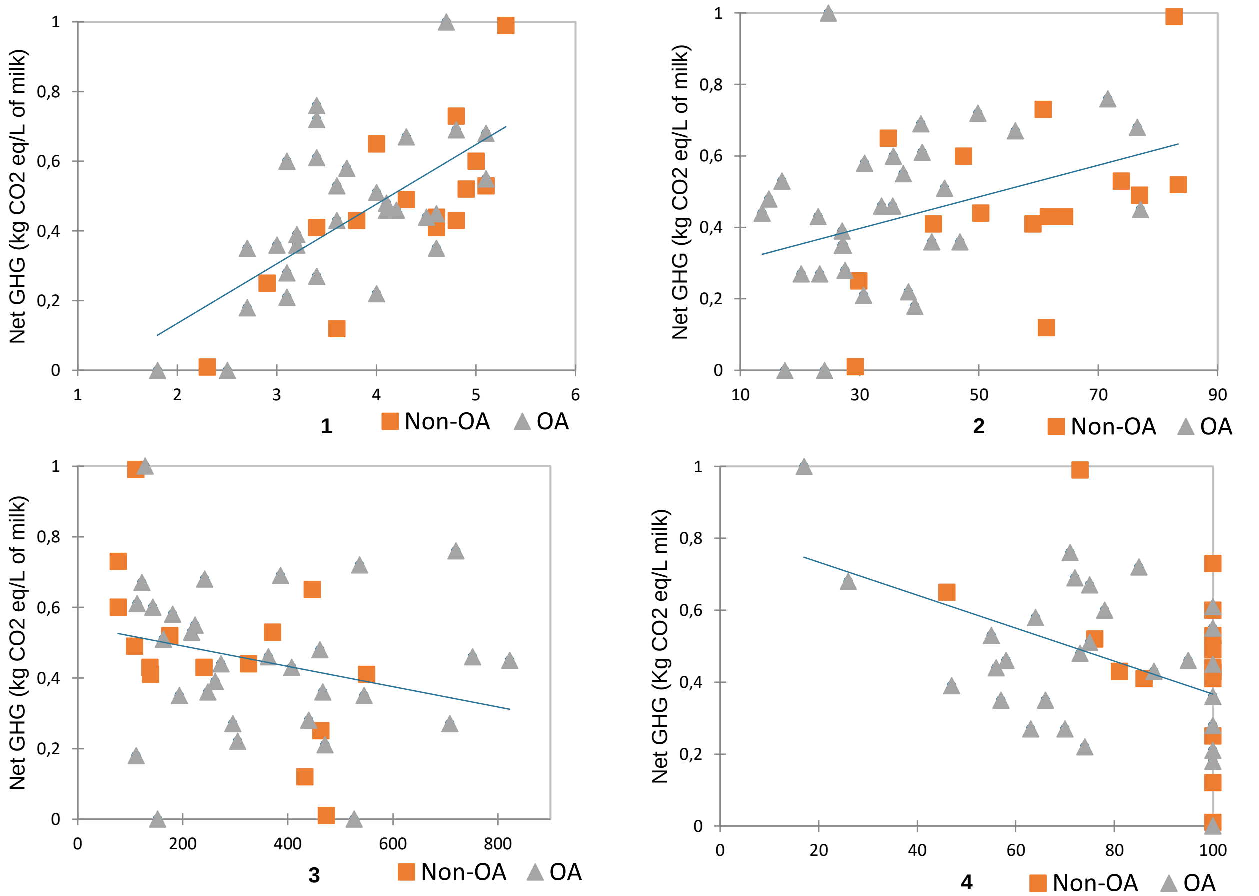


*Figure 17 - Relationship between net GHG emissions and **1**. Yield grass (tMS/ha SAU) / **2**. Nitrogen balance (kg N/ha) / **3**. Biodiversity maintained (ha eq. biodiv/ha of UAA) / **4**. %Permanent grassland/SAU (%)*

- achievement of neutrality)." Invalidated, it is rather the share of permanent grassland in the UAA that has a major role in carbon storage
- Hypothesis 4: "Nitrogen surplus results are correlated with GHG emissions." Validated, there is a correlation between the nitrogen balance and net GHG emissions.

All of these assumptions relate to GHG emissions per liter of milk, the conclusions might be different if we reasoned per hectare of UAA.

4. What are the levers of action to act on GHG emissions?

The ANCOVA has made it possible to highlight the explanatory variables of the variability of GHG emissions, now the important thing is to know which action levers can vary these variables.

First, UAA size and number of livestock units are weakly positively correlated with net GHG emissions, so smaller farms in terms of area and animals seem to be more favourable to net GHG reductions.

- Herd management (reproduction, feeding, ...)

On herd management, the explanatory variables for GHG emissions are: age at first calving, consumption of concentrates/heifer LU, rearing rate, number of LU. These variables are all related to whether or not there are unproductive animals (especially heifers) on the farm. The more unproductive animals there are, the more enteric methane emissions increase since these animals do not produce milk.

In view of the results, it would be tempting to want to increase milk production per cow since it is strongly negatively correlated with gross GHG emissions, but it is also positively correlated with net GHG emissions. In order to increase milk production per cow, good control of concentrates is required, and fodder requirements are increasing while the quantities of fodder harvested are not tending to increase with climate change. The risk would therefore be to resort to GHG-emitting practices such as the use of fertilisers or turning over grasslands to increase yields (Cassez, pers. com.). Thus, a balance must be struck between milk productivity per cow and other breeding factors, particularly in terms of feed management.

Protein autonomy is also a factor put forward, it reflects the autonomy of the farm, i.e. if the farm produces enough nitrogen or not. To achieve better protein autonomy, one solution may be to have better fodder richer in total nitrogen and to make fewer external purchases (Idele, pers. com.), or to reduce the age at first calving (Fischer, 2021).

- Surface management and agro-ecological elements

In terms of land management, the share of permanent grassland in the UAA has a positive impact on net GHG emissions since grasslands store a lot of carbon (570 kg C/ha/year). On the other hand, we can question the temporal limit of this carbon storage since it is rapid in the first 30 to 40 years but slows down thereafter, and tends towards a balance between inputs and outputs (Gac *et al.* , 2010). The establishment of hedges is also one of the levers for action to store carbon and offset GHG emissions (125 kg C/ha/year). In the same idea, agroforestry (which consists, among other things, of planting trees in open fields) is also presented as a practice that can mitigate GHG emissions since, in the same way as hedges, these trees store carbon (between 0.1 and 1.35 tC/ha/year over 20 years) (Ademe, 2015). In addition, hedgerows and agroforestry provide shade, act as windbreaks and buffer temperature variations, which can be favourable to animals in case of heat stress that is likely to increase in the coming years (Moreau *et al.* , 2018).

The results for the area under intra-feed crops are surprising, as we would have expected to have lower GHG emissions when there is intra-feed since there are fewer feed purchases, but it is the opposite effect that we find in the results. This may be related to the "slack in feed management" hypothesis mentioned earlier, so perhaps better technical management of intra-feed would have less

impact on emissions. Moreover, if crops are rotated with temporary grassland, carbon storage is less important than in permanent grassland (Dollé *et al.* , 2013).

Finally, on the management of grazing time, the correlation with GHG emissions is positive, which is not what we expected, since according to Idele, extending grazing time by 15% would reduce GHG emissions by 2 to 4%. At the same time, it saves time and fuel, and the fatty acid profile (omega 3 and saturated fatty acids) of the milk would be better (Idele, pers. com.)

- Nitrogen management

If we now look at the nitrogen balance, we can see that as the nitrogen balance increases, GHG emissions also increase. Even though we have not studied the fate of nitrogen, this is an important fact given the climate of the area. Climate change leads to alternating hot weather and heavy rainfall, which accelerates the removal of nitrogen from the soil and its release into waterways. Indeed, with the great heats the nitrogen which would be stored is mineralized and is ready to be washed away in case of heavy rains. Moreover, in the Climalait study presented earlier, predictions are made about the increase in temperature in the years to come. Finally, this correlation means that the actions implemented (studies, changes in practices, etc.) to avoid or reduce nitrogen pollution are also beneficial to the reduction of GHG emissions.

- Electricity consumption

Regarding electricity consumption, we found that as electricity consumption increases, GHG emissions decrease. According to the study by Lambotte *et al*, electricity consumption is mainly related to milking equipment and hay drying, both of which increase milk production. Indeed, in this study, the quantities of hay are positively correlated with electricity consumption (Lambotte *et al.* , 2021). On the other hand, even if nuclear energy generates few GHG emissions, it impacts the environment through global warming.

