Animal welfare study report – CVE solar power plant in Bissey-sous-Cruchaud

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Study conducted jointly by Statkraft, CVE and INRAE to assess the effects of the presence of photovoltaic panels on sheep grazing over a period of two years (2022-2023).

Summary

Animal welfare study report - CVE solar power plant in Bissey-sous-Cruchaud(71)

In the past, a few studies have shown beneficial effects of the presence of photovoltaic panels on animal production, but they cover relatively short periods of a few weeks or months and do not simultaneously integrate all the principles related to the assessment of animal welfare, i.e. feeding, housing, health and behaviour.

As examples: a 2021 study (Alyssa C. Andrew, et al.) shows that sheep stocking is higher in pastures under solar panels (36.6 lambs/ha) than in open pastures (30 lambs/ha) in late spring. The live weight production between pastures under solar panels (1.5 kg ha/day) and open pastures (1.3 kg ha/d) are comparable. This same study highlights a saving in water consumed by sheep in pastures with panels (- 0.72 l/head/day of water compared to open pastures), however only a trend was noted the following spring. When sheep have the choice of sheltering from solar radiation between photovoltaic panels and canvases blocking 80% of the radiation, it has been shown that below an intensity of 800 W.m-2, they spend 38% of their time under the panels compared to less than 1 % under the canvas. When solar radiation is above 800 W.m-2, sheep spend more than 70% of their time under photovoltaic shelters (Maia et al., 2020). In cattle, Sharpe et al (2020) show that the breathing frequency of cows with and without panel shade is similar in the morning, but in the afternoon, cows with shade have lower respiration rates (66 breaths/min) than cows without shade (78 breaths/min). In the afternoon and until midnight, cows with panel shade have lower internal body temperatures than cows without shade.

The CVE solar power plant in Bissey-sous-Cruchaud (71) has been maintained since its commissioning in 2021 by eco-grazing. The objective of this project is to study the medium-term effects, in this case 2 successive years, of the presence of photovoltaic panels on sheep grazing (behaviour, animal welfare, health and production of available fodder).

1. ANIMALS, EQUIPMENT AND METHOD

1.1. The herd

A flock of 20 Tarascon sheep was monitored over a period of 2 years (2022-2023). The ewes in the open air have access to a plot of land whose coverage by photovoltaic panels is about 6 hectares. The maintenance of these sheep is provided by the eco-grazing company : Ecomouton. The loading (number of ewes/ha/day) was estimated by Ecomouton with the aim of maintaining the plant without the need for mechanical shearing and without the need to feed the ewes during the year.

1.2. Data acquisition schedule

Measurement campaign	Date 2022	Intervention	Date 2023	Intervention
0	25-Jan-22	State of play	20-21April-23	Sensor installation and observations
1	2-3-Mar-22	pose Sensors and observations	27-April-23	Withdrawal and observations
	8-9-Mar-22	Withdrawal and observations	14-Jun-23	Sensor installation and observations
2	28-29-March-22	pose Sensors and observations	13 July	Withdrawal and pose Sensors and observations
	6-Apr-22	Withdrawal and observations	09-Aug	Withdrawal and Sensor installation and observations
3	10-11-May-22	pose Sensors and observations	? October (s44)	withdrawal
	24-May-22	Shrinkage and observations Forage analysis		
4	20-Jul-22	pose Sensors and observations		
	28-Jul-22	Withdrawal and observations		
5	29-Nov-22	pose Sensors and observations		
		Withdrawal and observation		
Total	35 days of sensor data 7 days of observation 7 health points		70 days of sensor data 3 days of observation 5 health points	

1.3. Sheep activity and position in the shade or sun

The ewes' standing-lying activity was acquired by attaching an accelerometer (Hobo Pendant G acceleration) to one of the hind legs of each ewe. The average leg tilt is recorded every minute. Over the entire period of the study, 105 days (24 hours) of data for 15 ewes can be used (loss of sensors during acquisition). An algorithm (Excel macro) transforms the tilt values into binary data (O : standing, 1: lying down) with a default tilt threshold that has been adjusted from the data acquired via direct observations.

The position of the ewes in the shade of the panels or in the sun was determined from data acquired by lux meters (Hobo MX2202) placed above the ewes between the 2 shoulders. 3 other sensors were placed in the bare area, between the rows and under a row of panels (see plan). The average brightness is recorded every minute. Over the entire period of the study, 100 days (24 hours) of data for 12 ewes can be used (loss of sensors during acquisition). The shade-sun position threshold of the ewes is set by the difference in brightness recorded under the panels and between rows and was adjusted from the data acquired via direct observations.

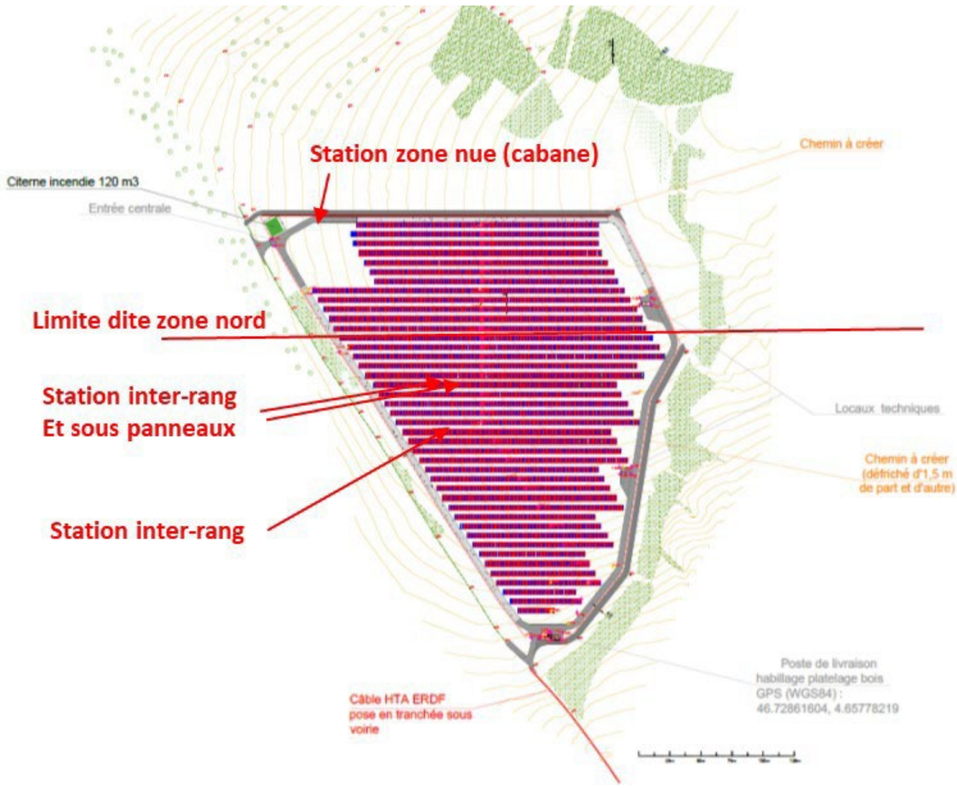
The standing-lying activity as well as the shadow-sun position were also acquired by live observations. Over a period of 3 hours, 3 ewes were continuously monitored and these 2 variables were recorded. Then, over a period of 1 hour, 5-minute scans were carried out on all the ewes. This data allows define the thresholds used in the automatic analysis of the data acquired by the sensors (accelerometers and lux meters). 10 *4 hours of observations were carried out over the entire period of the study.

1.4. Observation santé

Visual observations were made to detect possible health problems. These observations concerned wounds, cleanliness, the presence of external parasites and nasal discharge (according to the Awin-ovine protocol). Over the entire study period, these health points were performed 12 times.

1.5. Climatic environment

4 weather stations (Besser), recording hourly averages of temperature, humidity and wind speed were installed in the plant at 1 meter at ground level. 1 station was located in a bare area, 1 under a row of panels and the other 2 in the inter-row (see map below).



