APPLICATION AND PERFORMANCE VERIFICATION OF ELECTRONIC NOSES FOR LANDFILL ODOUR MONITORING

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ABSTRACT: In recent years, the attention towards air quality issues has increased significantly and has brought odours to be included among atmospheric pollutants to be monitored and controlled. Instrumental Odour Monitoring Systems (IOMS) are more and more used as air quality monitoring tools for the assessment of the odour impact related to different industrial activities. They are particularly useful for the continuous monitoring of odour sources for which dispersion modelling is hardly applicable, for example because the odour source is difficult to characterize, as it is the case for landifills. This paper presents a case study involving the application of IOMS for the direct assessment of the odour impact of an Italian landfill at a specific receptor. Two commercial IOMS, i.e. the RubiX WT1 and the Sacmi EOS507F, were installed respectively at the landfill fenceline and at the receptor, located at about 2km far from the landfill, to continuously characterize the ambient air. The choice of the location of the two instruments was based on their specific peculiarities and different sensitivities. Besides describing the methods adopted for the monitoring and its results, this paper also focuses on the procedure developed to verify the reliability of the IOMS responses through the execution of specific field tests. The proposed testing procedure involves specific field tests for the verification of the instruments' capability to detect or classify odours to be carried out after the IOMS training and their installation at the monitoring site. The final objective of such performance verification is to guarantee the plant manager as well as the local authorities the consistency of the IOMS monitoring results. Indeed, the development of specific quality protocols for the instrument performance verification is a key element for their diffusion as monitoring tools on the global marketplace.

Keywords: performance verification; electronic noses; odour monitoring; landfill; classification accuracy; IOMS

1. INTRODUCTION

In recent years, citizens' attention towards air quality issues has increased significantly; this has brought odours originating from various industrial activities to be recognized as important environmental pollutants to be monitored and controlled (Brancher et al., 2017; Nicell, 2009). This entails the necessity to have specific methods for odour measurement in order to quantify emissions and/or evaluate citizens' exposure to odour. In the last 15 years, Instrumental Odour Monitoring Systems (IOMS), of which the most common ones are electronic noses (electronic noses), have become more and more popular as odour impact assessment tools (Cipriano et al., 2019; Deshmukh et al., 2015).

Such instruments entail the big advantage that they can provide continuous and fast results with a limited budget, and that they can be used for the direct determination of odours at receptors. This type of measurement is particularly useful when dealing with odour sources that are difficult to characterize, thus making dispersion modelling hardly applicable (Capelli et al. 2014), as it is the case for landfills (Capelli et al., 2018). In some cases, IOMS can be used not only for the detection, but also for the classification of the detected odours at receptors. For this purpose, the IOMS needs to be specifically developed for application at far distance for the source (Dentoni et al., 2012), i.e. it shall have high sensitivity to odours and identify them at concentrations that are close to the odour detection threshold. This classification capability can be exploited to recognize the most critical odour sources that are responsible for the perception of odours at receptors, thus suggesting possible technical interventions to limit the odour impact.

Due to their high potential as air quality monitoring tools, the application of electronic noses for the continuous monitoring of odours from landfills has been studied by different research groups (Capelli et al., 2008; Romain et al., 2008), and is now a scientifically recognized method. As an example, recently, in the Region of Puglia (Southern Italy), the Competent Authority has prescribed the installation of electronic noses at the fenceline of some landfills for the continuous monitoring of emissions (Cangialosi et al., 2018), and such prescriptions are becoming a common trend.

This paper presents a case study regarding the monitoring of odours from an Italian landfill performed by means of two different IOMS, i.e. the RubiX WT1 and the Sacmi EOS507F. These instruments for environmental odour monitoring, despite being based on a similar technology, have been developed and optimized for different specific applications. The WT1 is a portable instrument for real-time detection of odours at plant fencelines, while the EOS507F electronic nose has been specifically developed for ambient air monitoring at receptors, i.e. at far distance from the emission source, with the aim of detecting the presence of odours and recognizing their provenance.

Because of their different characteristics, the two instruments were used in a complementary way for the assessment of the landfill odour impact. The EOS507F was installed at a receptor located at about 2 km South from the landfill with the objective of analyzing the ambient air continuously, detecting odours and recognizing their provenance. The WT1 was installed at the landfill fenceline along the same direction with the purpose of detecting the presence or absence of odours from the landfill, and thus confirm the validity of the detections by the EOS507F.

Besides the description of the methods adopted for the landfill monitoring by IOMS and its results, this paper also proposes a procedure to verify the reliability of the IOMS responses through the execution of specific field tests.

As a matter of facts, despite their progressive evolution from mere research objects to proper air quality monitoring tools (Cipriano et al., 2019), which entails the necessity of the development of specific quality protocols for the instrument qualification, as it has been the case for other environmental automated monitoring systems (EN 14181:2014), standardization and quality verification in the field of electronic noses is still very lacking. This lack of standardization and regulation is being one of the main limiting factor to the widespread diffusion of electronic noses on the global marketplace, making that these instruments are still viewed with scepticism by plant managers as well as by local authorities.