With ANCOVA, which allows the study of covariates to be integrated, it is clear that it is important not to focus solely on the difference between organic and non-organic farming. In view of the project's objectives, what is expected above all is to know what levers can be used in general, to understand what goes towards carbon neutrality and what does not.

Moreover, if we cross-check these results with the classification of farms, we could suppose that it seems necessary to be in organic farming to reach carbon neutrality but that it is not sufficient. As a reminder, group 1, which was the closest to carbon neutrality, was made up of 87% organic farms. However, ANCOVA shows us that the reduction of unproductive animals, the moderate size of farms, the high proportion of permanent grassland in the UAA, good control of feed and productivity per dairy cow are just as important in moving towards carbon neutrality.

In the results of our study, we find elements similar to other studies such as the Life Carbon Dairy project and the study by Michaud (2016), in which strong variations in GHG emissions within the same production system were also observed. In terms of practices, we find the importance of permanent grasslands in offsetting gross emissions, but also the limitation of unproductive animals and the management of concentrate consumption, which are levers common to these studies.

Finally, if we recontextualize the results in relation to the production area, they can be put into perspective with the Comté specifications and the future measures that will be adopted. The limitation measures concerning: the size of the farms, the milk production per cow, the number of cows per farmer are in line with the results of this study. The same applies to the proportion of permanent grassland, which is a key element in offsetting GHG emissions, particularly in the PDO area where the majority of systems are grassland-based. Thus, the monitoring of farms in parallel with the evolution of the specifications could be a perspective of the project.

IV. Limitations and prospects

1. Limitations on data interpretation

Finally, the study does not allow us to conclude on the effect of the production method on GHG emissions. Indeed, we observe a great variability of GHG emissions between farms, but it is not the production method (organic farming or not) that is responsible for this variability.

Furthermore, it is important to insist on the fact that these results concern only our sample of farms, which has its own particularities, and that it would not be fair to generalize the results to the whole Comté PDO area. In fact, the farms in our sample represent only 2% of the farms in the Comté PDO, and 21% of those in organic agriculture within the Comté PDO. These data confirm the fact that our sample is asymmetrical when characterized by production mode.

Finally, when interpreting the results, it is important to distinguish between the carbon footprint of farms and the environmental impact of farms, since studying the carbon footprint only addresses part of the environmental impact of livestock production. A more complete approach would require the study of nitrogen residues accumulated over several years, or pesticide residues for non-organic agriculture.

2. CAP2ER: a powerful tool but with certain limitations in its construction

The CAP2ER tool used in this study is a powerful tool that enables a diagnosis and a complete action plan to be drawn up by reasoning at the system level. Moreover, it is likely to be used more and more because it is promoted by the interprofession and some Regions support its use. The interest of this tool is also that, in the longer term, the objective is to constitute a national observatory that will enable users to situate the farms among themselves (Cousiné *et al.* , 2021).

Despite the efficiency of the tool during data entry, some difficulties were encountered, it would be useful to improve these points in the next versions of CAP2ER so that the reliability of the results is not impacted.

First of all, in the "agro-ecological elements" category, the hectares of forest and woodland edges are not counted even though they are very important elements in the Jura Massif PDO area since livestock farming makes it possible to exploit environments that are difficult to use. Indeed, forests represent 38% of the total carbon stock on French soils (INRA, 2019).

Concerning effluent management, the quantities available for spreading are calculated by the software (according to the type of building, the number of animals and the number of days spent in the building) but they are often lower than the quantities given by the farmers. For liquid manure, this may be due to dilution phenomena when the pits are open or when green and white water go into the same pit. For manure, the only explanation we found was the approximation of the farmers' statements. Still on the subject of effluents, when two types of effluents are produced by the same category of animal, it is only possible to report one.

Finally, concerning feed, we were confronted with certain situations where farmers were feeding sorghum or forage corn on the ground, which cannot be entered into the software and must be entered as silage, and which will therefore have an impact on the GHG emission results. For feed purchases, the tool calculates the impact of the manufacture and transport of these feeds, however, it is not possible to indicate the origin of these feeds (local or not), except for soybeans, which may come from France or from deforestation areas.

The CAP2ER tool is based on LCA, which also has limitations in terms of the environmental assessment of herbivore products. The unit in which the impacts are expressed is one of them, since the impacts expressed per kg of product favour the most productive systems (in milk here), whereas they might have a greater impact per hectare. It is therefore necessary to take this parameter into account when analysing the results. This choice of unit is inherited from the application of LCA to the industrial sector, so agriculture is only considered through its production function.

The question of land use should be further explored in order to distinguish between arable land and natural land (potentially mechanisable or not, with good or poor potential), the latter being

only able to be used for livestock production. According to LCA aggregation methods, grassland systems (including organic farming and herbivore systems) are generally penalized, even though they are often the only ones able to use these areas, which provide ecosystem services (Gac *et al.*, 2020).

Finally, the accessibility of the tool could be a problem since it is only usable by people who have training and who are technicians or livestock advisors. On the other hand, this may be a guarantee of the reliability of the data entered. In addition, the handling can sometimes be complicated given the amount of information to be entered. The difficulty of collecting information can lead to a collection effect on the results, and therefore uncertainties in the comparison of data collected by different people.

3. The continuation of the Clim'AOP Jura project

1.1. The next steps in the short and long term

In the near future, a first presentation of the results will be organised in the form of feedback to groups of farmers in the sample to allow them to position themselves and discuss the results among themselves. In addition, it could be relevant to complete and balance the sample already constituted to have as many conventional farms (selected outside the Confédération Paysanne network) as organic farms, which could allow for a more in-depth comparison.

Within the Confédération Paysanne, it is planned to carry out an analysis of the farms involved in the peasant farming approach, since this was one of the initial ambitions. This analysis could provide answers as to the effectiveness of the principles of peasant agriculture which seem a priori to be favourable to the environment.

For further analysis, economic data will also be added to the database to clarify the link between environmental and economic performance.

In addition, the sociological approach also carried out on part of the sample with the aim of understanding farmers' motivations for adapting to climate change could be cross-referenced with the technical results obtained with the CAP2ER diagnoses. In an anonymous and non-judgmental way, it will be interesting to compare "what farmers think they are doing well to contribute to mitigating climate change" with the results actually found on their farm or in the sample studied.

In the longer term, and as part of a new study, it would be relevant to repeat CAP2ER diagnoses on the farms already surveyed in order to see if there has been an evolution over time. At the same time, the results could be related to the new measures taken in the Comté specifications, since it can be expected that the new requirements will contribute to reducing the environmental impact of the farms. Finally, it would be interesting for the sector to try to have a global approach of the carbon footprint of the Comté cheese production as a whole, by studying the possible levers of improvement for the downstream actors.

1.2. Positioning of the results of the sample in relation to the farms in the Jura Massif PDO area

Initially, in year 1, the objectives of the project and of this internship were, on the one hand, to analyse the results within the sample and to identify levers for action. This part of the project was carried out even though it was planned to have 50 farms in the sample, but in the end there were only 46 due to lack of time and because it was difficult to obtain complete data on some farms despite the voluntary sample. On the other hand, the second objective was to compare the results of the sample farms, which are mostly organic or in a peasant farming approach, with other farms in conventional farming in the PDO area. Initially, the use of the results of the study conducted by Michaud (2016) had been mentioned, however, the results obtained date from 2015 which would have biased the analysis, since improvements were made on the CAP2ER tool and the climatic conditions were not the same over the two years of study. The second possibility to make this comparison was to ask Idele for an extraction of the results of all dairy farms under PDO for the year 2019. It is possible to make

this request, but the process of authorizing access to the data and then extracting it takes time and did not fit into the timeframe of the internship. This part of the project will therefore be continued in year 2 and may result in a new "agri-environmental" internship. The last year of the project will be devoted to communicating the results in the form of conferences and debates, professional publications and various articles, with the aim of publicising and encouraging practices that will make it possible to approach carbon neutrality on PDO farms in the Jura massif.

V. Conclusion

In this context where climate change is becoming increasingly worrying, many initiatives are being taken to mitigate this phenomenon. In particular, the construction of tools to evaluate the environmental performances of dairy cattle farms.

Within the framework of the Clim'AOP Jura project, our study focused on the analysis of the environmental performance of PDO farms in the Jura Mountains and more specifically on the study of their GHG emissions. The objectives of this project were to analyze the carbon footprints of the farms in our sample and to identify the practices that could allow the farms to get closer to carbon neutrality, since this is the case for some of the farms in the sample.

