detritus | Multidisciplinary Journal for Circular Economy and Sustainable Management of Residues

CISA

TOWARDS REAL-TIME MONITORING OF ODOUR EMISSIONS FROM WASTE TREATMENT PLANTS: A CASE STUDY

Christian Ratti, Beatrice Julia Lotesoriere, Carmen Bax * and Laura Capelli

Politecnico di Milano, Department of Chemistry, Materials and Chemical Engineering "Giulio Natta", Piazza Leonardo da Vinci 32, 20133 Milan, Italy

Article Info:
Received:
15 September 2023
Revised:
29 January 2024
Accepted:
19 February 2024
Available online:
31 March 2024

Keywords:
Odour concentration
Ambient air quality
Quantification
Electronic nose
IOMS

ABSTRACT

The most recent Best Available Techniques (BAT) for waste treatment plants indicate odour as environmental pollutants to be monitored and controlled. In Italy, the prescription of permanent installations of electronic noses (or Industrial Odour Monitoring Systems - IOMS) in the environmental permit of waste treatment plants (WTPs) is becoming more and more frequent. IOMS are intended to provide a real-time estimation of the odour concentration at the fenceline of the plant. Although this type of IOMS application is becoming very common, it is far from being state-of-the-art. In this context, this paper describes a research project aimed at the implementation at the fenceline of a WTP of an IOMS network, comprising two IOMS and a meteorological station. The paper focuses on presenting the experimental procedure involved for training IOMS and verifying their performance in the field. 5 olfactometric campaigns were carried out at the plant to build IOMS calibration models aimed at WTP odours detection, classification, and quantification. Results of field performance testing proved, with classification accuracies above 95% achieved by both IOMS, a very good capability of properly trained IOMS to recognize WTP odours. Moreover, they pointed out a great agreement between the estimations of the odour concentration provided by the IOMS and the odour concentration assessed by dynamic olfactometry, thereby boosting the research in this field. Finally, the paper reports the results of 1-year monitoring at the WTP with the purpose of evaluating the possibility to define an alarm threshold for the odour concentration.

1. INTRODUCTION

Odours currently are one of the major causes of citizens' complaints to local authorities and, in the case of activities related to the treatment and disposal of wastes, often represent a limiting factor to the operation of plants (Capelli et al., 2020). The most recent Best Available Techniques (BAT) conclusions for waste treatment include odours among the environmental parameters to be monitored (Pinasseau et al., n.d.). For these reasons, odours are subjected to regulations and rules at national and European level have been published to regulate the odour impact from industrial facilities (Brancher et al., 2017).

Different approaches have been developed to characterize environmental odours (Bax et al., 2020b). Dynamic olfactometry is the reference method for odour quantification at emission sources (standardized by the EN 13725:2003) and can provide information to be used as input for dispersion modelling to evaluate citizens' exposure to odours. The major limitations related with this approach are that this technique is discontinuous, and its inapplicability to ambient air, making it unsuitable for a real-time monitoring of odour exposure. An alternative sensorial technique that can be used to measure odors in the field is represented by field inspection. It allows estimating the degree of annoyance in term of "odour hours" in a determined area. However, as dynamic olfactometry, this technique is discontinuous and considerably time- and cost-intensive. Thus, it is not suitable for the continuous monitoring of odours (Bax et al., 2020b). The use of electronic noses (or Industrial Odour Monitoring Systems - IOMS), able to perform a continuous real-time monitoring of odour emissions, allows overcoming these limitations. Indeed, despite the costs and time required for a proper instrument training, they have proved to be effective for the real-time of odour emissions directly at the emission sources or either at the nearest sensible receptors (De Vito et al., n.d.; John et al., 2021; Oliva et al., 2021; Panzitta et al., 2022; Prudenza et al., 2023).

Currently, in Italy, the permanent installation of IOMS is sometimes prescribed within the environmental permit of waste treatment plants (Cangialosi et al., 2018). Such

* Corresponding author:
Carmen Bax
email: carmen.bax@polimi.it

Detritus / Volume 26 - 2024 / pages 106-113
https://doi.org/10.31025/2611-4135/2024.18361

systems are usually prescribed with the purpose of continuously monitoring the ambient air at plant fencelines to detect, classify and quantify odour emissions from the plant. The final goal is, in general, the real-time identification of anomalous odour emissions, thus enabling prompt interventions aimed at reducing odour events on the neighborhoods. Despite the increasing number of such prescriptions, the use of IOMS for the continuous monitoring of odour emissions and the real-time measurement of odour concentrations is still far from being state-of-the-art. In this context, this paper describes a research project aimed at the implementation of an IOMS network at the fenceline of waste treatment plant (WTP), producing biomethane and high-quality compost, intended to provide a real-time estimation of the odour concentration. The IOMS network comprises two electronic noses produced and commercialized by Ellona (i.e., WT1 1179 and WT1 1180) and a meteorological station.

The paper focuses on the description of the experimental procedure involved for the IOMS training and data processing. Furthermore, it presents the results of one-year monitoring at the WTP fenceline with the purpose of evaluating the applicability of IOMS for a real-time estimation of the odour concentration at the fenceline of a WTP plant and the possibility to set an alarm threshold for the odour concentration.