For this reason, the present work has been focusing also on the development and the application of a specific procedure for the instrument performance testing. The performance verification is based on field tests for the evaluation of the instruments capability to detect the presence of odours (both for the EOS507F and the WT1) and, for the EOS507F, to correctly classify them. More in detail, the IOMS performance is assessed in terms of accuracy indexes, i.e. $AI_{detection}$ and $AI_{classification}$, which provide information about the instrument capability of detecting and classifying odours, respectively. This information is fundamental in order to guarantee both the plant managers as well as as the local authorities that the responses provided by the IOMS used for the assessment of the landfill odour impact are reliable and accurate. Indeed, the development of specific quality protocols allowing for the instrument performance verification is a crucial step towards the evolution of IOMS as recognized air quality monitoring tools with a legal value.

2. MATERIALS AND METHODS

2.1 The electronic nose

Electronic noses are instruments capable to mimic human olfaction in odour detection and classification, which comprise (Figure 1):

- A matrix of sensors to simulate the receptors of the human olfactory system;
- A data processing unit that performs the same function as the olfactory bulb;
- A pattern recognition system that recognizes the olfactory patterns of the substance being tested, a function performed by the human brain.

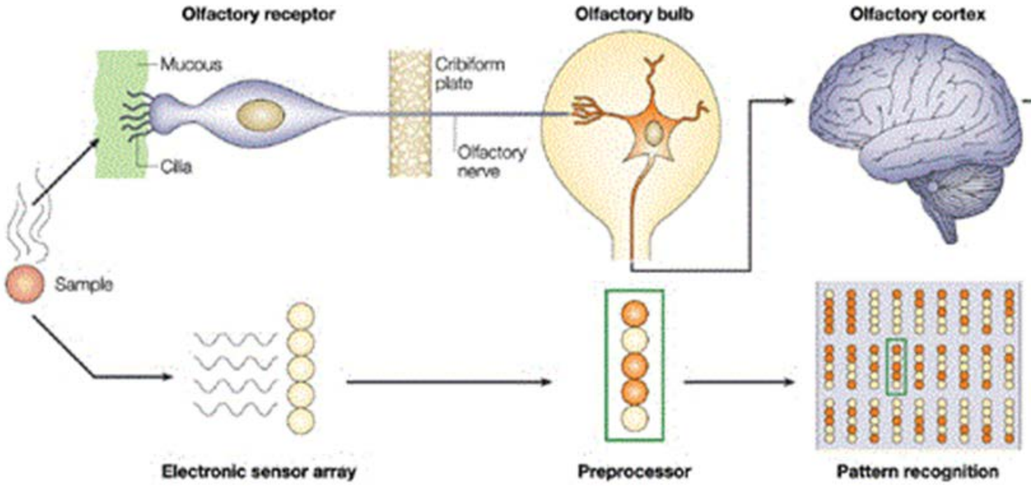

Figure 1. Analogy between the electronic nose and the human sense of smell (Turner et al., 2004)

These devices allow the identification of mixtures of odour samples as a whole, providing their olfactory fingerprint (identifiable to a source that released the mixture), without recognizing the individual odour-generating compounds. To do this, the instrument must be trained: it must be provided with a database of olfactory fingerprints relating to the odours to which it may be exposed to during the analysis. That database is put together by analyzing air samples with known olfactory qualities at different odour concentrations and thus defining the olfactory classes to be recognized.

2.2 IOMS used for the study

2.2.1 The SACMI EOS507F

The EOS507F, produced by Sacmi s.c., is an electronic nose that has been developed in collaboration with the Olfactometric Laboratory of the Politecnico di Milano specifically for environmental odour monitoring in open field and at far distance from the emission source, i.e. at receptors (Dentoni et al., 2012). It is equipped with 6 Metal Oxide Semiconductor (MOS) gas sensors, different in morphology and operating temperature, produced by Sacmi s.c., which are characterized by a high sensitivity in order to allow for the detection of odours at very low concentrations that are typical of the receptor level (Eusebio et al., 2016).

At receptors, where the presence of malodours is lamented by the citizens, it is important that IOMS are capable not only to detect odours at low concentrations, but also to identify them, thus recognizing their provenance. For this reason, the EOS507F has been optimized by Sacmi in order to perform a qualitative classification of the analyzed ambient air, by attributing it to an olfactory class. For this purpose, the instrument needs to be trained before its installation in the field: during training the database of the different odour classes that are relevant for the specific application is created (see par. 2.3). After its installation in the field, the EOS507F analyzes the ambient air continuously and registers the 6 sensor reponses with a frequency of 1 second. Based on a comparison of the sensor responses produced during the ambient air monitoring wih the database acquired during the training phase, the instrument is capable to attribute the analyzed air to a specific odour class. In the case of absence of odours, the resulting odour class is “AIR”.

