# Transposable decision-making tool for the energy recovery of grasslands respecting biodiversity using coupled experimental design and GIS

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**Abstract:** Grasslands, vital for biodiversity and ecosystem services, are shrinking under the impact of urbanization and annual cropping, losing millions of hectares in France and Europe since 1960. Management choices are essential to reinforce their functions. The need for sustainable development calls for innovative solutions that reconcile biodiversity, urbanization, and global energy demand. Anaerobic digestion appears to be a promising option, producing renewable energy and valorising organic waste from grasslands. However, the challenge lies in reconciling bioenergy extraction with biodiversity preservation. The airport's meadows, 70% of which are grassland, illustrate this dilemma. The study proposes a tool for extracting energy from grasslands that are difficult to access, focusing on Paris-Beauvais airport. Initial results assess the potential for methane production, aiding decisions to export grass waste to local digesters for renewable energy, striving to minimize the impact on biodiversity by combining mathematical modelling with advanced spatial analysis.

**Keywords:** Mathematical Modelling, GIS, Machine learning

## Introduction

Grasslands are open environments rich in biodiversity. They provide a habitat for species and ensure various ecosystem services (fodder production, carbon storage or regulation of the nitrogen cycle). Grasslands perform also other essential functions, such as limiting soil erosion and diffuse pollution. Over the last two decades, these environments have declined towards in favour of urbanisation and annual fodder crops. Since 1960, 4 million hectares have been lost in France and 7 million on a European scale. The choice of techniques and management are decisive for increasing their functions on a territorial scale. Societal shifts towards sustainable development require innovative solutions that balance biodiversity conservation, urban development, and the growing global demand for energy. Anaerobic digestion could offers significant advantages in this context, as it enables the production of renewable energy in the form of gas, electricity and heat, while recovering organic waste. The grasslands energy potential is being studied more and more, particularly in view of the increasing energy needs of populations. However, it leads to questioning the capacity´ of grasslands to be valorised in bioenergy while preserving the biodiversity. The case of airport grasslands is an ideal example to highlight this issue. Over 70% of these meadows are grassland and are home to a rich flora and fauna.

The aim of this study is to propose a tool to help with the energy recovery of grass biomass from meadows in difficult-to-access areas, which can be transposed to other plots. The method will be developed in the case of airport grasslands, with a focus on

Paris-Beauvais airport (France). Initial results have made it possible to have a fast-estimation of the methane production potential of grasslands at Paris Beauvais-Tillé airport, an area that is difficult to access, to provide crucial data for deciding whether to export this grassland waste to a local digester to promote local, renewable energy production while ensuring minimal impact on biodiversity.

## Material and Methods

### *Study area and sampling plan*

The study area is the Paris-Beauvais airport. It is located in the town of Tillé (France), 3.5 km northeast of Beauvais. The airport covers an area of 230 ha, more than half of which is grassland (160 ha). The study involves converting a part of the airport's 160 ha of grassland into energy. These areas are monitored by the AéroBiodiversité association to help the airport conserve the biodiversity already present on the site. There are no fewer than 76 plant species, including 3 orchid species and 23 bird species (Aérobiodiversité, 2020). This diversity is made possible by the chalky soil typical of the Picardy plateau. In the course of its work, we used 2 accessible zones named area 1 and area 2 as the basis for our research protocol.

The sampling protocol used to take biomass samples in autumn and spring is based in part on the habitat mapping of Paris-Beauvais airport carried out by the Aérobiodiversité team. To ensure that the zones are representative, 6 quadrants were sampled in area 1 and 2. Each quadrant measures 1m². All 6 quadrants are thus spread over the entire airport surface and located where safety regulations allow sampling. These quadrants were named Si.j, A and S representing the season (Automn or Spring), i representing the zone (1 or 2) and j the quadrant (1 to 6).

### *Physicochemical characterizations and field measurements*

Different measurements were taken for each quadrant. First, plant communities were identified, and abundance measured for each species present. The abundance of species in different zones is studied using a Non-Metric Multi-Dimensional Scaling (NMDS) test on R software.

The total solid content (TS) and the volatile solid (VS) of each sample were determined by a drying at 105 ◦C for 24 h and a combustion at 550 ◦C for 2 h. The biochemical methane potential (BMP) was measured using an AMPTS I device (Automatic Potential Test System, Bioprocess Control, Sweden) according to Holliger et al. (2016). The pH of each sample was measured using a pH meter from Mettler Toledo, Switzerland. The total volatile fatty acid content (VFA) and buffer capacity (TAC) were assessed through two titrations employing sulfuric acid and an automatic titrator from Mettler Toledo, Switzerland. C/N ratio was determined as well as hemicellulose, cellulose and lignin contents of each sample were measured using a Van Soest test. An ANOVA highlighted that seasonality has a direct impact on TS.

### *First-order modelling: calibration and validation method*

Once the methanogenic potential measurements have been taken during spring season, the results of these data are extrapolated according to a first-order model with interactions. This model is proposed a priori according to the equations (1).

$$\begin{cases} TS = \alpha_1 x + \alpha_2 y + \alpha_3 xy \\ VS = \alpha_4 x + \alpha_5 y + \alpha_6 xy \\ y_{CH4} = \alpha_7 x + \alpha_8 y + \alpha_9 xy \end{cases} \qquad (1)$$

Where $TS$ is the total solid content expressed in %TF (total fresh content), VS is the total volatile content in %TS, $y_{CH4}$ is the total methane yield expressed in $Nm^3_{CH4}.t^{-1}_{VS}$, $\alpha_i$ are the regressors representing the geolocation impact on methane production to be determined. This model was calibrated using the normalized spring dataset implemented with bootstrapping to resampling available data and obtain a more accurate confidence interval.