Based on Statkraft-CVE schema

To assess the level of heat stress in ewes, the heat load index (HLI) was calculated. This index takes into account not only temperature but also relative humidity as well as wind speed and solar radiation. Solar radiation was acquired with sensor-lux meters (Hobo MX2202) placed next to the weather stations.
HLI is calculated from another index called Tbg (Black Globe Temperature). The Tbg is calculated from the following formula (Hahn et al. 2003):
Tbg = 1,33 x TA – 2,65 x TA0,5 + 3,21 x log10 (Rad + 1) + 3,5
with TA : Ambient Temperature in °C and Rad: Solar Radiation in W/m2.

The HLI is then calculated from two formulas according to the Tbg threshold. HLI
if Tbg>25°C = 8.62 + 0.38 RH + 1.55 Tbg – 0.5 Wind + e (2.4 – Wind)
HLI si Tbg<25°C = 10,66 + 0,28 HR + 1,3 Tbg – Vent
with Wind : Wind speed (m.s-1), R : Relative humidity (%)

The stress thresholds used were set by Gaughan et al., (2008) HLI
< 70 : no risk of stress for animals
70 < HLI < 77 : mild stress 77 <
HLI < 86 : moderate stress HLI > 86
: severe stress

The perception of perceived heat stress by the ewes was also assessed by live observations. On hot days (temperatures > 30°C), the respiratory rate of the ewes as well as panting (open-mouth breathing) was visually assessed.

1.6. Soundscape

The sound level (dBa) was recorded in the middle of the control panel (DL161S Voltsoft sound level meter). 1 measurement was acquired every second by moving at a steady pace (0.8 m/s) from the edge of the power plant to the inverter (see plan). These measurements were carried out in June, August and October 2023.

1.7. Quantity and quality of fodder

To assess the quantity of fodder available under the panels and between the rows, defensive areas (diameter 110 cm) were set up. 3 zones were located under the panels, 3 others between the rows. Grass heights in each of the areas were measured in May and July 2022.

In June 2023, grass heights were measured in grazed areas with a herbometer. 100 measurement points were made under the panels, 100 others between rows and 100 others 1 metre from the upper part of the panels (see diagram, results section).

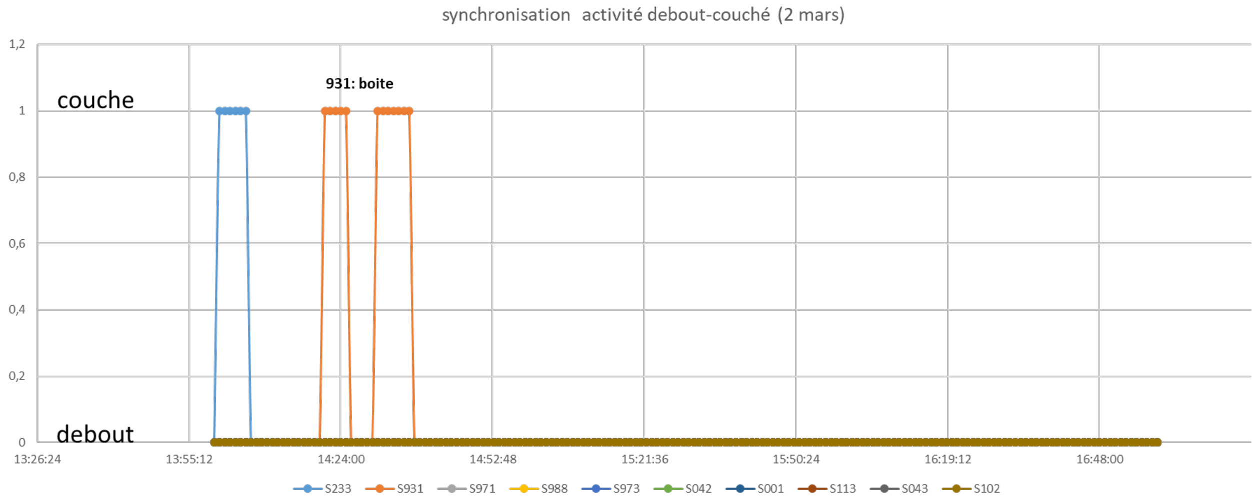
At the end of May 2022, forage analyses were carried out (Bourgogne du Sud cooperative) from samples taken in each of the defence zones.