The electronic nose is also equipped with specific systems for humidity regulation and realization of reference (non-odorous) air, enabling an outdoor use, even in the presence of variable weather conditions (Dentoni et al., 2012).

2.2.2 The RUBIX WT1

The WT1, commercialized by RubiX S&I SAS, is an outdoor device for fenceline monitoring of odours and air pollutants, capable to provide a direct assessment of the odour impact at the plant fenceline.

The WT1 uses commercial sensors: it can be equipped with up to 6 electrochemical cells among 20 (e.g. H_2S, NH_3, RSH, NO_2, NO, SO_2, O_3), 4 MOS sensors for odours, and PID in option. For the specific landfill monitoring, the WT1 sensor array was equipped with 4 MOS sensors and 2 electrochemical sensors specific for H_2S and NH_3.

This electronic nose is characterized by a fast response time, and provides real time monitoring of ambient air at plant fencelines and continuous odour detection, and it is capable to supply real time alerts, based on the combination of the MOS sensors outpurs. Therefore, it can be successfully used for continuous process control and measuring odour nuisance at plant fenceline.

For this specific case study, the Rubix WT1 was used at the plant fenceline for the purpose of indicating in real-time the presence/ absence of odours, without performing a qualitative classification of the different landfill odours.

2.3 IOMS training

The IOMS training represents the most important phase of the IOMS application for environmental odour monitoring. It consists in the creation of the dataset (i.e. the Training Set – TS) of the landfill odours that the instrument will be exposed to during the monitoring phase, which the IOMS uses as a reference for the characterization of the analyzed ambient air. The first step of the training phase involves the identification and the characterization of the main odour sources of the plant to be monitored.

In general, potential landfill odour emissions may arise from fresh waste disposal and pretreatment units, landfill gas leakage from landfill surface and leachate tanks (Davoli et al., 2003; Romain et al., 2008). These odour sources are the ones that were considered for the definition of the odour classes to be recognized in the present case study.

Two olfactometric campaigns were organized in order to collect representative odour samples at the emission sources, which were then analyzed by dynamic olfactometry according to EN 13725:2003 to determine their odour concentration.

These samples were presented to the IOMS to build the training set (TS), which must be representative of the conditions at the monitoring site in terms of concentration level. Therefore, the samples were analysed pure or after adequate dilution with odourless (“neutral”) air, depending on their odour concentration. Indeed, the dilution factor applied to the training samples account for the fact that odour concentrations measured at the emission sources (i.e. landfill gas 110’000-300’000 ou_E/m^3, fresh waste 150-400 ou_E/m^3, leachate tanks 250-800 ou_E/m^3) are generally higher than the concentration levels that are typically found at the fenceline (i.e. 100-500 ou_E/m^3) or at receptors (i.e. 1-200 ou_E/m^3).

For this reason, the samples used for the training of the two IOMS were prepared and analyzed in consideration of the planned location for the odour monitoring of each IOMS (i.e. plant fenceline for the WT1 and receptor at 2 km from the landfill for the EOS507F). More in detail, the samples used for the instruments training were prepared in the following odour concentration ranges:

- for the WT1, installed at the landfill fenceline: 80 - 400 ou_E/m^3;
- for the EOS507F, installed at the receptor: 15 - 250 ou_E/m^3.

2.4 IOMS performance testing

Although an IOMS cannot be assimilated to an Automatic Measurement System (AMS), in principle, the approach of the EN 14181:2014 can be re-adapted for defining a procedure for IOMS performance verification (Cipriano et al., 2018). Based on this idea, recently, our research group has been working on the development of a testing procedure, which involves three levels of testing (Li Voti et al., 2018), of which the third level is based on the execution of specific field tests after installation of the IOMS in the application. A similar approach has been adopted for the drafting of the very recent Italian technical norm on IOMS for environmental odour monitoring within the UNI 1605848 project (Cipriano et al., 2019).

This paper focuses on the third level of the testing procedure, which, as already mentioned, is related to the instrument specific application. More in detail, this testing level is inspired to the Quality Assurance Level (QAL2) foreseen by the EN 14181:2014, and focuses on the evaluation of IOMS capability to detect and classify the odours to be monitored after IOMS training and installation at the monitoring site.

The IOMS performance in the field is evaluated in terms of accuracy indexes $AI_{detection}$ and $AI_{classification}$, which are assessed by means of specific detection and classification tests that are carried out in the field, in the same conditions at which the IOMS will be operating during the monitoring. Those tests involve the collection of new samples at the odour emission sources considered for the electronic nose training, and their analysis in the field after dilution with ambient air during the monitoring phase.

The results of the field tests can be expressed in the form of confusion matrixes to evaluate the IOMS capability of odour detection (Table 1) (i.e. discrimination between odourless air and odour samples) and odour classification (Table 2) (i.e. discrimination between different odour classes).