The average net carbon footprint of our farms' sample in the Massif Jurassien PDO is 0.45 kg CO_2 eq/L of milk and the gross carbon footprint is 1.03 kg CO_2 eq/L of milk. The national averages from the Low Carbon Dairy Farm results (between 2013 and 2019), are 0.83 kg CO_2 eq/L of milk for net emissions and 0.97 kg CO_2 eq/L of milk for gross emissions. The gross emissions of our sample are slightly higher, but the net emissions are much lower and highlight the importance of carbon storage on the farms we audited. The descriptive analysis showed significant variability in GHG emissions between the farms studied. Thus, a classification of the farms allowed us to identify 4 groups that differ in their emissions, and we were able to associate these differences with the practices implemented on the farms and thus better understand the variability of GHG emissions. An ANCOVA analysis was then used to identify which practices were beneficial to GHG emissions mitigation. The main levers of action highlighted by the study were: limitation of the size of the farms in terms of surface area and animals, large areas of permanent grassland, large hedgerows, good nitrogen management, limiting the number of unproductive animals (rearing rate, age at first calving), and limiting the consumption of concentrates for heifers. Finally, within our sample, the production method (organic or not) did not emerge as an element with a significant impact on GHG emissions.

The use of the CAP2ER tool allowed us to identify limitations that could impact the results and that could be improved for future versions. The first two limitations on the construction of the tool are the consideration of the locality of the food purchased and the consideration of forests and forest edges. The other limitation identified is the choice of the unit per kg of product, but this depends more on the LCA than on the CAP2ER tool, however, it seems necessary to consider this limitation when interpreting the results. Indeed, the risk is to favor the most productive systems. The LCA also does not take into account the impacts related to the use of pesticides, antibiotics and pest control products. However, work led by the National Research Institute for Agriculture, Food and the Environment on organic LCA is underway to better evaluate organic farming systems.
Linking our results with the economic results of the farms could lead farmers to reflect on their entire production system and could be an additional source of motivation to reduce their GHG emissions.

Finally, this study was carried out on the milk production part of the PDO chain in the Jura Mountains, but other actors upstream (feed and fertilizer manufacturers) and downstream (processing and maturing) are also involved in cheese production. For the future, it seems necessary to also study the milk processing part in the analysis of environmental performance. Ideally, the sector could go so far as to question the social and environmental impacts of all its links, right up to the marketers.

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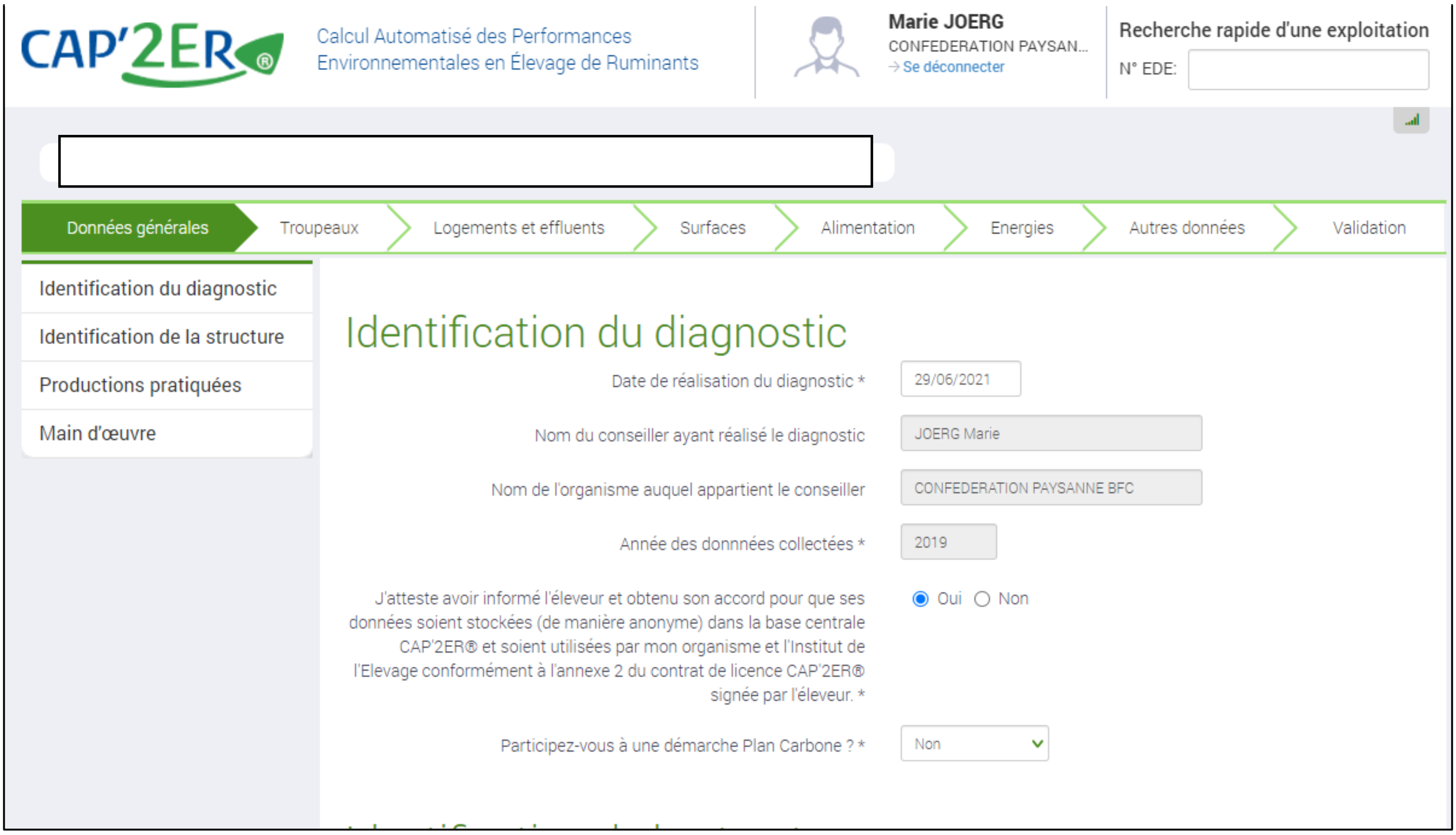
Table of appendices

Appendix 1 - Tabs to enter in CAP2ER



Appendix 2 - Result file obtained after a CAP2ER diagnosis

CAP'2ER Niveau 2

Diagnostic CAP'2ER® réalisé par : JOERG Marie - CONFEDERATION PAYSANNE BFC - 18/06/2021

MON EXPLOITATION

Mes ateliers animaux

BOVINS LAIT 67,6 UGB

Montbéliarde - 46

BOVINS VIANDE Non

Non

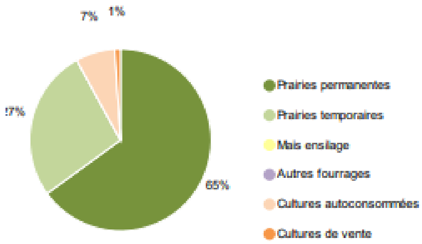
Non

Exploitation en

Elevage spécialisé
Zone Prioritaire PMPOA hors ZV
Agriculture biologique

Mes surfaces

103,1 ha de SAU*
dont 94,6 ha de SFP**

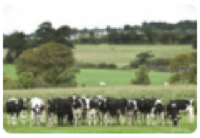


** SAU = Surface Agricole Utile - ** SFP = Surface Fourragère Principale*

MON ATELIER BOVIN LAIT

Système de référence : Montagne Herbager

MON TROUPEAU



Lait vendu corrigé*	Vaches laitières	Production par vache	Production par ha	Age au 1er vêlage	Chargement apparent
323 297	52	6 612	3 995	31,0	0,8
litres		L bruts/VL	L bruts/ha SFP lait	mois	UGB/ha SFP lait