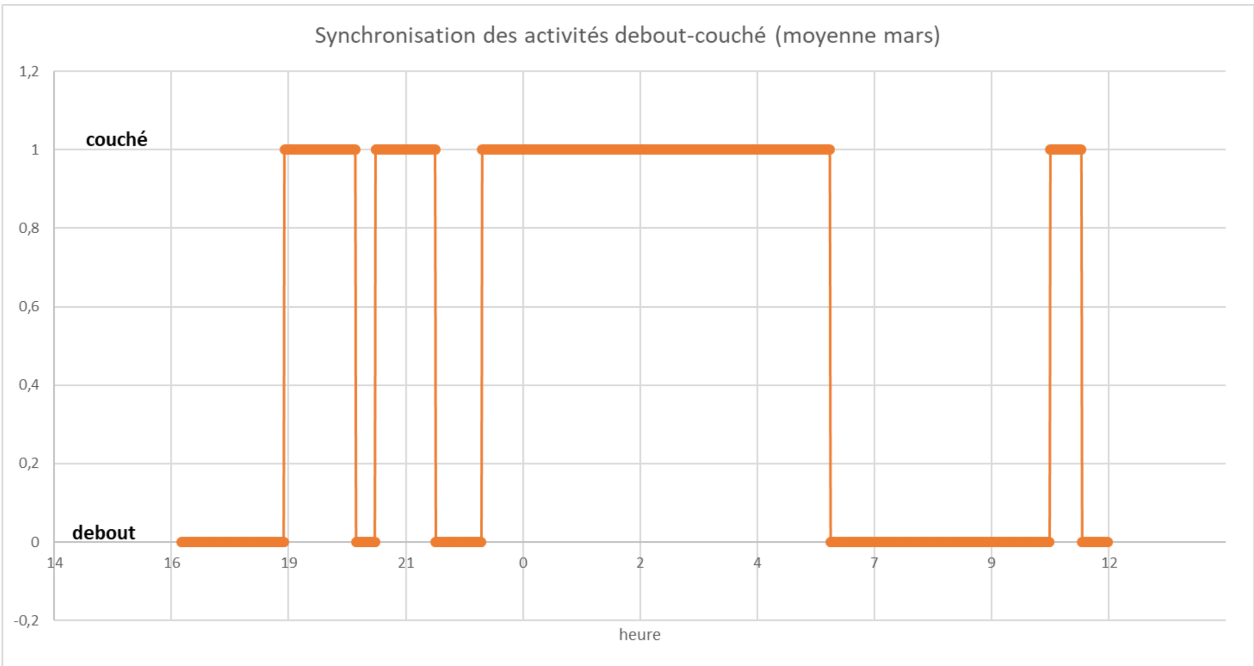
2. RESULTS AND INTERPRETATIONS

2.1. Sheep activity and position in the shade or sun

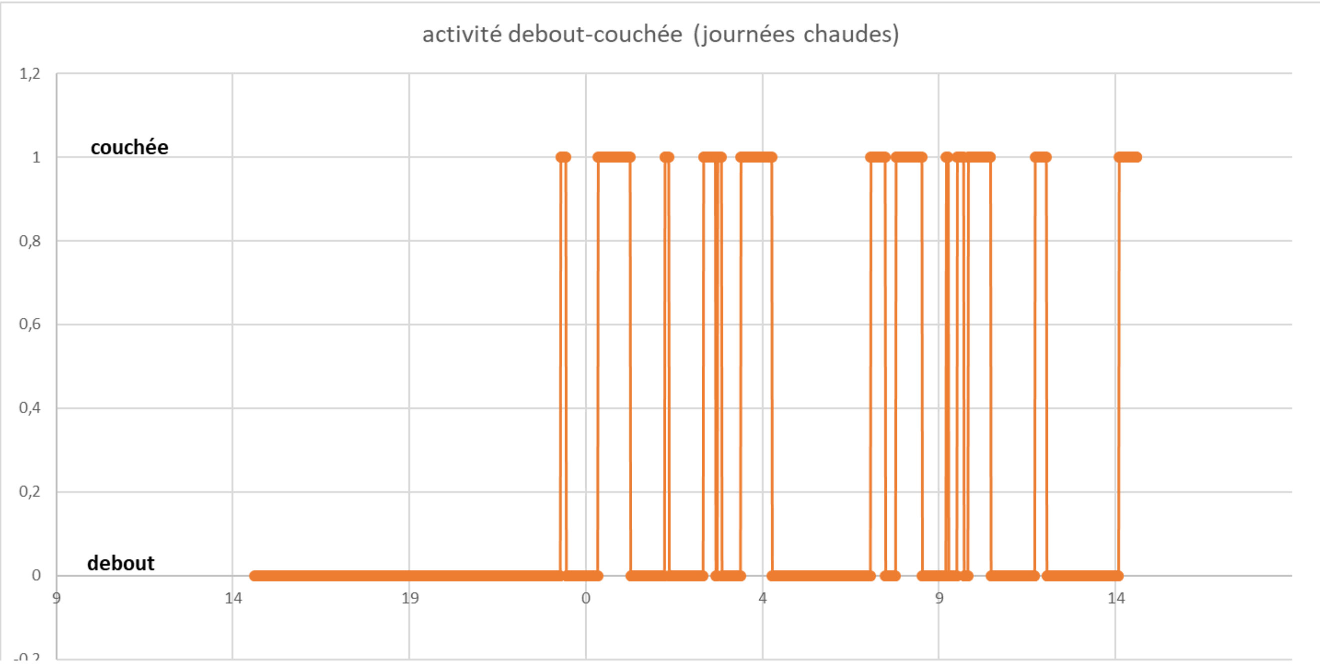
Over the entire study period, ewes spent an average of 428 min/day lying down and 1012 min/day standing. These data are in agreement with the circadian cycle of 3*8 hours that ruminants perform, namely 8 hours of ingestion (standing), 8 hours of rumination (standing and sometimes lying down) and 8 hours of rest (lying down and sometimes standing).

The 2 graphs below show that the activity (standing-lying down) is synchronized at the herd level. The ewes are up around 6 a.m. until 7 p.m. with a period of rest, lying down, around 11 a.m. Behavioural observations show that during this period the ewes graze or ruminate. From 11 p.m. to 6 a.m., the ewes are laid to rest. Only one ewe (no. 931) is out of sync with the flock during the day. This ewe had a lameness, which may explain this behavior. The pain induced by lameness forces the animal to change position more often than a painless animal.

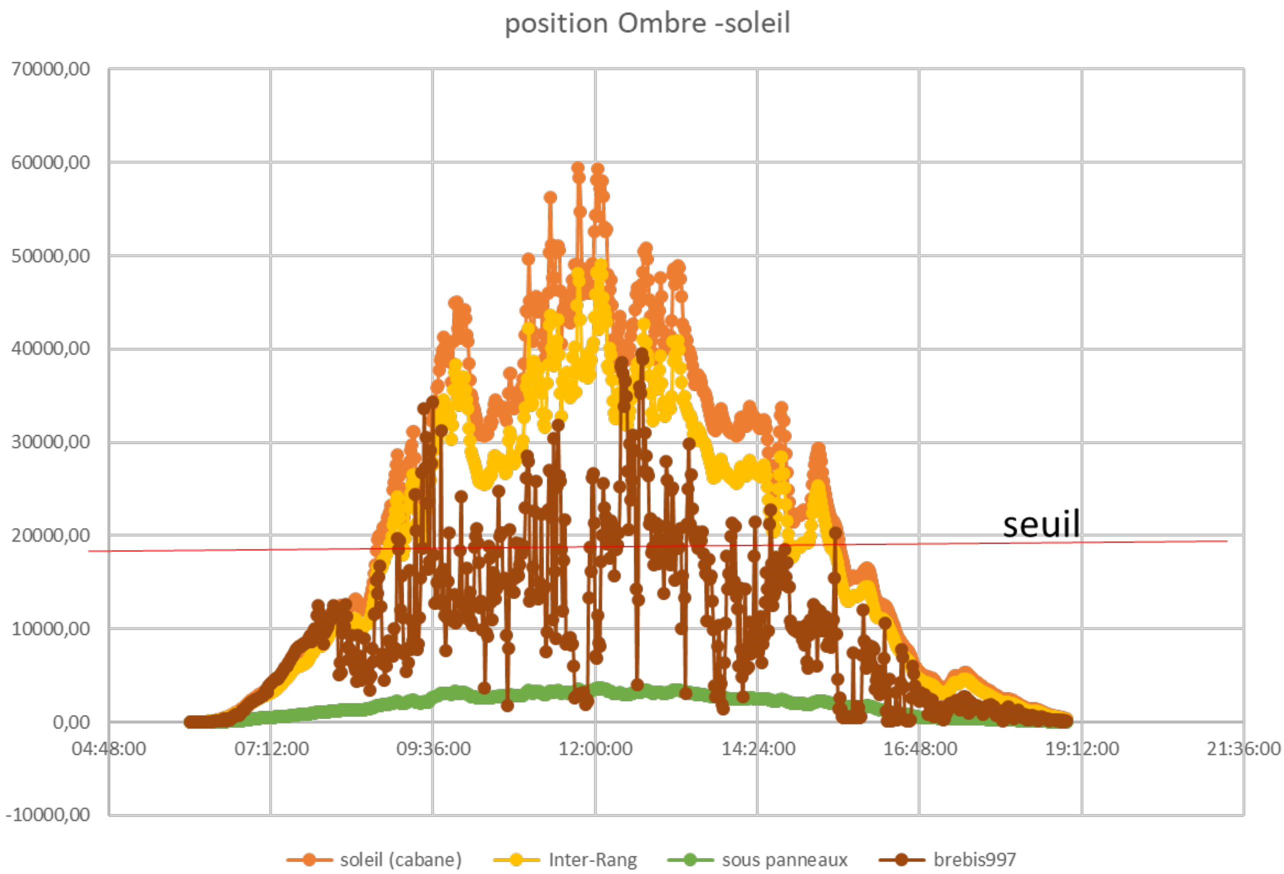




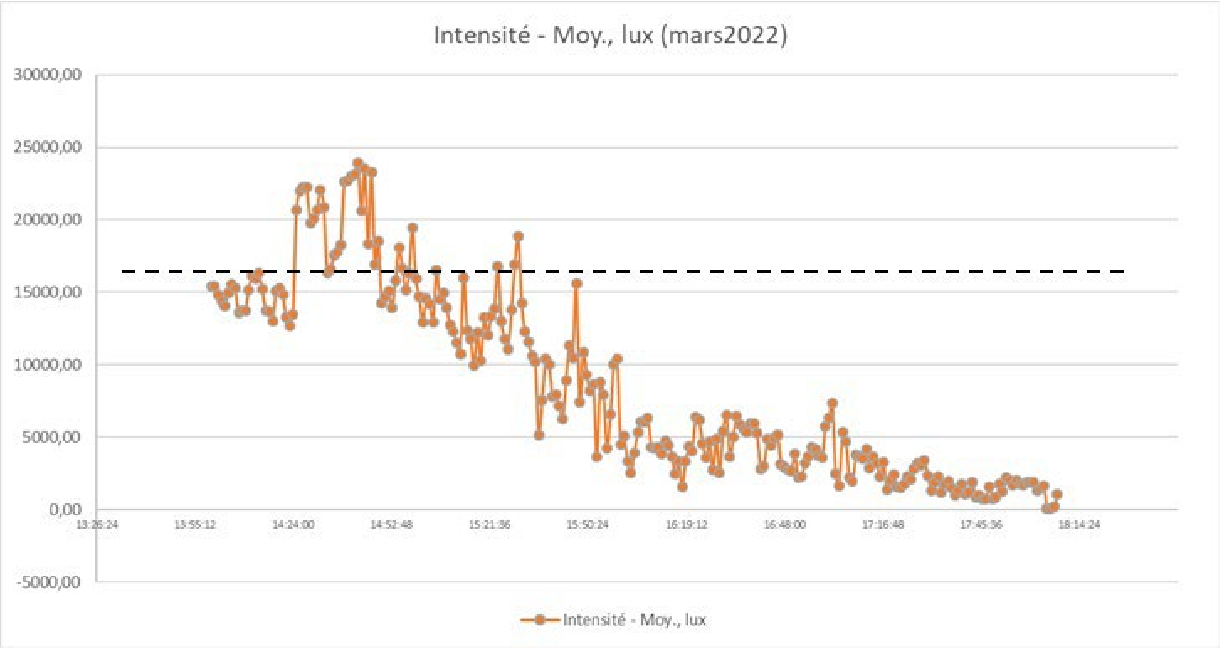
On hot days (below at the end of May 2022, a particularly hot period), the ewes are in a standing position earlier in the morning (5 a.m.) and lying down later (11 p.m.). Their standing-lying activity is more alternating than in cooler periods but remains synchronized at the herd level.