Capability of Odour detection		**Electronic nose output**	
		Odour	*Air*
Odour class	*Odour*	TN	FN
	Air	FP	TP

Table 1. Confusion matrix for the evaluation of the capability of odour detection (TN=true negatives; FN=false negatives; FP=false positives; TP=true positives)

Capability of Odour classification		**Electronic nose output**			
		Class 1	*Class 2*	*Class 3*	*Class 4*
Odour class	*Class 1*	TP_1	E_{12}	E_{13}	E_{14}
	Class 2	E_{21}	TP_2	E_{23}	E_{24}
	Class 3	E_{31}	E_{32}	TP_3	E_{34}
	Class 4	E_{41}	E_{42}	E_{43}	TP_4

Table 2. Confusion matrix for the evaluation of the capability of odour classification (TP_i=n. of correct classified measures for i-class; E_{ij}=n. of i-samples classified as j-samples)

The accuracy index AI is defined as the ratio between the number of correctly classified measures and the total measures (R_{tot}) of samples of known quality and concentration performed:

$$AI_{detection} = (TN + TP)/\sum R_{tot} * 100$$

$$AI_{classification} = (TP_1 + TP_2 + TP_3 + TP_4)/\sum R_{tot} * 100$$

Regarding the classification tasks, also the recall index is evaluated for each odour class considered. The recall index is the ratio between the number of correctly classified measures of an odour class and the total number of measures carried out for that class:

$$Recall_i = \left({TP_i}/{TP_i + \sum_j E_{ij}}\right) * 100$$

2.4 Odour impact assessment

The odour impact is assessed in terms of frequency of landfill odours detection by the IOMS over the monitoring period.

Despite the lack of specific regulation, concerning the evaluation of the acceptability of the odour impact relevant to an industrial activity, it is possible to refer to the German guideline “GIRL - Geruchsimmision-Richtlinie” dated 13 May 1998 on odour inputs.

This guideline establishes an acceptability criterion in terms of “odour hours”, which can be perceived by the neighboring population. The limit of acceptable “odour hours” is fixed at 10% for residential or mixed areas, while this limit is set at 15% for industrial or agricultural areas. The “odour hour” is defined by referring to a specific analysis method called “field inspection”, which has been recently standardized in Europe by the EN16841:2016 (CEN, 2016), and represents an hour in which the odour is perceived for more than 10% of the time, therefore for more than 6 minutes. Although the percentage set by this guideline and the definition of odour hours are not directly applicable to the case of IOMS, it is reasonable to refer to the aforementioned guideline, as to date there are no other legislative references regarding specifically environmental odour monitoring carried out by IOMS.

In this study, the odour impact at the considered receptor located at about 2 km South of the landfill was assessed by processing the EOS507F detections during the monitoring period.

In order to validate the IOMS odour detections, the meteorological conditions (i.e. wind speed and direction) relevant to the monitoring period were evaluated in combination with the EOS507F responses. Indeed, IOMS detections of landfill odours occurring when the wind had an incompatible direction with the location of the receptor were considered as false positives, and excluded from the calculation of the landfill odour impact.

Moreover, also the comparison of the outputs of the two instruments, i.e. the EOS507F installed at the receptor located at 2 km South from the landfill and the WT1 installed along the same direction at the (southern) plant fenceline, was considered for validation. More in detail, when the EOS507F registered the presence of odours from the landfill at the receptor, then also the WT1 was expected to register the presence of odour at the plant fenceline. If this was not the case, then the detections were further investigated by considering the wind direction and the qualitative classification given by the EOS507F, in order to evaluate the existence of possible interfering odour sources that may be responsible for false positive odour detections.

3. RESULTS AND DISCUSSION

3.1 Field tests for IOMS performance verification

As already mentioned, this paper only focuses on the final level of IOMS performance testing, i.e. the field tests that are carried out in order to verify the instrument performance after training and installation in the specific application. Thus, the considerations regarding the first two levels of testing are not reported, since they have already been discussed in previous works (Eusebio et al., 2016; Li Voti et al., 2018).

During the landfill monitoring phase, 24 field tests (i.e. 12 measurements of non-odorous air and 12 measurements of landfill odour samples) were carried out after EOS507F and WT1 installation at the monitoring sites, i.e. the landfill fenceline and the receptor, respectively, with the aim of testing the WT1 and EOS507F performance in detecting landfill odours.

The odour samples for the field tests were prepared at different concentration levels, which are representative of the odour concentrations at which the IOMS is expected to be exposed during the monitoring phase, as it was the case for the training samples (see par. 2.3). Thus, the IOMS performance was tested using samples at different concentration levels comprised within the concentration range of the training set. The odour concentrations of the odour samples used for testing the capability of odour detection of the two IOMS are reported in Table 3.