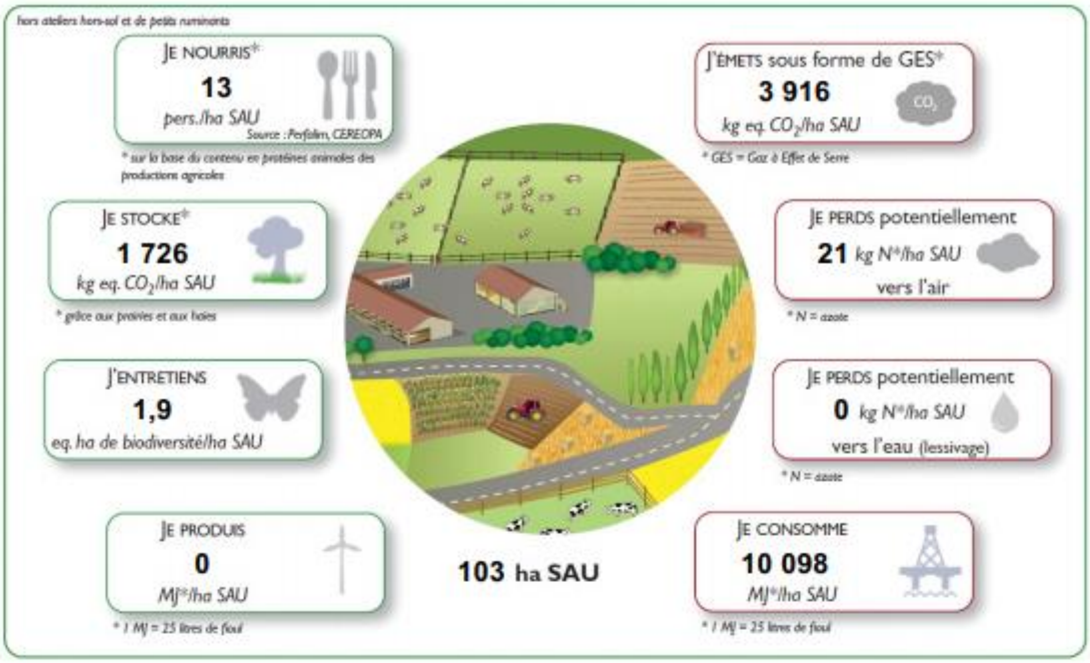
MES SURFACES

SAU Lait**	SFP lait	Prairies permanentes	Prairies temporaires	Linéaires de haies	Azote organique
93	85	60	25	5 616	62
ha	ha	ha	ha	mètres	kg N/ha SAU lait**

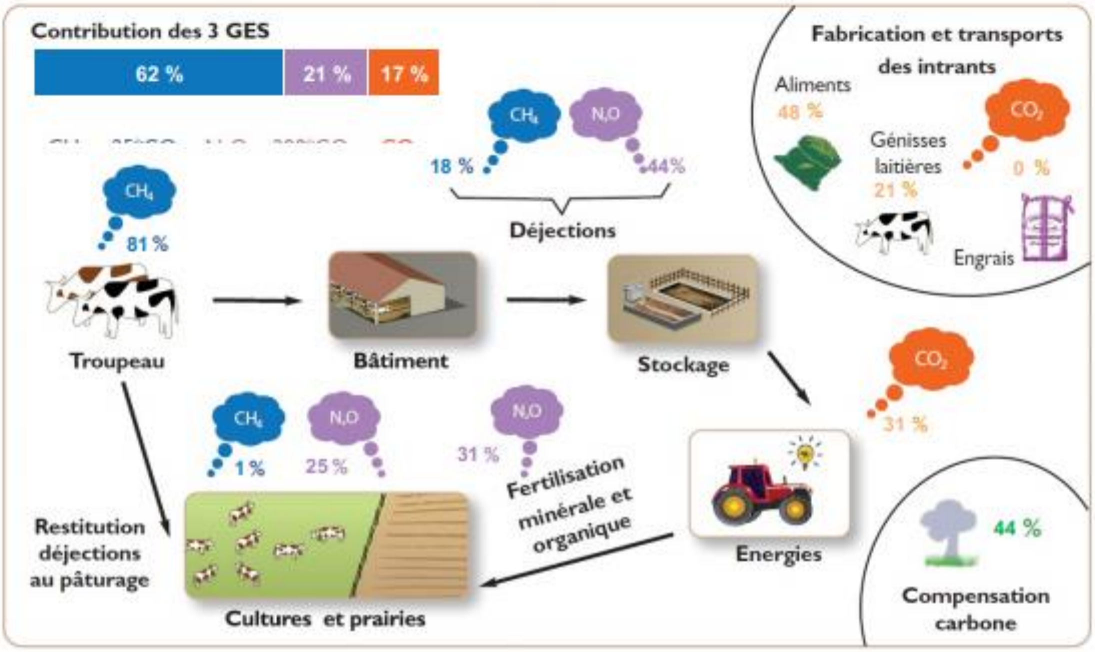
**Lait vendu corrigé 40-33 g/kg - **SAU lait = SFP de l'atelier lait + ha de céréales autoconsommées par l'atelier lait*

Diagnostic CAP'2ER® Niveau 2 – Version 6 du 11/05/2021 *1 / 8*

LE BILAN ENVIRONNEMENTAL POTENTIEL DE MON EXPLOITATION

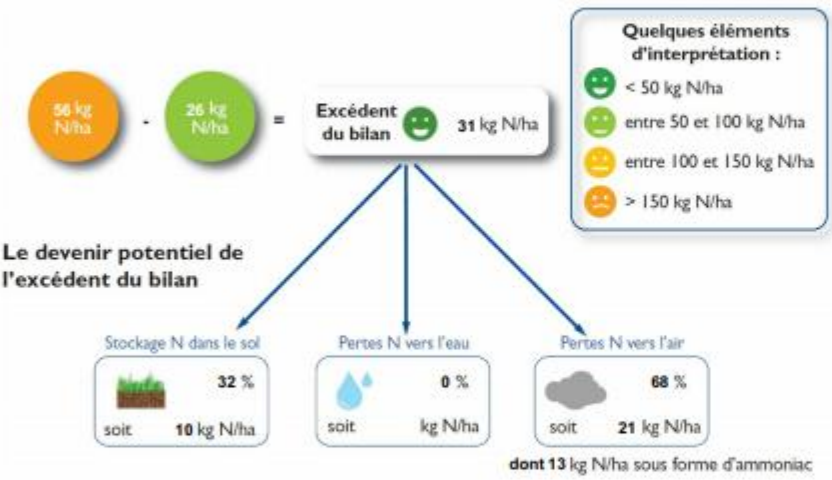


LES SOURCES DE GES À L'ÉCHELLE DE MON EXPLOITATION



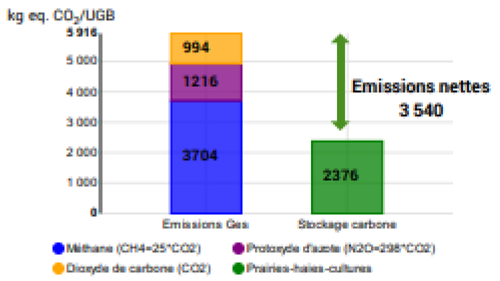
Bilan de l'azote à l'échelle de l'exploitation

La différence entre les entrées et les sorties est appelée excédent du bilan.

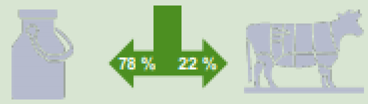


Le rapport entre les sorties et les entrées est appelée efficience de l'azote.

Les gaz a effet de serre et le stockage de carbone de mon atelier



Les émissions de GES sont réparties entre le lait et la viande produits par l'atelier de la façon suivante :

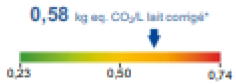


Les résultats du produit lait

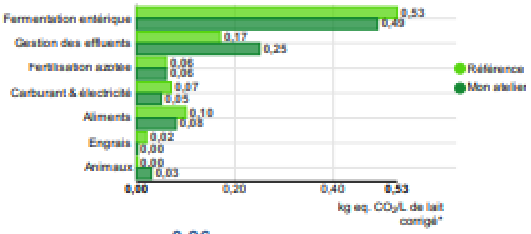
Empreinte carbone nette

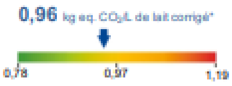
40%

de mes émissions de GES sont compensées par le stockage de carbone

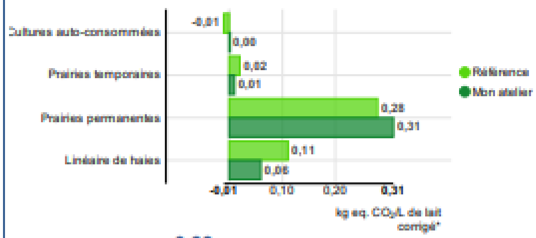


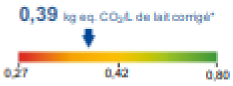
Emissions de GES (CH_4, N_2O et CO_2)