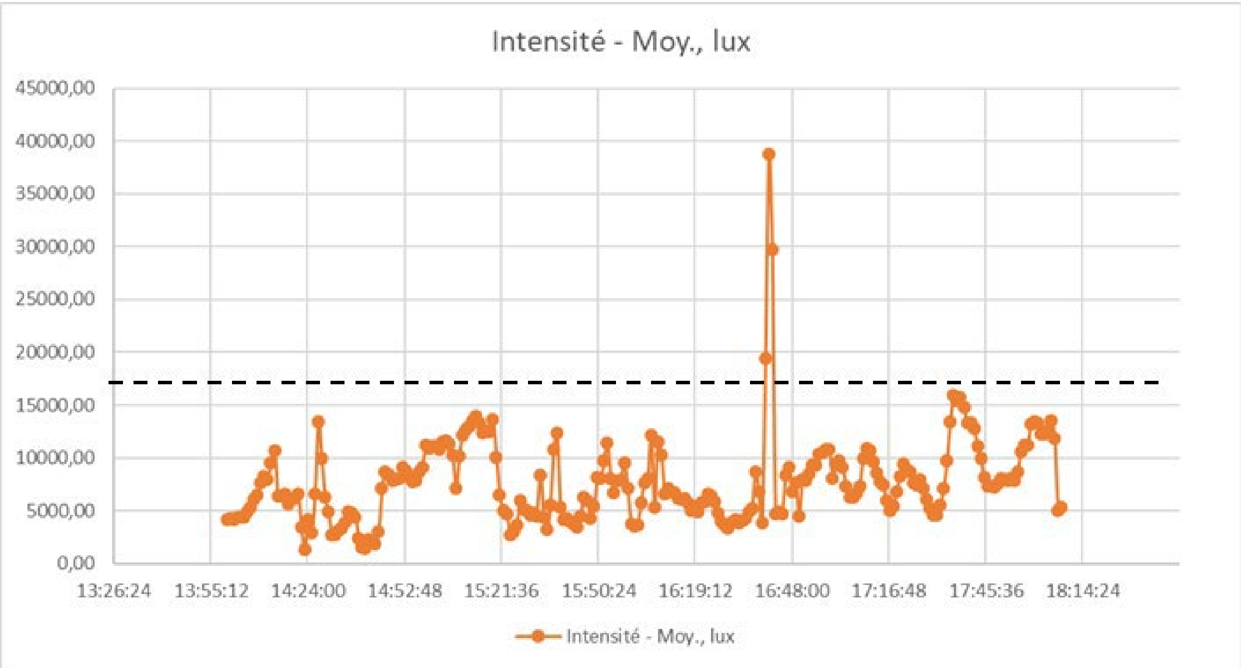
Behavioural observations (position in the bare area or under panels) made it possible to define a brightness threshold recorded by the sensors attached to the ewes which is 17,000 lux above the value recorded by the sensor positioned under the panels. This difference is linked to the fact that the sensor placed on the ewes does not have a fixed angle, it varies with the position of the ewes unlike the sensor positioned under the panels.



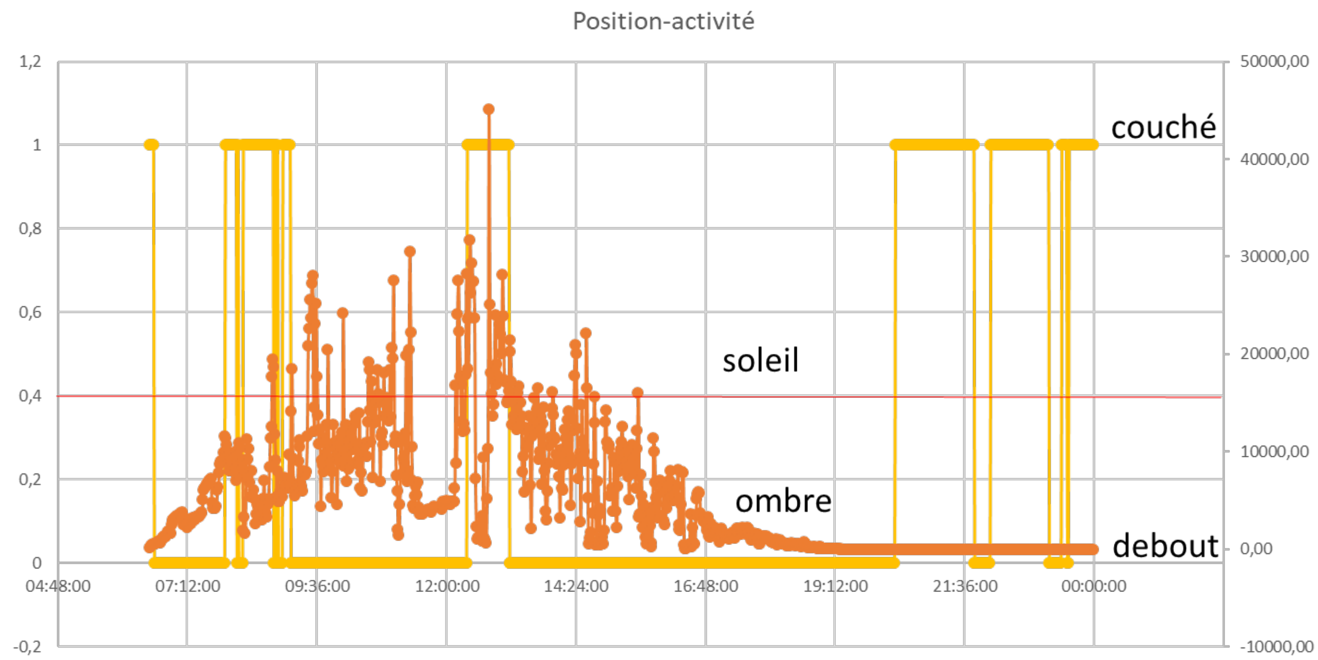
Below 9,000 lux outdoors, light sensors are not accurate enough to determine the position of ewes in bare areas or under panels, i.e. before 9 a.m. and after 4 p.m. on average.



In March 2022 (graph above), ewes in the afternoon are in the bare area. On the other hand, in July 2023 (graph below) they remain in the shade under the signs in the afternoon.



Over 90 days of data acquisition (loss of sensors), it was possible to couple the data acquired by pedometers and lux meters. In early spring and fall, there is no standing-lying activity associated with a shade-sun position. On the other hand, in late spring and summer (graph below), standing activity, including ingestion activity, is associated with a position in the shade.



2.2. Observation santé

1 2 3

photo AWIN

At the end of spring 2022, during 2 successive surveys, 8 ewes had a level 2 nasal discharge
2 ewes during this same period showed lameness with a shortening of the stride and head *flicking* when the affected limb (here posterior) touched the ground.

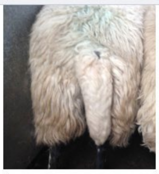
No injuries were found on the ewes. However, in 2022, following the regrouping of the flock, a sheep was seriously injured with a tear in the skin and muscles at the shoulders which required the intervention of a veterinarian, local anesthesia, suturing, antibiotic treatment and the removal of this ewe from the plant (collection at the shepherdess of Ecomouton).