IOMS	**Tested odour concentration levels $[ou_E/m^3]$**
WT1	80 – 100 – 150 – 200 - 400
EOS507F	15 – 40 – 50 – 80 - 150

Table 3. Odour concentrations of the odour samples used for testing the capability of odour detection

The IOMS outputs relevant to the field tests for the evaluation of the instrumental odour detection capability were processed and organized in confusion matrixes, which are shown in Table 4.

Capability of Odour detection		**EOS507F output**	
		Landfill odour	*Air*
Odour class	*Landfill odour*	12	0
	Air	0	12

Capability of Odour detection		**WT1 output**	
		Landfill odour	*Air*
Odour class	*Landfill odour*	10	2
	Air	0	12

Table 4. Confusion matrixes relevant to the IOMS odour detection capability evaulation

Both the EOS507F and the WT1 proved capable to recognize very well landfill odours, achieving performances expressed in terms of accuracy index $AI_{detection}$ of 100% and 92%, respectively, at the different concentration levels tested. These high accuracy indexes prove the IOMS to be able to disunguish accurately the presence of odours from odourless air, and thus guarantee the consistency of IOMS detections during the monitoring phase.

As previously mentioned, the EOS507F, which is specifically developed for the qualitative characterization of ambient air at the receptor level, was installed at about 2km from the landfill, with the aim of assessing the landfill odour presence and its provenance. For this reason, for this instrument, also the classification capability of odorous air into the different landfill odour classes considered for training was evaluated. This verification was carried out by means of specific field tests for the evaluation of the instrument capability of classifying different landfill odours.

More in detail, the classification tests involved 36 measurements, which were carried out in the field by analazying newly prepared odour samples of fresh waste, landfill gas, and leachate. Moreover, also samples of odourless ambient air were analyzed to check the capability to recognize also the odour class "neutral air" correctly.

As already discussed for the field tests performed for the evaluation of the odour detection capability, also for the classification tests, the odour samples presented to the EOS507F were prepared as to have different odour concentration levels, all comprised within the odour concentration range considered for training (see par. 2.3). The odour concentrations of the different odour samples used for testing the capability of odour classification of the EOS507F are reported in Table 5.

Odour class	**Tested odour concentration levels $[ou_E/m^3]$**
Landfill gas	20 – 40 – 50 – 70 – 100 - 150
Fresh waste	20 – 30 – 50 - 100
Leachate	20 – 30 – 50 - 100

Table 5. Odour concentrations of the odour samples used for testing the capability of odour classification

The EOS507F outputs relevant to the field tests for the evaluation of the instrumental odour classification capability were processed and organized in form of a confusion matrix, which is shown in Table 6.

Capability of Odour classification		**EOS507F output**			
		Landfill gas	*Fresh waste*	*Leachate*	*Air*
Odour class	*Landfill gas*	6	0	0	0
	Fresh waste	1	5	0	0
	Leachate	0	0	6	0
	Air	0	0	0	18

Table 6. Confusion matrix relevant to the EOS507F odour classification capability

The Sacmi EOS507F proved a very good capability in discriminating between the main landfill odour sources, i.e. fresh waste, landfill gas and leachate, achieving a classification accuracy index $AI_{classification}$ of 97%. The instrument showed to be very effective in classifying landfill gas and leachate (i.e. $Recall_{LandfillGas}$ and $Recall_{Leachate}$ of 100%), wheras the EOS507F was a little less powerful in classifying fresh waste samples, whereby the $Recall_{FreshWaste}$ was 83%.

This very good classification capability proves the EOS507F to be a reliable tool for the detection of landfill odours at far distance from the source, and also for the recognition of the detected odour provenance.

3.2 Landfill odour monitoring

The IOMS detections during the monitoring were processed in terms of frequency of detection over the monitoring period in order to assess the odour impact at the receptor of the monitored landfill.

Figure 2 and Figure 3 report the IOMS detections relevant to the monitoring period at the receptor and at the fenceline, respectively.