*Advanced spatial analysis*

In order to obtain spatial and consistent values of observed samples, a spatial model was built based on high spatial resolution data from satellite images. The calibration and validation of the spatial model was performed based on data collected during spring season which involves a series of steps. The methodology starts with data preparation and pre-processing, ensuring precise spatial alignment between the model output and satellite data. Data derived from satellite consist on spectral information from spectral bands (Red, Green, Blue, Near Infrared and Red Edge) at a spatial resolution of 10m and 20m. Spectral indices like NDVI (Normalised Difference vegetation Index) were extracted from spectral bands. Data normalisation was performed to avoid problems with features in input and have these features on a similar scale. Following this, correlation indices using Pearson and Spearman are used to quantify the relationship between model outputs and satellite-derived values. Evaluation primarily focuses on spring data, using metrics like correlation coefficients ($R^2$) and mean errors (RMSE) to assess the model's accuracy during this season. Detailed spatial analysis, statistical tests, error analysis, temporal consistency checks, and machine learning algorithms are employed to refine and validate the model. In this study Random forest algorithm was used to make prediction of new values over the study area. Finally, the outcomes are summarized in a comprehensive report, emphasizing the achieved correlation between the model and satellite data in spring and emphasizing the methodology's effectiveness and potential implications for future research or applications.

## Results and Conclusions

*Methanogenic potential test over each season*

The anaerobic digestion is validated by the positive control reaching 85% of the theoretical cellulose value. These tests were carried out over a 30-day period. The methanogenic potential revealed strong disparities between areas and seasons, showing a strong heterogeneity of species and their valorisation potential according to their geolocation and season. These results validated the need for coupling mathematical modelling and advanced spatial analysis.

*Calibration and validation modelling steps*

The regression model obtained and the regressor values are described in equation (2). These equations were solved to describe the global methane yield and the VS availability according to x-position and y-position.

$$\begin{cases} TS = 0.3078x + 0.3668y - 0.3837xy \\ VS = 0.9589x + 0.9364y - 0.7669xy \\ y_{CH4} = 357.10x + 300.15y - 422.26xy \end{cases} \quad (2)$$

The methane yield, TS and VS position dependence are proportional, which is consistent with the fact that these variables represent the overall availability of digestible biomass as illustrated in Figure 1.

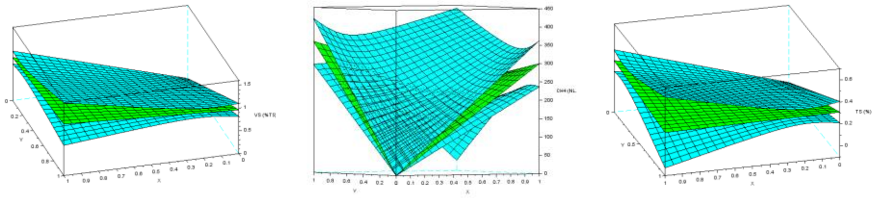

**Figure 1** Calibration results for methane, TS (%) and VS (%TS) prediction

Advanced spatial modelling part is currently under active development. Results is under refining and testing to ensure its accuracy and reliability. Spatial model outputs will be added once the accuracy assessment phase is completed. Based on earlier model outputs, prediction accuracies show a robust and comprehensive results.

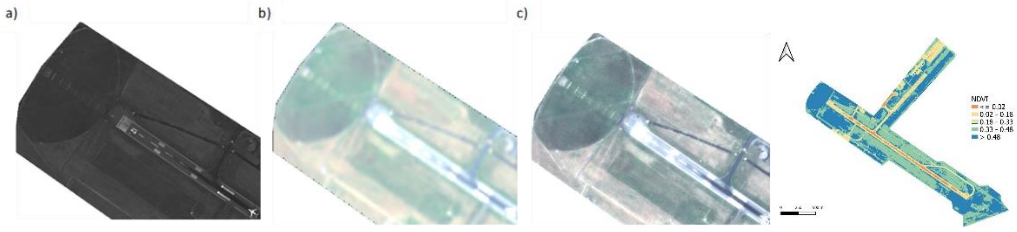

**Figure 2** Resolution enhancement using Pan sharpening algorithms on SPOT image. a) Panchromatic image at 1.5m resolution, b) multispectral images at 6m resolution, c) multispectral image at 1.5m resolution.

Figure 2-d shows the spatial variability of NDVI values over the study area. NDVI map was obtained based on pansharpened images of SPOT data (Figure 2 a,b,c). NDVI index is widely used to characterise vegetation density and health. The maximum NDVI value observed is around 0.65, however the minimum value is around -0.13. The study area presents different vegetation densities. High vegetation density is observed in area far from the landing zone with a mean value of 0.47. on the other hand, sparse vegetation cover has NDVI values around 0.3.

Once mathematical modelling and advanced spatial analysis have been coupled, the final model will need to be validated by comparison with experimental autumn data. This will ensure the model's robustness, while considering seasonality.

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