At the end of spring 2022, during a health survey, the ewes were infested with ticks (5 to 6 per ewe). Ticks were not present at the next health survey.

In 2022, 1 sheep was found dead on the plant. As the sheep has not been autopsied, no explanation can be put forward.

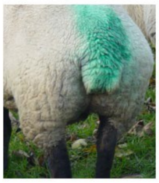
In 2023, 2 ewes had an abscess on their necks, the origin of which could be a cut during the shearing which was carried out a few days before the observation

Concerning cleanliness : Fecal soiling is the presence of fecal matter on the wool around the anus, the diabe, the tail and the hindquarters. Blood sausages are clumps of feces that hang from wool. They are associated with diarrhea, which can result from endoparasite infestation or nutritional imbalance, and are a risk factor for skin myiasis or fly disease.



Score 0, 1,2 (Awin)

0 : No faecal soiling : the wool around the breech area and under the tail is clean.



1 : A small amount of feces in the wool around the anus.

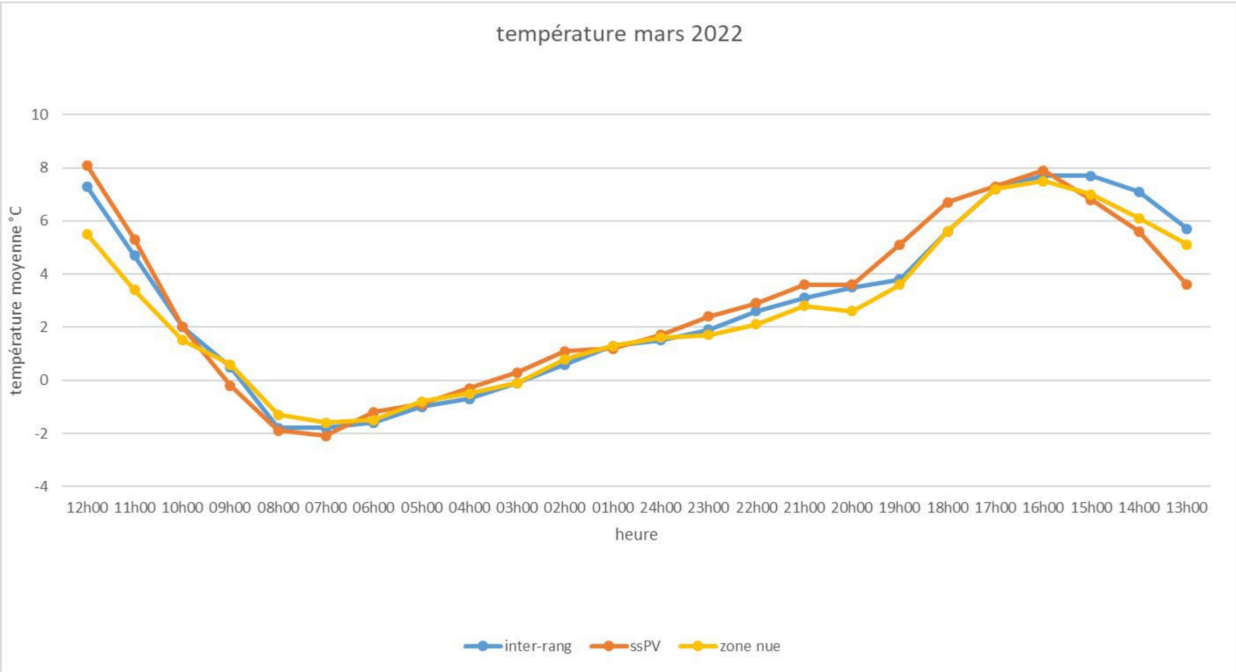
2 : Some dirt around the anus and the puddings (areas padded with feces adhering to the wool) in this area only.

Over the entire study period, the observed scores ranged from 1 to 2. No diarrhoea was observed either by observing the cleanliness of the ewes or by the consistency of the faeces.

2.3. Climatic environment

At the end of winter 2022 (March), from 9 p.m. to 10 a.m., there is no significant difference between the temperatures recorded in the inter-row and in the bare area.

During the night (6 p.m. to 6 a.m.) the temperatures, cumulatively, under signs are slightly higher than those recorded between rows and in bare areas. From 10 a.m. to 12 p.m., the temperatures under the panels are higher than those recorded in the bare area, then there is an inversion in the early afternoon.

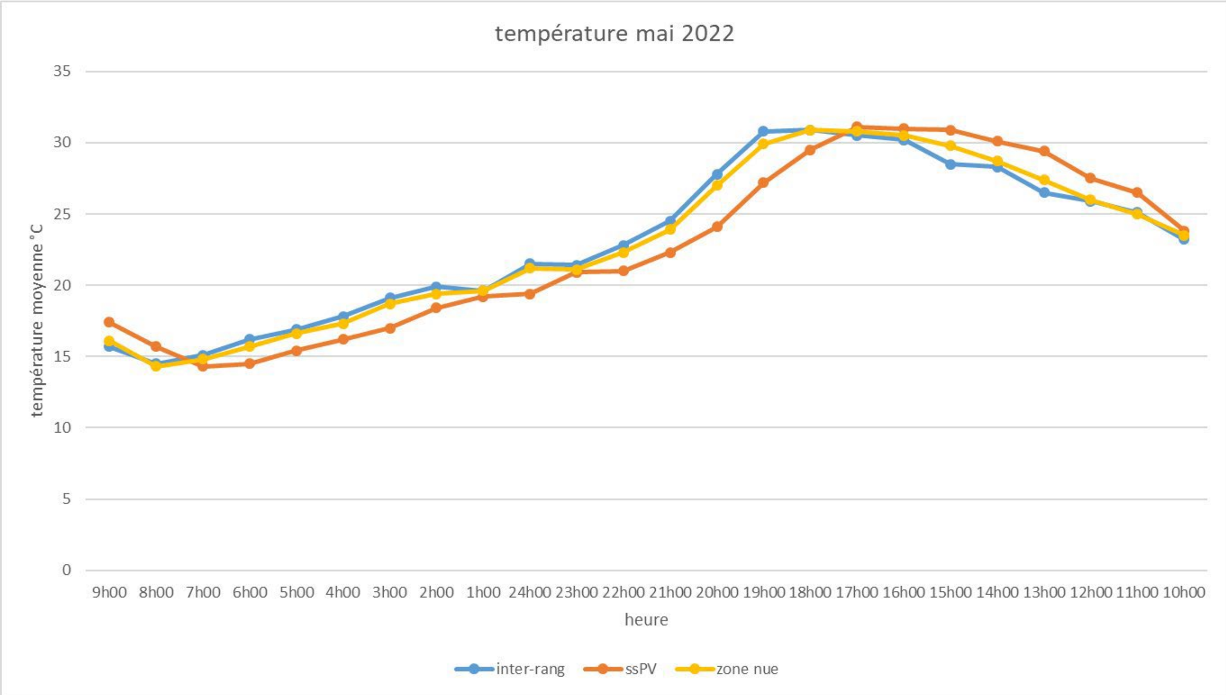


Average hourly temperatures over the 10th days of March 2022 (Note : The data recorded at the 2 stations in inter-row, not being significantly different, were averaged.)

Occasionally, it was noted that at the end of winter in the morning around 8 a.m. the ground was covered with white frost between the rows but not under the signs, even if they were still in the shade.