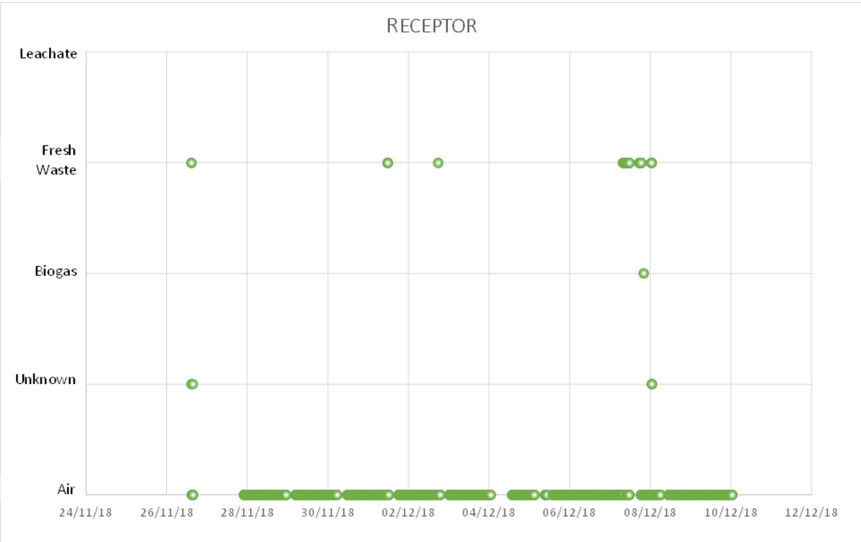

Figure 2. Odour detections by the EOS507F at the receptor

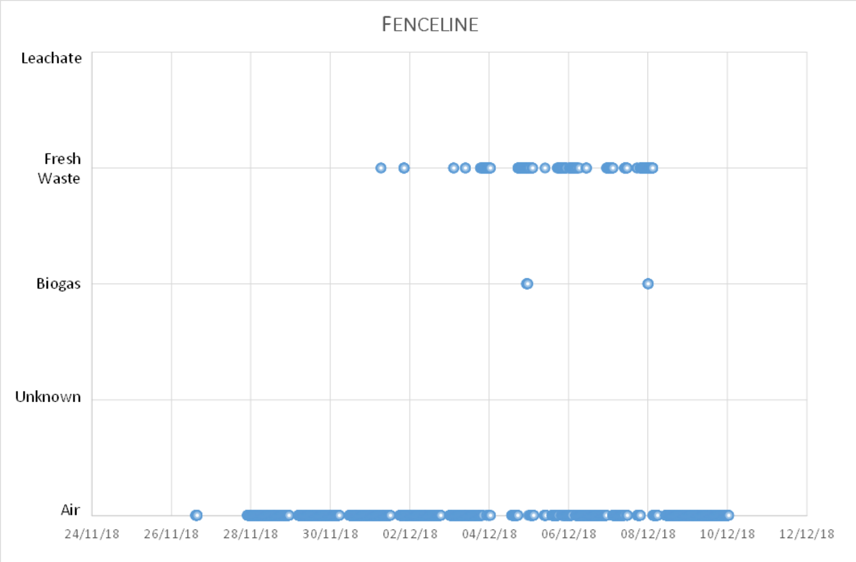

Figure 3. Odour detections by the WT1 at the landfill fenceline

In order to evaluate the effective impact of odours from the landfill at the receptor, the odour detections by the EOS507F were compared with the meteorological conditions, and more specifically with the wind speed and directions relevant to the monitoring period, with the aim to identify eventual anomalous detections, which might be not related to the landfill but to other interfering sources.

For the purpose of analysing the wind conditions, Figure 4 reports the wind rose relevant to the monitoring period, which clearly shows the existence of a prevalent wind blowing from North to South, thus favouring the detection of odours from the landfill at the receptor, which was located 2km South of the landfill. Indeed, as can be seen from Figure 4, during the monitoring period, the presence of winds blowing from the landfill to the receptor occurred for over 60% of the time.

Regarding the comparison of the periods in which the EOS507F detected the presence of odours at the receptor with the wind conditions, only 10% of the total odour detections registered during the monitoring period occurred during periods in which the wind had an incompatible direction with the relative positions of landfill and receptor. Therefore, these detections were considered as anomalous and classified as false psitives, and thus they were excluded from the computation of the landfill odour impact.

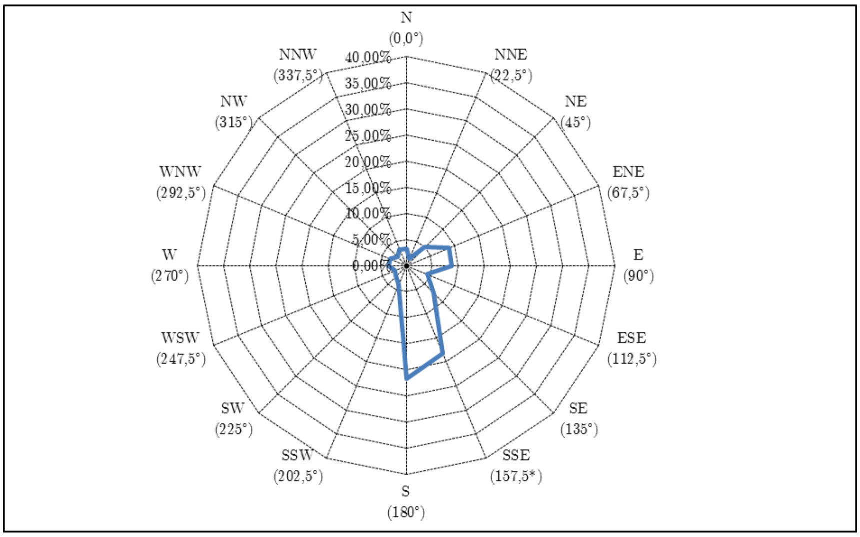

Figure 4. Wind rose relevant to the monitoring period

Moreover, another important step of the analysis of the monitoring results consisted in the comparison of the times of the odour detections by the EOS507F at the receptor with the odour detections registered by the WT1 at the fenceline. In 75% of the cases, the detections of odours from the landfill by the

EOS507F at the receptor were verified by the registration of time-compatible odour episodes also by the WT1 at the landfll fenceline.