Stockage de carbone



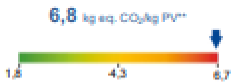


Comparaison par rapport à un système fourrager équivalent

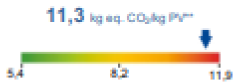
**L de lait vendu corrigé 40-33 g/kg*

Les résultats du produit viande

Empreinte carbone nette



Emissions de GES



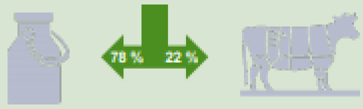
***kg PV = kg de poids vif vendu*

Les consommations d'energie de mon atelier

Les consommations d'énergie de mon atelier

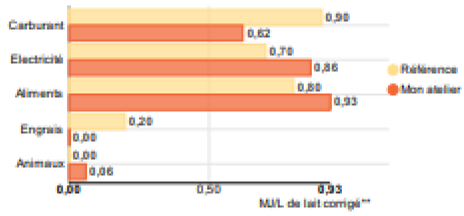
Mon atelier consomme
1 022 519 MJ*

Les consommations d'énergie sont réparties entre le lait et la viande produits par l'atelier de la façon suivante :

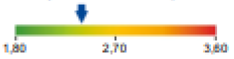


** 1 MJ = 25 litres de fioul*

Les consommations d'énergie du produit lait



2,46 MJ/L de lait corrigé**



Comparaison à un système fourrager équivalent

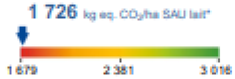
*** L de lait vendu corrigé 40-33 g/kg*

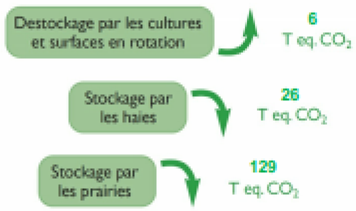
Les contributions positives de mon atelier

Mon atelier stocke

161 T eq.CO_2

1 726 kg eq. CO_2/ha SAU lait*

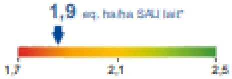


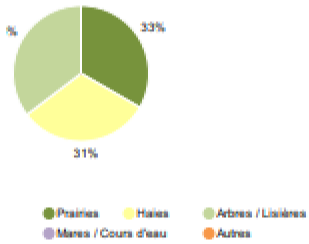


Mon atelier entretient

180 eq. ha de biodiversité

1,9 eq. ha/ha SAU lait*

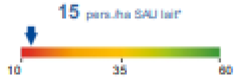




Mon atelier nourrit

1 355 personnes

15 pers./ha SAU lait*



Sur la base du contenu en protéines animales des productions agricoles

Comparaison à un système fourrager équivalent

** SAU lait = SFP de l'atelier lait + ha de céréales autoconsommées par l'atelier lait*

Les performances de mon atelier bovin lait

Gestion du troupeau

- Production laitière corrigée TB/TP	6 495 L/VL	2 721 – 5 902 – 8 720
- UGB génisses/VL	31 %	28 – 46 – 66
- Taux de renouvellement	33 %	18 – 28 – 38
- Age au 1[er] vêlage	31,0 mois	23,0 – 34,0 – 45,0

Alimentation du troupeau

- Concentrés des VL	171 g/l	0 – 238 – 495
- Azote excrété	96 kg N/UGB	62 – 89 – 142
- Concentrés des génisses	266 kg/UGB génisse	0 – 500 – 1 800
- Autonomie protéique	74 %	0 – 50 – 100

Gestion des surfaces

- Azote minéral épandu	0 kg N/ha SAU lait	0 – 18 – 124
- PP / SAU Lait	64 %	0 – 67 – 100
- Pression en azote organique	62 kg N/ha SAU lait	10 – 41 – 160
- Part PT dans les rotations	67 %	0 – 50 – 100
- Rendement en herbe valorisée	3,7 t MS/ha	3,2 – 4,7 – 6,1
- Haies	60 ml/ha SAU lait	0 – 117 – 235

Gestion des effluents

- Temps au pâturage - VL	152 jours/VL/an	99 – 173 – 365
- Couverture de la fosse à lisier	Caillebotis	
- Matériel d'épandage des effluents liquides	Pendillard	
- Délai d'incorporation	au-delà d'une semaine	

Energies

- Carburants	60 L/ha SAU lait	0 – 92 – 379
- Electricité	100 kWh/1000 L lait	0 – 86 – 1 188

Comparaison par rapport à un système fourrager équivalent

Mes résultats économiques (selon la méthode COUPROD)

Critères économiques	Résultat	Référence
Echelle exploitation		
EBE/PB de l'exploitation	NaN %	41 %
Revenu disponible de l'exploitation		
Echelle atelier lait		
Productivité de la main d'œuvre	148 332 litres/UMO atelier lait	142 389 litres/UMO atelier lait
Coûts de production		
Charges alimentation / Produits		
Rémunération du travail permise par le produit		

Mes conditions de travail

Comment est vécu votre volume de travail au quotidien ?	
Points positifs >=5	***Points à améliorer <5***
Globalement, je suis satisfait(e) de mes conditions de travail sur mon exploitation	
Le volume global de travail sur l'exploitation est acceptable	
La charge quotidienne liée au troupeau est acceptable	
La pénibilité physique sur mon exploitation est acceptable	
En période de pointe, la charge de travail reste acceptable	
J'arrive à me libérer autant que je le voudrais dans la journée et en semaine	
J'arrive à partir autant que je le voudrais pour le WE ou pour des congés	

Appendix 3 – Date base used for the statistical analysis plus definition and unit of each variable. Source: personnal

No_exploitation	groupe	AB	GES_brutes_lait corrige	GES_nette par Litre lait	UMO	stockage_CO2 par LitreLaitCorrige	PL par ha_SFP	chargement_UGB par haSFP	N_orga_epandu SAU lait	nb_UGB	UGB par UMO	SAU	SAU par UMO	SFP
1	1	1	1,06	0,27	3	0,8	1966	0,6	49,32	81,3	27,1	150	50,0	145
2	1	0	0,93	0,01	2	0,92	2203	0,5	46,57	38,2	19,1	74	37,0	74
3	4	1	1,14	0,46	1,9	0,68	2782	0,6	47,51	88,3	46,5	151,89	79,9	137,72
4	3	1	1,05	0,45	2,3	0,59	3249	0,9	91,73	90,3	39,3	107	46,5	107
5	3	0	1,04	0,6	1	0,44	3846	0,9	80,3	44,8	44,8	49,5	49,5	49,5
6	3	1	1,02	0,55	2	0,47	3930	1	79,52	44,3	22,2	43,52	21,8	43,52
7	4	0	1,29	0,99	2	0,3	5046	1,1	106,45	57,8	28,9	55,8	27,9	54
8	3	0	1,15	0,73	1	0,42	4106	1,1	95,23	46,2	46,2	44	44,0	44
9	1	1	1,02	0,36	3	0,66	2555	0,7	67,41	127,5	42,5	206	68,7	206
10	1	1	1,02	0,36	1,5	0,66	2428	0,7	76,5	43,6	29,1	62,31	41,5	62,31
11	1	1	0,88	0,18	1,5	0,7	2333	0,5	54,03	41	27,3	79	52,7	79
12	2	1	1,34	0,46	1,5	0,88	2123	0,8	73,37	66,8	44,5	80	53,3	79
13	3	1	1,02	0,69	3,9	0,33	4862	0,9	84,76	97,6	25,0	121,39	31,1	108,4
14	3	1	1,04	0,67	2	0,37	3811	1	89,61	62,9	31,5	61	30,5	61
15	3	0	0,93	0,43	1,3	0,5	4151	1,1	108,33	47,8	36,8	47	36,2	47
16	2	1	1,09	0,51	2	0,58	2574	1	79,49	53,6	26,8	55	27,5	55
17	3	0	0,89	0,43	2	0,46	3618	0,7	66,7	58	29,0	81	40,5	81
18	3	1	0,96	0,58	2,3	0,39	3995	0,8	61,73	67,6	29,4	103,06	44,8	94,58
19	3	0	0,96	0,52	2	0,45	3717	0,9	108,51	55,7	27,9	63	31,5	63
20	4	1	1,28	0,76	4,3	0,52	2330	0,9	107,43	225,4	52,4	293,86	68,3	255,2
21	3	0	0,98	0,65	2	0,33	3482	0,9	71,88	90,8	45,4	118	59,0	108
22	2	1	1,26	0,6	1	0,66	3243	0,9	65,27	34,6	34,6	48	48,0	48
23	2	1	0,94	0,22	2	0,72	2679	0,7	73,69	66	33,0	98,77	49,4	98,77
24	2	0	0,89	0,12	2	0,77	2718	0,7	64,07	62,1	31,1	85,51	42,8	85,51
25	3	0	1,02	0,53	1,8	0,49	4226	1,2	101,81	71,2	39,6	60	33,3	60
26	2	0	1,11	0,41	2	0,69	2804	0,8	70,07	69,7	34,9	84	42,0	84
27	3	1	0,99	0,43	2	0,56	2820	0,7	62,41	96,4	48,2	148,8	74,4	138
28	3	1	0,86	0,53	1,7	0,33	4395	1,2	67,57	70,1	41,2	111,62	65,7	78,34
29	2	1	1,15	0,61	1	0,54	4657	1,2	88	39,6	39,6	50	50,0	50
30	3	1	0,95	0,48	2,9	0,47	3089	0,8	60,88	144,9	50,0	225,46	77,7	193,79
31	1	1	0,98	0	1	1,17	1327	0,4	34,59	47,1	47,1	114	114,0	114
32	3	1	0,86	0,39	2	0,47	3158	0,8	64,58	47,8	23,9	74,23	37,1	70,23
33	4	1	1,23	0,72	2	0,51	3308	0,8	82,35	110	55,0	130	65,0	130
34	2	0	1,16	0,25	2	0,91	2312	0,8	57,55	52,4	26,2	65	32,5	65
35	3	1	0,82	0,44	3,1	0,38	3699	0,8	59,43	85	27,4	126,71	40,9	109,07
36	1	1	0,87	0	2	0,9	1560	0,5	43,55	34,9	17,5	64,86	32,4	64,86
37	2	1	0,99	0,27	1	0,72	2427	0,8	67,05	44,7	44,7	60	60,0	54
38	3	1	0,96	0,68	1,9	0,29	3581	1	123,99	81,9	43,1	104	54,7	86
39	3	1	0,89	0,35	1	0,54	3733	1	66,24	54	54,0	65,61	65,6	58
40	3	0	0,89	0,44	1,5	0,45	3470	0,8	79,51	68,8	45,9	84,53	56,4	84,53
41	4	1	1,2	0,35	1,9	0,85	2211	0,6	54,92	91,6	48,2	162	85,3	147
42	3	0	1	0,41	2	0,59	2983	0,7	68,41	55,7	27,9	75	37,5	75
43	1	1	0,95	0,28	2	0,67	2138	0,6	62,46	61,2	30,6	101,55	50,8	101,55
44	2	1	1,19	0,21	2	0,98	2495	0,8	56,89	58,1	29,1	78,2	39,1	78,2
45	3	0	0,91	0,49	2	0,42	4311	0,9	90,38	55,1	27,6	61	30,5	61
46	4	1	1,29	1	0,9	0,29	3623	1,1	88,69	52,8	58,7	85	94,4	72,5