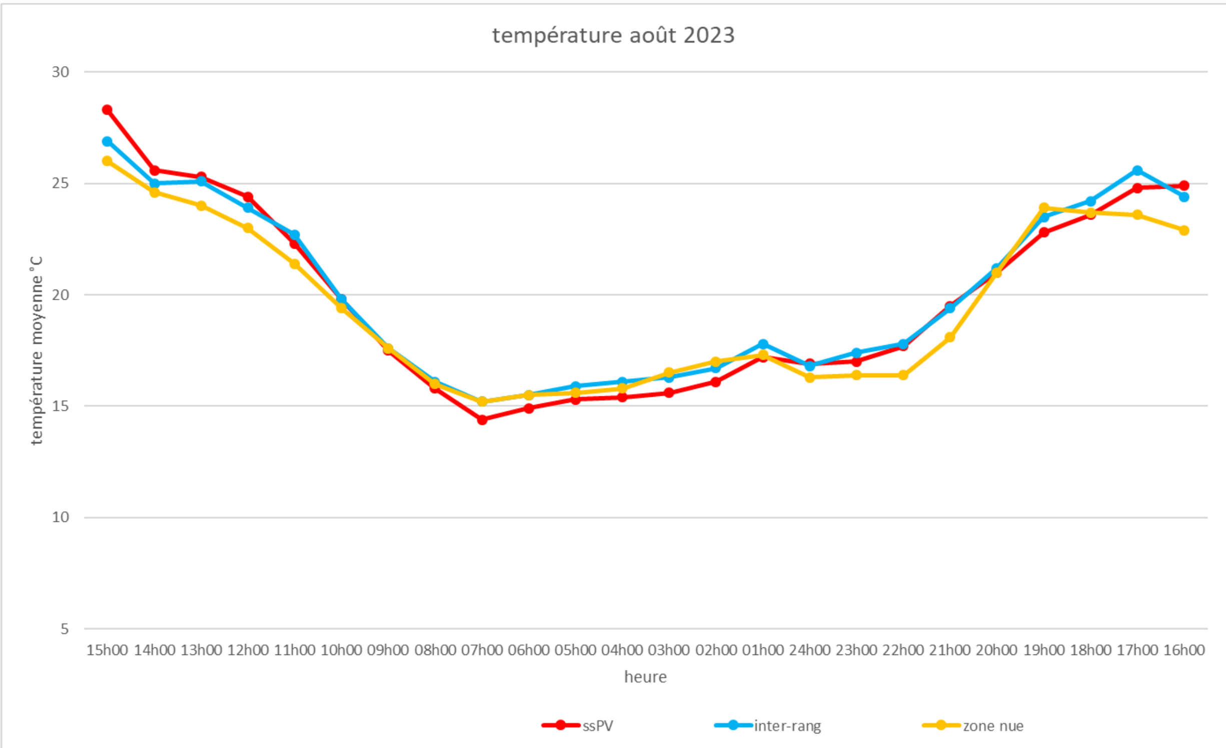
The higher cumulative temperatures during the night under the panels than between the rows may explain the absence of frost under the panels at the end of winter.

In May 2022, temperatures between rows and in bare areas are never significantly different. During the night, temperatures under the panels are lower than those in the inter-row and bare area. There is an inversion between 11 a.m. and 3 p.m., a period during which the temperatures under the panels are higher than elsewhere in the plant.



Average hourly temperatures over the 10th days of May 2022

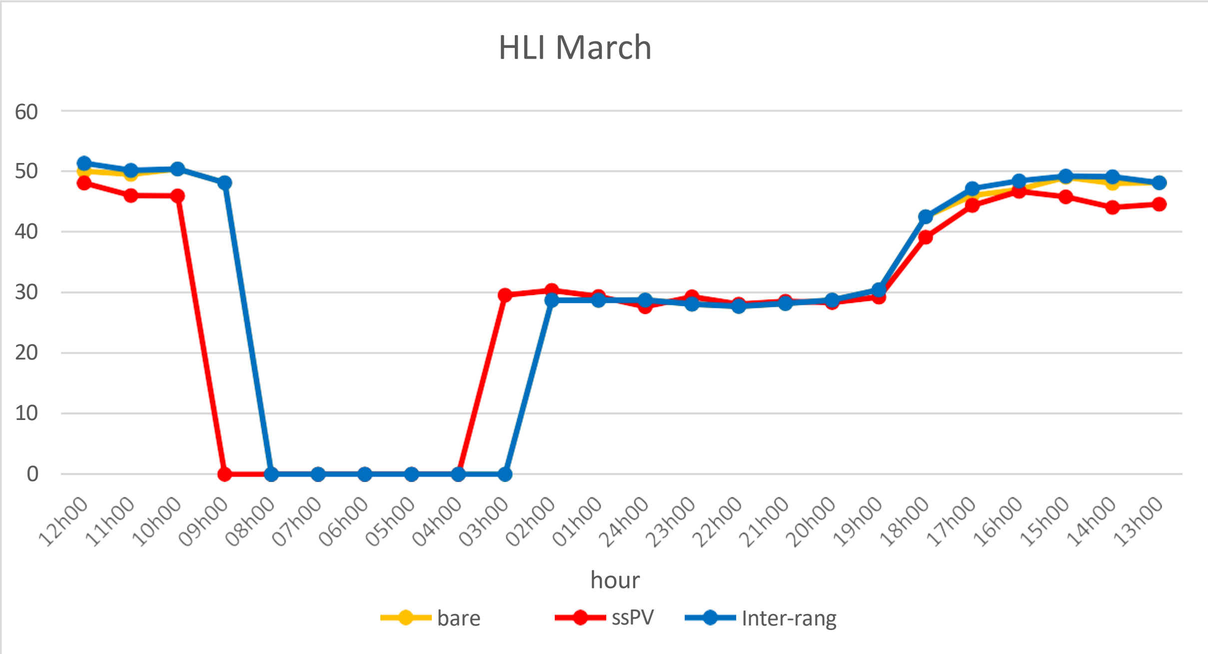
In August 2023, there is no significant difference between the temperatures under the panels and between the rows. Cumulative temperatures are lower in the bare area at 11 a.m. and 11 p.m. than under the signs and between rows.



Average hourly temperatures over the 10th days of August 2023

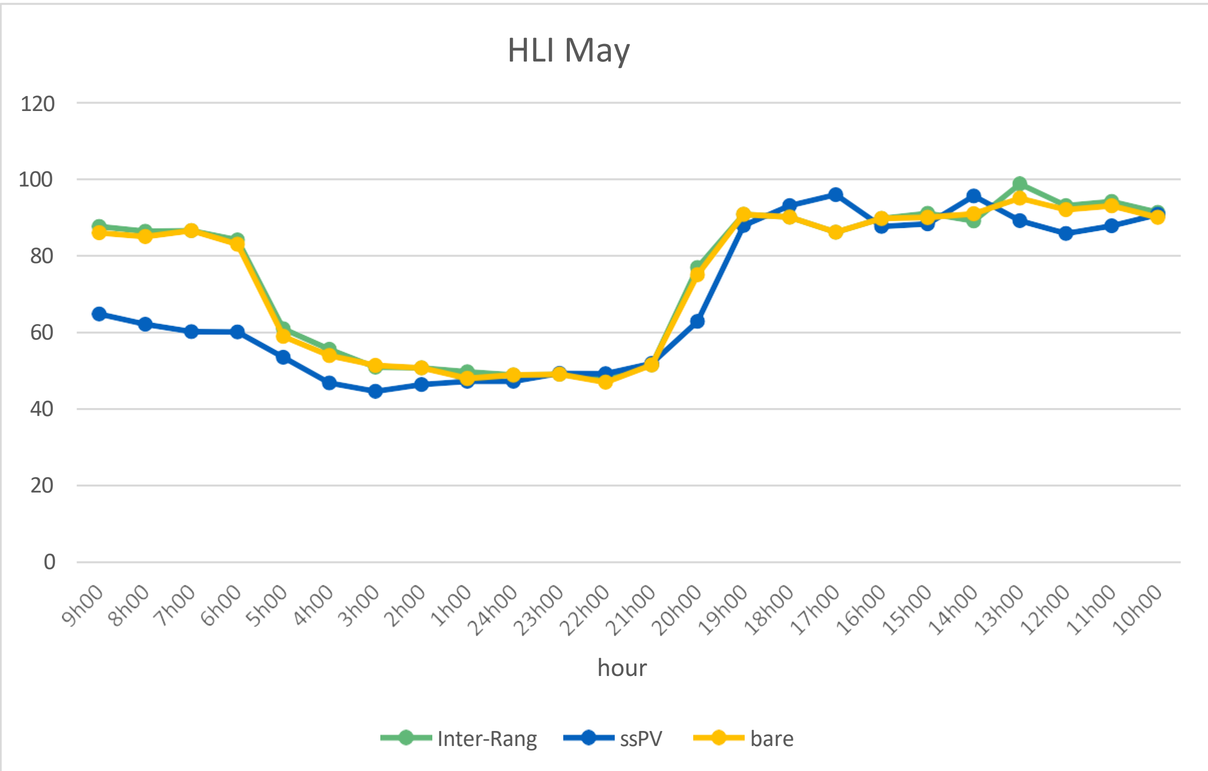
The following 3 graphs represent the thermal feeling perceived by ewes (HLI). Although the temperature under the panels was sometimes higher than in other areas of the plant, the HLI under the panels is still lower. The lower levels of solar radiation under the panels explain these lower HLI values. In May (5 p.m.), however, an HLI under signs was recorded

This result is higher than that of the other areas of the plant, and is explained by the absence of wind under the panels at this measurement point.