For the remaining 25% of the cases, when the EOS507F reported the presence of odours from the landfill, the WT1 output stated a condition of odour absence. Therefore, those detections were considered anomalous and further investigated. By analyzing the outputs of the EOS507F in correspondence of these anomalous odour detections, we noticed that the EOS507F classified the analyzed air as “unknown”. This means that the analyzed air stimulated the sensor responses in such a way to not be classified as odourless (“Air”). However, the olfactory pattern relevant to the sensor responses was different from any of the landfill odour classes considered for the electronic nose training, which gives that the instrument classified the odour as “unknown”. Based on these considerations, these anomalous detections were also considered as false positives, and therefore excluded from the computation of the landfill odour impact.

This double-check procedure, together with the field tests for the instruments performance verification, has the aim to guarantee that the odour detections at the receptors are effectively imputable to the monitored landfill and not to other interfering sources, which might have a similar odour that is erroneously attributed to the landfill.

Finally, the electronic nose installed at the receptor (i.e. the EOS507F) detected the presence of odour for 4% of the whole monitoring period, whereas the electronic nose installed at the plant fenceline (i.e. the WT1) registered the presence of odour for 14% of the time (Figure 5).

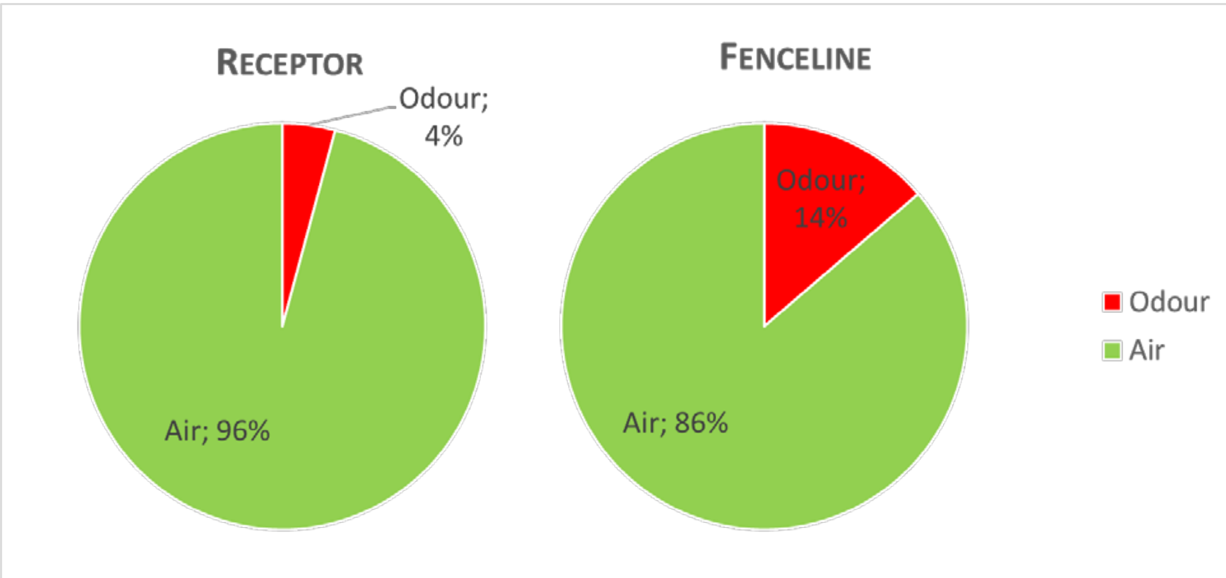

Figure 5. Percent of verified odour detections at the receptor (left) and at the plant fenceline (right)

The results of the EOS507F classification of the detected odours into the different odour classes considered for training is shown in Figure 6. The majority of the odours detected by the IOMS were attributed to the fresh waste; therefore, the fresh waste resulted as the main odour source of the monitored landfill, i.e. the source whose odour is most frequently recognized by the electronic noses. Indeed, fresh waste odour was detected for 3% of the monitoring period at the receptor. This result can be explained by considering that, during the monitoring period, the landfill had an anomalous amount of its surface being waste exposed to the atmosphere, due to the fact that a significant part of old landfill lots has been re-opened in order to allow for the landfill heightening.