No_exploitation	cultures_intra conso	nb_VL	ha_PP	ha_PT	metres_haies	bilan_N_kg par ha	eq_ha_biodiv	PL corr_par VL	%UGB_genisses	%renouvellement	age_velage 1_mois	gr_concentre_par litre	gr_concentre_par UGB genisses	%autonomie_prot
1	3,33	55,2	105	40	7091	20,2	708,05	4925	47,21	35	32	61	20,23	96,72
2	0	27	74	0	7548	29,25	473,13	5705	41,33	22	36	171	353,64	74,13
3	9,33	65	88,28	47,6	17567	33,69	751,69	5565	35,85	30	38	237	270,06	82,47
4	0	59,5	104,04	0	9009,51	77,05	822,43	5287	51,83	31	33	222	344,52	78
5	0	33,8	48,09	0	1215,52	47,42	77,02	5388	29,53	8,8	30	228	698,66	73,74
6	0	34,1	43,52	0	2628	37,32	223,13	4898	29,97	29	38,5	184	219,57	81,86
7	3,23	35,4	40,5	13,5	2008	82,7	109,97	7554	63,28	47	30	194	1037,99	72,43
8	0	30,5	44	0	2439	60,78	76,56	5763	51,34	21	30	241	603,87	67,83
9	0	86,7	195,86	0	4338,29	46,81	466,34	5457	47,09	34,6	33	152	151,65	76,38
10	0	29,8	58,7	0	975,92	42,07	247,55	4483	46,21	20	37	160	245,84	72,06
11	0	26,3	79	0	988	39,24	110,88	6615	56,05	38	36	156	63,83	77,27
12	1,25	38,7	76	3	11974	35,57	362,76	4131	70,03	31	38	177	242,34	90,31
13	10,7	76,5	86,94	21,46	9450	40,25	385,74	6821	27,59	20	30	237	626,81	78,27
14	0	43,1	46	15	1921	56,12	122,1	5220	41,3	12	33	204	83,25	74,53
15	0	31,6	45,49	0	5979,33	64,37	137,32	5736	51,27	33	33	214	308,12	72,91
16	0	32,1	41	14	8253	44,26	162,69	4357	66,79	30	32	146	91,25	77,77
17	0	39,4	81	0	4930	61,6	240,37	7158	47,13	25	27	215	521,09	73,62
18	7,44	51,6	60,02	25,37	5615,72	30,85	180,1	6495	31,05	33	31	171	266,12	73,94
19	0	38,2	48	15	7284	83,39	175,02	5851	45,76	23	35	202	201,01	77,87
20	13,16	118,9	210	42	22918	71,59	719,65	4735	89,57	35	40	269	214,53	80,44
21	8,47	57,7	51,41	51,41	9629,97	34,79	446,16	5889	57,33	24	36	276	191,97	81,55
22	0	27,9	30,75	8,66	6940,54	35,68	142,27	4345	23,84	15	35	221	214,06	64,53
23	0	44,3	71,2	24,65	20395,27	38,16	304,01	5526	48,96	36,2	37	139	43,93	87,65
24	0	34,7	85,51	0	23252	61,32	432,36	6806	78,88	40	30	182	683,56	73,06
25	0	47,4	60	0	10668	73,86	370,58	5153	50,25	29	34	211	574,94	70,26
26	0	48	72	12	13955	59,05	549,76	4699	45,25	18,7	33	312	313,26	65,78
27	7,26	58	125,65	5,71	6094	23,04	407,13	6083	66,21	38	32	132	319,59	89,94
28	10,39	43,3	39,21	17,8	10846,77	16,97	216,06	5757	61,94	37	36	263	162,01	72,34
29	0	29	32,16	0	7217,73	40,5	112,61	4928	36,38	31	36	164	601,49	53,4
30	10,64	94,8	149,3	27,29	15262,97	14,79	460,68	5768	52,8	30	36	158	309,61	94,41
31	0	29,6	114	0	1849	24,15	526,09	4908	59,09	43,9	33	208	0	74,5
32	5,39	34,2	31,1	30,89	7101,6	27,1	261,51	5623	39,77	23,4	34	178	243,24	78,9
33	0	70	110	20	12346	49,82	536,23	5837	57,1	23	38,5	243	386,32	71,55
34	0	41,3	65	0	10794	29,87	462,42	3545	26,9	30	36	223	137,67	80,22
35	13,92	56,9	66,36	34,94	10368,66	13,69	272,27	6485	49,4	22,8	33	181	341,6	95,85
36	0	21	64,86	0	1398	17,47	152	4706	66,19	9,5	34	55	0	94,32
37	10	27,5	38	16	11174	23,32	295,11	4654	62,4	22	38	247	143,92	89,76
38	9,02	48,5	25	59	9104	76,51	241,54	6179	68,87	20,6	33,5	157	119,1	93,69
39	11,6	41,5	35,66	18,77	9890,99	27,1	193,44	4636	30,05	24	33	193	178,79	91,06
40	0	40,5	84,53	0	3807	50,3	324,76	7069	69,83	30	36	236	247,77	71,28
41	9,26	52,4	107	40	15258	27,3	544,63	5796	74,85	40,1	34	220	620,73	82,51
42	0	37,3	75	0	3888	42,34	138,1	5749	49,33	28	35,5	152	237,74	82,01
43	0	30,2	97,66	0	6502,7	27,57	439,11	6930	102,65	46	38	239	188,46	81,94
44	0	42,5	76,54	0	17648,92	30,66	470,77	4314	36,73	11,7	36	145	258,45	75,98
45	0	38	61	0	3080	76,89	108,11	6776	44,97	34	32	233	362,24	65,62
46	9,88	38,7	9,71	38,12	8136,69	24,75	127,92	4276	36,51	10	41	217	81,13	80,77