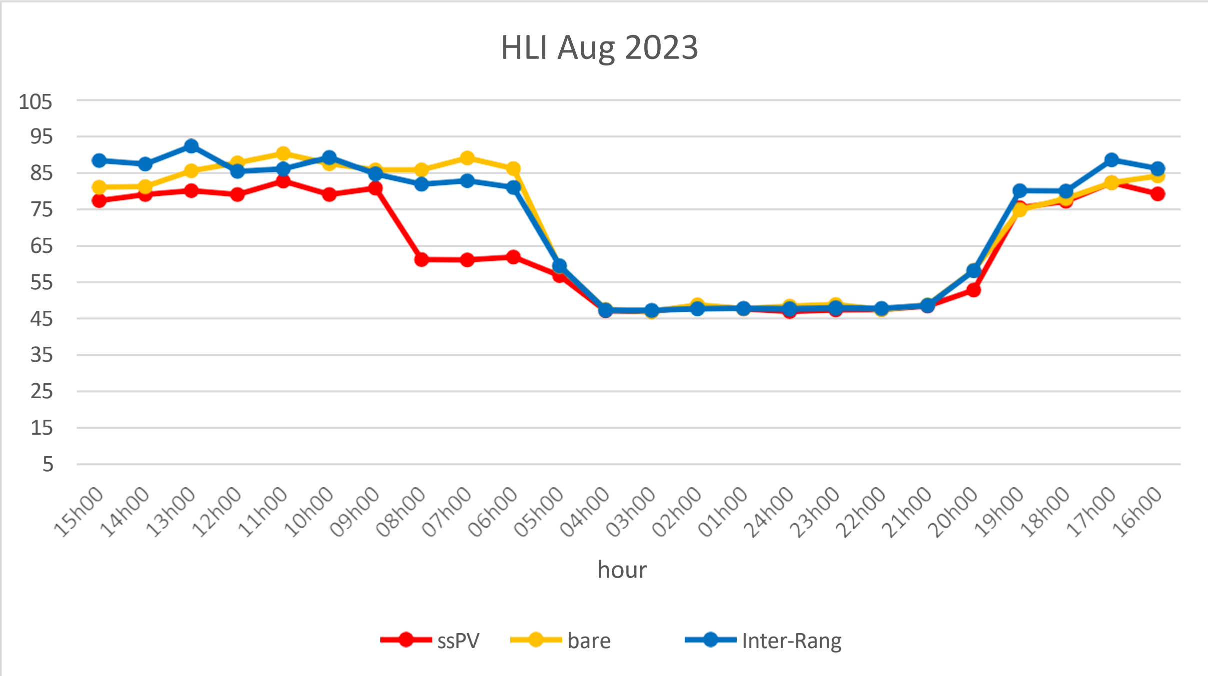
Average hourly HLI on the 10th days of March (HLI=0 means that temperatures were negative)

In May, from 10 a.m. to 7 p.m., the HLI indicates marked stress regardless of the location of the plant. From 6 a.m. to 9 a.m., the HLI indicates an absence of thermal stress under the panels, while the other places in the plant induce moderate stress.



Average hourly HLI on the 10th day of May

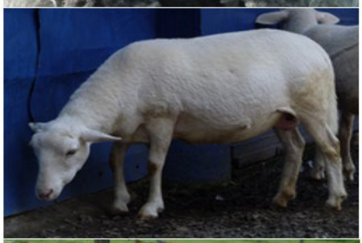
In August, from 10 a.m. to 5 p.m., the HLI indicates a marked state of stress in the inter-row or bare area, while under the signs the moderate stress stage is never exceeded.



Average hourly HLI on the 10th day of August

On 4 hot days (>30°C in a bare area), the respiratory rate of 4 ewes over a period of 2 hours was visually evaluated. The average was 53 beats/minute, the ewes were always under the panels. According to the Awin scores (below), the ewes were under high heat stress, however in another study (Parasol project, personal data), in similar climatic conditions the ewes in the bare area had respiratory rates of 70 beats/minute. Similarly, on the power plant, when the ewes were in the shelter after the sensors were installed, their beats were 80/minute (the stress of restraint may have increased the respiratory rate of the ewes).

Normal: Breathing is at a normal rate (about 20 breaths per minute), with the mouth closed.

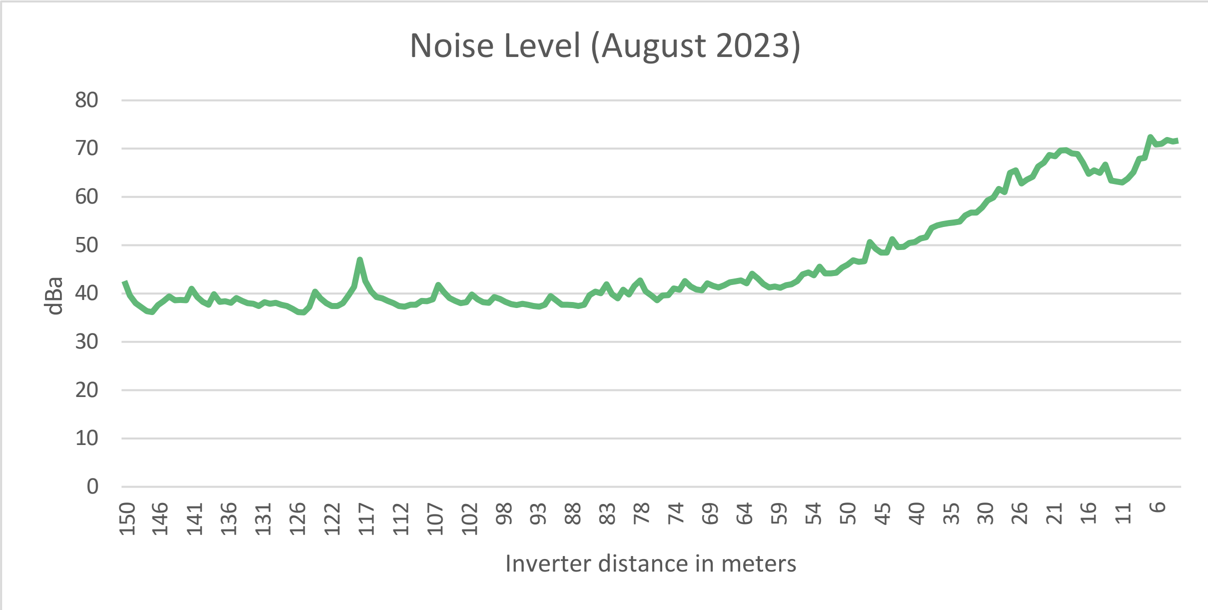


Medium stress: The respiratory rate is greater than 30 breaths per minute but less than 40 and the breathing is done with the mouth closed.

Panting, high stress: The respiratory rate is greater than 40 breaths per minute and/or occurs with the mouth open.

2.4. Soundscape

The noise level, when the panels were in operation, gradually increased in dBa between the edge of the plant and the inverters located in the middle of the panel row.