At the receptor, the EOS507F detected for about 1% of the monitoring period odours that weren’t attributable to any of the landfill odour classes considered during training, i.e. they were classified as “unknown”. If the meteorological conditions and the detection of the electronic nose at the plant fenceline were compatible with these “unknown” odour detections, these were not excluded from the computation of the landfill odour impact. Indeed, the classification of an odour as “unknown” doesn’t necessarily mean that the odour doesn’t come from the landfill, but just that it doesn’t belong to any of the odour classes considered during the training. However, the possibility exists that, in particular conditions, the landfill may emit specifc odours that turn out to be different enough from those considered during the electronic nose training for the instrument to classify them as “unknown”.

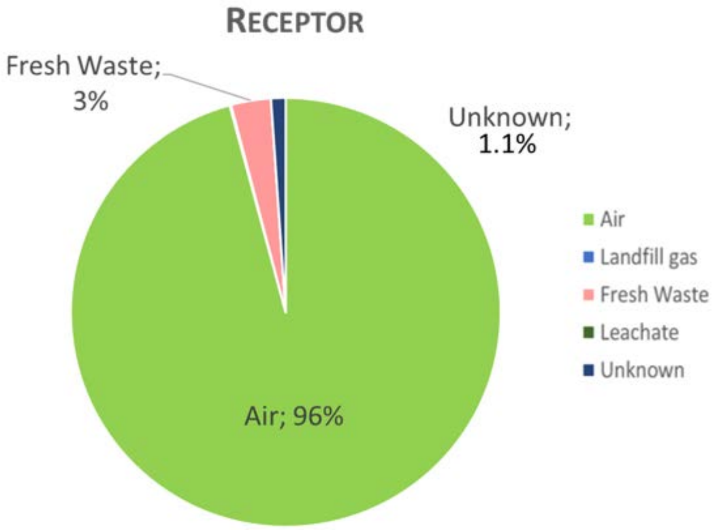

Figure 6. Percent of detection of the different odour classes by the EOS507F at the receptor

Based on the results of the monitoring, it is possible to conclude that the landfill odour impact assessed at the receptor (i.e. 4%), being below 10%, falls within the acceptability criteria fixed by the adopted reference method fixed by the german “GIRL” for residential areas.

4. CONCLUSIONS

This paper presents the odour monitoring of an Italian landfill performed by means of two different IOMS, i.e. the Sacmi EOS507F and the Rubix WT1. The first was installed at a receptor located at about 2 km from the landfill to perform a qualitative characterization of the ambient air and assess the landfill odour impact. The RubiX WT1, instead, was installed at the plant fenceline along the same direction with the aim of using its detections to validate the IOMS results at the receptor and identify eventual anomalous detections, which might be not related to the monitored landfill, but to other potential interfering odour sources. Besides the description of the methods adopted for monitoring the odours of the landfill by IOMS and the resulting odour impact assessment, this paper proposes an experimental protocol for the verification of IOMS performance in the field. The proposed experimental protocol involves specific tests to be carried out directly in the field for the verification of IOMS capability of detecting and classifying odours.

The results presented in this work prove both instruments to achieve very high accuracies in odour detection at the odour concentration levels that are relevant for the specific application (92% for the WT1 and 100% for the EOS507F, respectively), and the EOS507F to correctly classify landfill odours with high accuracy (i.e. 97%). Based on these results, it is possible to state the high potential of electronic noses as air quality monitoring tools for the specific purpose of odour impact assessment.

Indeed, since electronic noses can be applied for the direct assessment of odours without the necessity of minutely quantifying each odour source, their use is particularly indicated in cases in which odour emissions are hardly quantifiable and implementable in an odour dispersion model, as it is the case for diffuse, fugitive or discontinuous emissions.

However, in order to allow for the detection and the identification of such complex odour sources, the instrument shall be properly trained. Indeed, the training phase represents a crucial step for an effective application of electronic noses for environmental odour monitoring purposes. For this reason, it is extremely important that the monitoring campaign is specifically designed case-by-case by experts of the matter, who have a deep knowledge of the specific processes that lead to the release of odorous emissions into the atmosphere and are capable of identifying all the potential odour sources to be considered for the instrument training. Moreover, specific sampling equipment shall be adopted in order to guarantee that representative samples of the emitted odours are collected and presented to the electronic nose during training.

Finally, it is important to highlight the importance of disposing of an Olfactometric Laboratory for measuring the odour concentration of the collected samples. The determination of the odour concentration is fundamental in order to define the dilution ratios needed for the preparation of samples at suitable concentration ranges for the electronic nose training and performance testing depending on the specific application. Indeed, despite the undeniable advantage compared to olfactometric measurements to allow for continuous and relatively cheap odour monitoring, the electronic noses cannot be effectively used without relying on dynamic olfactometry.

In the end, if suitable instruments are selected for each application, and if they are properly trained, they represent powerful and reliable tools to detect and discriminate different odours and thus to identify the main odour sources that are responsible for the perception of odours of the monitored plant at specific receptors. This in turn can be a very useful information in order to optimize cost-benefits in the interventions for the control and limitation of odour impacts.

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