No_exploitation	kg_concentre_par VL AN	rdt_herbe_valorisee_t MS par ha	%PP_SAU lait	%PT_rotation	metres_haies_par ha Lait	temps_paturage_par VL AN	carbu_litres _haSAUlait	elect_KWh_1000 LitresLait	%autonomie_fourragere	GES_brutes _haSAU	Stockage_carbone_ha SAU	GES_nettes _haSAU	GES_brutes _UGB	GES_nettes _UGB
1	315	3,4	70	80	47,27	217	55,93	168,95	63,37	2576,23	2559,82	16,41	4990,6	31,77
2	1030	2,3	100	0	102	230	51,72	246,36	94,76	5058,10	2145,22	2912,88	5575,27	3204,99
3	1398	4,1	58	67	115,66	150	80,2	138,56	100,00	7568,50	1748,81	5819,69	7306,63	5618,33
4	1259	4,6	100	0	86,6	155,5	67,09	79,06	92,56	6426,01	2346,19	4079,82	6120,01	3885,54
5	1246	5	100	0	25,27	160	96,7	129,73	83,78	4882,55	2608,25	2274,30	4787,52	2222,93
6	923	5,1	100	0	60,39	144	62,16	105,36	100,00	4172,62	2153,63	2018,99	5827,28	2819,62
7	1493	5,3	73	0	35,99	193	146,22	88,82	97,78	4777,34	2207,24	2570,10	5401,99	2905,47
8	1430	4,8	100	0	55,43	178	43,14	110,53	90,24	3984,45	1342,95	2641,50	5156,8	3411,55
9	875	3,2	100	0	22,15	153,5	53,49	95,6	87,68	3855,43	3339,34	516,09	5308,83	710,65
10	768	3	100	0	16,63	133,5	53,67	109,56	87,88	6031,51	2907,56	3123,95	5082,73	2632,54
11	1095	2,7	100	0	12,51	160	50,7	84,64	84,52	4158,69	2604,99	1553,70	5011,9	1872,46
12	767	4,2	95	0	149,68	183,5	44,71	153,16	84,34	3637,60	2853,71	783,89	4512,29	972,39
13	1630	4,8	72	50	77,85	182	151,62	80,22	93,06	4510,10	2298,51	2211,59	5541,27	2717,24
14	1103	4,3	75	0	31,49	152	90,08	219,3	96,04	3936,92	2329,72	1607,20	5301,06	2164,1
15	1278	4,8	100	0	131,44	162	49,86	111,8	77,56	5053,05	2323,53	2729,52	5594,12	3021,79
16	645	4	75	0	150,05	162,5	81,64	128,19	91,77	2628,34	1971,86	656,48	4849,34	1211,21
17	1601	3,8	81	0	60,86	177	37,04	69,28	93,95	3126,55	1854,34	1272,21	5378,16	2188,4
18	1131	3,7	64	67	60,35	152	60,04	100,09	100,00	4281,00	2420,27	1860,73	5050,98	2184
19	1240	4,9	76	0	115,62	169	72	82,53	96,95	5116,44	2368,92	2747,52	5026,34	2699,12
20	1340	3,4	71	40	77,99	134	85,87	106,44	87,34	3227,45	2085,49	1141,96	5182,16	1812,67
21	1711	4	46	60	85,36	169,5	45,15	81,39	80,58	3158,47	2042,43	1116,04	4485,74	1566,85
22	1011	3,1	78	0	176,11	183	91,11	78,11	86,01	2716,98	2149,27	567,71	5235,15	1093,87
23	805	4	74	0	212,78	159	46,69	166,92	100,00	4083,99	2679,67	1404,32	4891	1681,81
24	1222	3,6	100	0	271,92	156,5	50,25	64,54	100,00	5143,07	1677,97	3465,10	6396,68	4309,71
25	1131	5,1	100	0	177,8	140	74,2	86,76	79,43	5034,64	1807,70	3226,94	4882,57	3129,47
26	1530	3,4	86	0	166,13	159	44,69	222,23	78,63	4394,11	2336,54	2057,57	4508,89	2111,31
27	844	3,6	88	0	42,87	174,5	57,2	85,18	74,09	3915,87	1558,53	2357,34	5915,71	3539,65
28	1590	3,6	55	44	152,34	153	119,23	60,38	92,10	4102,28	1669,64	2432,64	5348,25	3171,5
29	848	3,4	100	0	224,5	169	111,57	79,62	60,67	4027,39	2066,27	1961,12	5499,13	2632,63
30	935	4,1	73	50	74,43	185	77,51	87,23	100,00	3342,16	2542,30	799,86	4989,21	1184,6
31	1062	1,8	100	0	16,22	146	17,46	98,2	100,00	3425,62	1925,07	1500,55	5269,27	2297,77
32	1017	3,2	47	71	107,62	175,5	85,27	94,99	44,74	2953,30	1052,50	1900,80	4362,56	2686,66
33	1492	3,4	85	0	94,97	154	123,88	57,94	25,47	3952,36	2007,45	1944,91	4820,56	2285,9
34	813	2,9	100	0	166,06	194	34,62	96,88	100,00	3256,08	1597,17	1658,91	5014,34	2529,18
35	1193	4,5	56	0	87,18	190	67,41	124,98	82,91	1803,36	2166,31	362,95	4364,83	0
36	267	2,5	100	0	21,55	161,5	35,48	44,73	74,36	3012,13	1614,34	1397,79	4603,03	2096,06
37	1177	3,4	63	70	186,23	169	79,07	80,3	100,00	5448,68	2259,38	3189,30	6439,35	3769,17
38	997	5,1	26	70	95,45	185	81,62	71,78	100,00	3211,41	1485,35	1726,06	4765,28	2551,07
39	945	4,6	57	77	159,45	182	77,01	149,76	95,52	2115,16	2190,78	-75,62	3930,91	0
40	1710	4,6	100	0	45,04	166,5	38,76	80,3	90,91	3188,00	2306,93	881,07	4279,2	1182,65
41	1363	2,7	66	78	94,19	194	82,37	129,41	100,00	4039,51	1167,84	2871,67	5003,85	3520,88
42	912	4,6	100	0	51,84	197	50,84	116,22	100,00	3396,94	2058,98	1337,96	4099,23	1597,58
43	1655	3,1	100	0	66,59	159	73,04	114,93	100,00	3470,92	2435,25	1035,67	6138,53	1831,65
44	653	3,1	100	0	230,58	172,5	54,14	118,49	100,00	3265,44	2305,44	960,00	5398,7	1573,25
45	1615	4,3	100	0	50,49	169	76,18	62,79	62,42	3748,77	3082,93	665,84	5038,55	889,07
46	972	4,7	17	50	144,7	194	81,61	64,55	73,91	3340,25	720,38	2619,87	5157,23	3997,52

Variable	Definition	Unit
%autonomie_fourragère	Percentage of forage autonomy	
%autonomie_prot	Percentage of protein autonomy	
%PP_SAU-lait	Percentage of permanent grassland in the milk AA	
%PT_rotation	Percentage of temporary grassland in rotations	
%renouvellement	Renewal rate	
%UGB_genisses	Percentage of LU heifers in the herd	
AB	Organic farming	
age_velage1_mois	Age at first calving	Month
bilan_N_kg-par-ha	Nitrogen balance	Kg N/ha
carbu_litres_haSAUlait	Fuel consumption	Liter/ha of milk UAA
chargement_UGB-par-haSFP	Stocking	LU/ hectare of fodder production area
cultures_intra-conso	Areas in intraconsumed crops	Hectare
elect_KWh_1000-LitresLait	Electricity consumption	Kwh/1000 liters of milk
eq_ha_biodiv	Biodiversity maintained	Eq. ha/ha of milk UAA
GES_alim_par-litre-LaitCorr	GHG emissions from feed	Kg CO2 eq/L of corrected milk
GES_brutes_ha-SAU	Gross GHG emissions	Kg CO2 eq/ha of milk UAA
GES_brutes_lait-corrige	Gross GHG emissions	Kg CO2 eq/L of corrected milk
GES_conso_NRJ-carbu_par-litre-LaitCorr	GHG emissions from energy and fuel consumption	Kg CO2 eq/L of corrected milk
GES_enterique_par-litre-laitCorr	GHG emissions from enteric fermentation	Kg CO2 eq/L of corrected milk
GES_Ferti_N_par-litre-laitCorr	GHG emissions from nitrogen fertilization	Kg CO2 eq/L of corrected milk
GES_gestion_effluents_par-Litre-LaitCorr	GHG emissions from effluent management	Kg CO2 eq/L of corrected milk
GES_nette-par-Litre-lait	Net GHG emissions	Kg CO2 eq/L of corrected milk
GES_nettes_ha-SAU	Net GHG emissions	Kg CO2 eq/ ha of milk UAA
gr_concentre_par-litre	Quantity of concentrates distributed to dairy cows	Gr/liter of milk
gr_concentre_par-UGB-genisses	Quantity of concentrates distributed to the heifers LU	g/LU heifer
ha_PP	Surface in permanent grassland	Hectare
ha_PT	Temporary grassland area	Hectare
kg_concentre_par-VL-AN	Quantity of concentrates distributed to dairy cows	Kg/dairy cows/year
metres_haies	Linear of hedges	Linear meter
metres_haies_par-ha-Lait	Linear of hedges	Linear meter/ha of milk UAA
N_orga_epandu-SAU-lait	Amount of organic nitrogen applied	kg N/ha pf milk UAA
nb_UGB	Number of animals in the whole herd	LU
nb_VL	Number of animals in the dairy herd	Dairy cow
PL-corr_par-VL	Quantity of milk produced	Liter of corrected milk/dairy cow
PL-par-ha_SFP	Quantity of milk produced	Liter of corrected milk/ha of main forage area
rdt_herbe_valorisee_tMS-par-ha	Yield of valued grass	Tonne of dry matter/ha
SAU	Useful agricultural area	Hectare