Sound atmosphere recorded in the inter-row in August 2023 at 1 p.m. from the edge of the power plant to The inverter

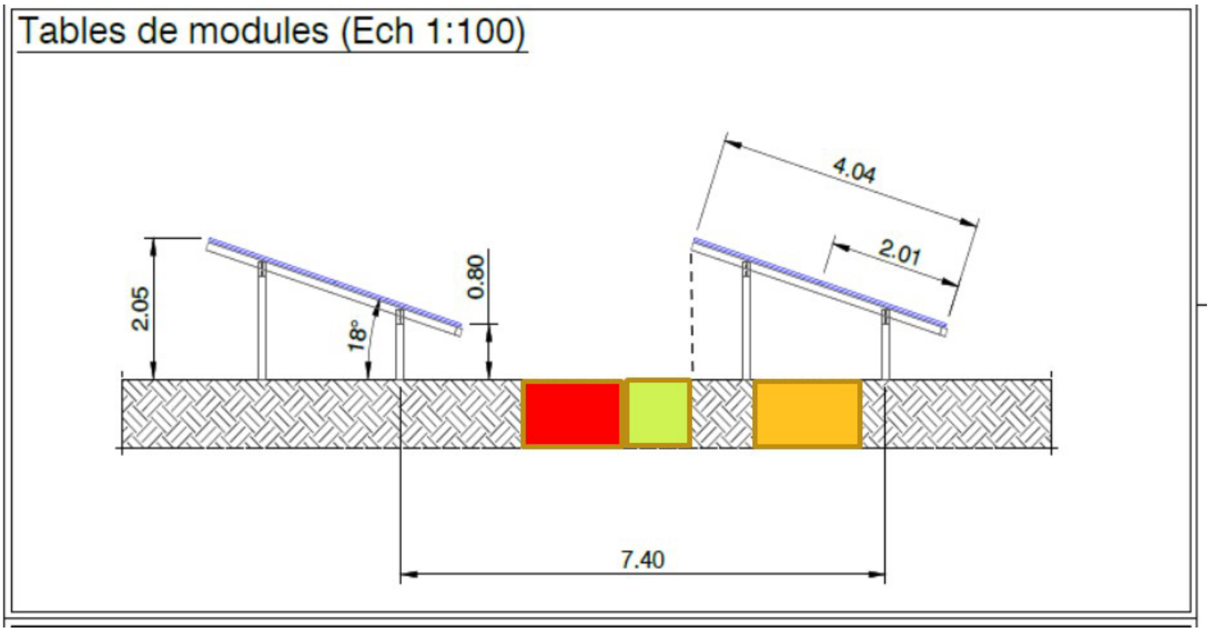
In June 2023 at 1 p.m. the noise level recorded at 1 meter from the inverter was 71 dBA, in August it was 72.4 dBa and in October it was 61.5 dBa.
During behavioral observations, ewes were never observed near the inverters in full activity. However, the areas near the inverters are grazed. It is likely that these areas are frequented by ewes during periods of little sunlight and low activity of the panels and inverters.

2.5. Quantity and quality of fodder

There is a very large variability in the amount of grass available between the north and south of the plant. The northern part is less conducive to grass growth than the southern part, both between the rows and under the panels. Point visual observations estimated in this northern area grass heights that did not exceed 5 cm in height throughout the study period.

The defensive zones have been placed in the southern part of the plant. The height of the grass under panels is higher than that between the rows. In May 2022, the average grass height in the 2 fencing zones under the panels was 12 cm compared to 10 cm in the 2 inter-row zones. In July 2022, the average grass height in the 2 defensive zones under panels was 6 cm compared to 3 cm in the 2 inter-row zones.

Grass height measurements carried out in June 2023 in grazed areas show a gradient between the inter-row and under the panels (see diagram below). The average height between the rows was 2cm (red area), 3 cm below the panels (orange area) and 7cm to 1m from the upper part of the panels (green area).



(based on Statkraft-CVE schematic)

The table below summarises the forage analysis data carried out on samples taken between rows and under the panels. The dry matter contents are higher in the inter-row than under the panels. However, the values of cellulose, Adf and Ndf levels are higher in inter-row sampling, which indicates a more fibrous forage, less consumed by the animals when they have the choice and with less good digestibility (Feed for ruminants INRA 2028). The samples under panels are richer in protein and nitrogenous fat. The dOM are slightly higher in the samples taken under panels, which reflects a better nutritional value of its forages.

	zone 1 interR	zone 5 interR	zone3 interR	zone2 sspanneaux	zone4 sspanneaux	zone6 sspanneaux	
Matière séche g/KG MB	354	384	375	193	133	169	
proteines g/kg MS	108	97	86	197	173	175	
Mat grasse azotée g/kg MS	19	13	10	28	24	25	
cellulose g/kg MS	289	321	339	275	275	276	
Adf g/kg MS	319	342	373	335	335	314	
Ndf g/kg MS	600	670	695	587	600	620	moins bonne digestibilité pour valeur hte
dMO	69	65	61	67	66	70	meilleure valeur alimentaire si élevée

3. CONCLUSION

This study, whose originality, compared to the existing bibliography, is to have been carried out over a period of 2 years, brings important conclusions about the impact of the presence of photovoltaic panels on the behaviour and well-being of sheep grazing in a photovoltaic power plant.

The data acquired by the pedometers placed on the ewes and the behavioural observations show that **grazing under panels does not modify the time budget of the ewes**, they remain over a period of time.

Sharing the activity of the classic 3*8 in ruminants. **Grazing in this photovoltaic power plant does not change the synchronisation of the flock**, the ewes are grouped together, no ewes are isolated from the flock and they are standing or lying down at the same periods.

The presence of panels, even if it does not prevent the ewes from feeling heat stress during very hot periods, limits the intensity of this heat stress. The heat load index (HLI) is lower under the panels, compared to bare areas. The panels are shelter areas for the ewes during hot periods. The lux meter data indicate that the ewes are sheltering under the

Panels during hot periods and behavioural observations show that under the panels, the ewes have attenuated heat stress reactions (breathing rate and panting) compared to data obtained in areas without shade.

The health of the ewes in this study regarding the presence of pests, anaemia or cleanliness is not affected by the presence of photovoltaic panels. A significant impact of the presence of the panels was observed on injuries. However, this negative impact can be explained by an unsuitable practice at the beginning of the study. Indeed, at the beginning of the study, the ewes were grouped together to carry out care (trimming, shearing, etc.) and the installation of sensors using dogs. This practice has induced stress in the sheep,

flight behaviour and caused injuries, sometimes serious. From the end of 2022, the plant was divided into several areas via wire mesh and the ewes were grouped together by luring them with food supplements, a **practice that was much less stressful for the ewes and which did not induce any injuries**.

The use of dogs to group sheep in a photovoltaic power plant is not recommended according to this study, this practice stresses the sheep and is a significant risk of injury on the panels and in addition it seems that dogs in this environment with many panel support structures do not know how to adapt their behavior to group the sheep. **It would be preferable in power plants to reduce the number of supports, to limit the protruding supports and to reduce the number of**

provide a minimum height of 80-90cm high as well as divide the park into several areas and

Provide a no-sign zone in the middle of the row.

The operation of photovoltaic panels induces noise levels (70dBa) in the inverters that could induce stress in the ewes. Literature studies show **that sheep get used to these sound levels** (Weeks 2008) but these studies are carried out on a short-term basis. **In the plant studied of more than 6 hectares, the ewes have the choice to avoid these noisy areas,** which could

limit the stress induced by this noise environment, however it could be relevant to deepen these possible effects or to reduce this noise level by isolating the inverters or perhaps placing them at the end of the row.

This study shows that the amount of forage available (grass height) is greater under the panels, and even more important at the edge of the panels compared to the inter-row. The dry matter levels are lower under the panels. However, the quality of the forage under the panels is higher than in the inter-row area.

The presence of the panels also seems to limit the impact of late frosts and therefore possibly protect the fodder available during these periods. The study here focuses mainly on the impact of the presence of panels to combat heat stress in hot periods, but **the presence of panels could also limit heat stress in cold periods, limit the effects of wind during these periods and thus extend the duration of grazing by improving the thermal comfort of animals and the availability of forage.**

4. REFERENCES

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