SAU-par-UMO	Useful agricultural area per unit of labor	Ha/UL
SFP	Fodder production area	Hectare
Stockage_carbone_ha-SAU	Amount of carbon stored	Kg CO2 eq/ha of milk UAA
stockage_CO2-par-LitreLaitCorrige	Amount of carbon stored	Kg CO2 eq/L of corrected milk
stockCO2_Haies_par-litre_LaitCorr	Quantity of carbon stored by hedges	Kg CO2 eq/L of corrected milk
stockCO2_PP_par-litre_LaitCorr	Amount of carbon stored by permanent grasslands	Kg CO2 eq/L of corrected milk
temps_paturage_par-VL-AN	Grazing time for dairy cows	Days/dairy cow/year
UGB-par-UMO	LU per labor unit	LU/UL
UMO	Labor unit	UL

Appendix 4 - Description of the sample of farms audited. Source: personnal

	Average	Minimum	Maximum	Standard deviation
Corrected milk production/dairy cow (corrected milk liter/dairy cow)	5534,37	3545,00	7554,00	926,05
Number of dairy cows	45,40	21,00	118,90	19,34
SFP	90,47	43,52	255,20	44,54
UMO	1,94	0,90	4,30	0,71
Stocking rate (LU/ha SFP)	0,83	0,40	1,20	0,20
Concentrate consumption/liter (g/l)	196,22	55,00	312,00	50,27
Protein autonomy (%)	78,60	53,40	96,72	9,23
Breeding rate (%)	51,45	23,84	102,65	16,84

Appendix 5 - R code for PCA and AHC and R outputs for the description of the 3 dimensions

```
res.PCA<-PCA(ACP,graph=FALSE)
plot.PCA(res.PCA,choix='var',title="Graphe des variables de l'ACP")
plot.PCA(res.PCA,title="Graphe des individus de l'ACP")
```

```
res.PCA<-PCA(ACP,graph=FALSE)
summary(res.PCA)
```

```
res.PCA<-PCA(ACP,graph=FALSE)
dimdesc(res.PCA)
```

Dimension 1

	correlation	p.value
GES_nette-par-Litre-lait	9.460E-01	3.780E-23
GES_gestion_effluents_par-Litre-LaitCorr	4.986E-01	4.202E-04
GES_conso_NRJ-carbu_par-litre-LaitCorr	3.982E-01	6.128E-03
GES_Ferti_N_par-litre-laitCorr	3.869E-01	7.898E-03
GES_brutes_lait-corrige	3.481E-01	1.775E-02
stockCO2_PP_par-litre_LaitCorr	-8.425E-01	2.120E-13
stockage_CO2-par-LitreLaitCorrige	-8.530E-01	5.201E-14

Dimension 2

	correlation	p.value
GES_brutes_lait-corrige	9.151E-01	5.689E-19
GES_enterique_par-litre-laitCorr	8.286E-01	1.169E-12
GES_gestion_effluents_par-Litre-LaitCorr	5.464E-01	8.546E-05
stockCO2_Haies_par-litre_LaitCorr	4.725E-01	9.145E-04
stockage_CO2-par-LitreLaitCorrige	4.653E-01	1.122E-03
GES_conso_NRJ-carbu_par-litre-LaitCorr	3.309E-01	2.467E-02

Dimension 3

	correlation	p.value
GES_conso_NRJ-carbu_par-litre-LaitCorr	5.668E-01	4.016E-05
stockCO2_Haies_par-litre_LaitCorr	3.025E-01	4.103E-02
GES_Ferti_N_par-litre-laitCorr	2.936E-01	4.768E-02
GES_alim_par-litre-LaitCorr	-8.488E-01	9.257E-14

Tableau des variables et leur nomenclature

Appendix 6 - Best model equation from ANCOVA for gross GHG emissions

Gross GHG emission = 1.49 - 1.46E-03*(**organic nitrogen applied**) - 6.04E-03*(**SFP**) - 1.00E-02*(**intra consumed crops**) + 7.37E-03*(**ha permanent grassland**) + 6.94E-03*(**ha temporary grassland**) - 1, 27E-04*(**milk production/dairy cow**) + 2.29E-03*(**%LU heifers/dairy cows**) + 0.01*(**age at 1st calving**) + 3.68E-04*(**gr of concentrates/LU heifers**) - 1, 21E-02*(**% protein autonomy**) + 7.50E-02*(**yield of grass**) - 3.46E-03*(**%permanent grassland/UAA**) - 3.09E-04*(**linear meters of hedges**) + 3.10E-03*(**grazing time/dairy cow/year**) - 3.08E-04*(**fuel quantity/ha UAA**) - 3.70E-04*(**electricity consumption/1000L milk**) + 1.34E-03***(%fodder autonomy**) - 0.13

Appendix 7 - Best model equation from ANCOVA for net GHG emissions

Net GHG emissions = 1.01 + 7.27E-03*(**number of LU**) - 3.13E-03*(**UAA**) - 1.93E-02*(**intra-consumed crops**) - 2.15E-03*(**nitrogen balance**) - 2.01E-04*(**eq. ha of maintained biodiversity**) - 5.61E-05*(**milk production/milk cow**) + 2.46E-03*(**%renewal**) + 9.32E-03*(**age at first calving**) + 5.36E-04*(**gr concentrate/liter**) + 3.65E-04*(**gr concentrate/heifer LU**) - 9.79E-03*(**%protein autonomy**) + 0.12*(**yield of valorized grass**) - 7, 31E-03*(**%permanent grassland/ha UAA**) - 1,19E-03*(**linear meters of hedges/ha UAA**) + 2,02E-03*(**grazing time/dairy cow/year**) - 4,23E-04*(**fuel quantity/ha UAA**) - 5,49E-04*(**electricity consumption/1000L milk**) - 3,83E-04*(**%fodder autonomy**) - 0,11

Bibliographical reference of the report :

Joërg M., 2021, Analysis of the environmental performance of a network of PDO dairy farms in the Jura Mountains. What contributions and solutions to greenhouse gas emissions for the farms studied?, Final thesis, VetAgro Sup.

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TRAINING: Master Global Quality in European Livestock Production

ABSTRACT

As part of the adaptation of the Jura Massif PDO sectors to climate change, the Confédération Paysanne Bourgogne Franche Comté wishes to become involved in greenhouse gas (GHG) emission mitigation approaches. The objective is to understand which practices can be used to approach carbon neutrality in the farms of the Massif du Jura PDO.

The study is based on data collection from 46 PDO farms (31 of which are organic) using the CAP2ER tool, followed by a statistical analysis to characterize the sample and identify action levers to address climate issues.

The data analysis showed that the sample is characterized by gross GHG emissions close to those of other grassland systems, but by much lower net GHG emissions that highlight the importance of carbon storage in these systems.

The comparison of the practices of four groups of farms with different GHG emissions highlighted the fact that the technical control of feeding, the share of permanent grassland and the size of the farms are significant elements that differentiate these groups.

Finally, what emerges is that it is not enough to produce organically to achieve carbon neutrality. It is necessary to find a balance between productivity and technical management, with moderate farm sizes, efficient feed and herd management (limiting unproductive animals). On the surface, the study showed the importance of permanent grasslands and hedgerows for the compensation of GHG emissions through carbon storage.

Key words : Environment, dairy farms, greenhouse gas, Comté, CAP2ER, Jura massif