2. MATERIALS AND METHODS

2.1 Waste treatment plant

The WTP under investigation converts the organic fraction of municipal solid waste (OFMSW, 80’000 ton/y) into biomethane (550 Sm^3/h) and high-quality compost (36’000 ton/y). After plastic and sand separation, the OFMSW is mixed with water and enters the anaerobic digestion tanks. Anaerobic digestion leads to the formation of biogas and digestate, which are further sent to upgrading and composting sections to obtain biomethane and high-quality compost, respectively. To prevent odour emissions into the atmosphere, OFMSW storage and treatments are carried out in closed sheds operated under slight vacuum and equipped with ventilators collecting exhaust air to a biofilter unit. Thus, the biofilter unit represents the only odour emission source of the plant. However, fugitive emissions from storage and treatments sheds cannot be completely neglected.

2.2 Monitoring systems

2.2.1 Description

The monitoring system comprises two IOMS (i.e., Ellona WT1 1179 and 1180) and a weather station (i.e., Davis Instruments, Vantage Pro2) (Figure 1). The two IOMS are equipped with 7-sensors each, comprising 4 metal oxide sensors (MOS), 2 electrochemical sensors specific for the detection of hydrogen sulphide (H_2S) and ammonia (NH_3) and one photoionization detector (PID) calibrated in isobutylene. The instruments also include sensors for monitoring temperature and relative humidity levels. The weather station Vantage Pro2 is equipped with Anemometer, Rain Collector, Temperature and Humidity Sensors. IOMS and meteorological data can be visualized in real-time and downloaded through the Ellona web interface.

2.2.2 Monitoring sites

The monitoring sites at the WTP fenceline were defined based on the results of a parametric dispersion modelling of the odour emissions from the WTP, which allowed correlating the odour condition at the fenceline with the impact at closest receptors. The two IOMS were installed at the western and eastern corner of the plant along the prevailing wind direction, as illustrated in Figure 2. More in detail,

a)

b)

FIGURE 1: Monitoring system: a. Ellona outdoor electronic nose and b. Davis Instruments, Vantage Pro2 meteorological station.

FIGURE 2: Illustration of monitoring sites at the WTP fenceline.

the WT1 1179 was installed in the proximity of WTP anaerobic digester and emergency flare, while the WT1 1180 is expected to be mainly exposed to diffuse emissions from OFMSW storage and treatments sheds.

2.3 Experimental protocol

2.3.1 General outline

The research was structured in six phases: 1) Analysis of the process and definition of the monitoring sites at the plant fenceline; 2) IOMS training for the implementation of specific quantification and classification models to be further used for the real-time analysis of the ambient air; 3) IOMS performance verification in the field; 4) Monitoring phase, during which the IOMS provided real-time estimations of the odour concentration at the monitoring sites; 5) Analysis of IOMS outputs relevant to the monitoring phase in combination with meteorological conditions; 6) Comparison of IOMS monitoring outcomes with odour observations made by human "sentinels" during the monitoring phase, with the purpose of defining suitable alarm thresholds for the real-time detection of odorous conditions potentially responsible for odour events in the vicinity of the plant.

Five olfactometric campaigns, distributed among different seasons, were conducted at the plant from February 2022 to October 2022 to train and test the IOMS. They involved the collection of odour samples at WTP emission sources (i.e., buildings dedicated to OFWMS storage, pre-treatments, and de-sandblasting, bio-pulpers, digesters, and biofilter), their olfactometric characterization according to EN 13725:2022, and their analysis by IOMS. A total of 230 samples, whose concentration ranged from 20 to 800 ou_E/m^3, were used. These data were split in a Training Set (TS) and in an independent external test set, for the field performance verification, following this criteria: 170 samples collected in the first four olfactometric campaigns were used to build the TS (Table 1), instead, the samples analysed in the last campaign conducted on October 2022 were incorporated in the external validation set (Table 2).

2.3.2 IOMS training phase

During training, odourless ambient air, collected at the fenceline when no odour could be perceived, were analysed to define the IOMS baseline. The training set (TS) was built combining IOMS sensors signals (i.e., MOS electrical resistances and concentrations provided by H_2S, NH_3 and PID sensors) with samples' class and concentration. Three classes were considered: air indicative of the absence of odour condition, biogas representative of fugitive leaks from digesters, and organic odour relevant to emissions from buildings dedicated to OFWMS storage and processing and biofilter. The TS was processed according to the procedure illustrated in Figure 3. After an initial pre-treatment aimed at normalizing the data and compensating potential interferences, different features (comprising electrical resistance ratio, area under the curve, etc…) from the sensors' signal curves were extracted and ranked by means of Boruta algorithm (Kursa & Rudnicki, 2010). Selected features were processed by Principal Component Analysis (PCA), and PCA scores on the first 3 principal components were used as input of a two-step classification model. The classification model, based on Support Vector Machine (SVM) (Cortes et al., 1995), was trained to detect WTP odours and identify their type (i.e., landfill gas or organic odour). Finally, a class-specific regression model, based on Support Vector Regression (SVR) (Smola et al., 2004), was used to estimate the odour concentration.

2.3.3 Field performance verification

According to the recently published Italian Standard on Instrumental Odour Monitoring with IOMS (UNI 11761:2023), field performance tests were carried out after the IOMS training and installation on site. They involved the sampling at emission sources of new samples and their analysis by dynamic olfactometry and IOMS. A total of 60 samples, defined as in Table 2, with odour concentration ranging from ca. 20 to ca. 700 ou_E/m^3, were analysed.

Such tests aimed at assessing the capability of the trained IOMS to estimate the odour class and concentration on external validation. IOMS classification performance was expressed in terms of classification accuracy and recalls for each class (Bax et al., 2020a). In addition, the IOMS odour quantification performance was evaluated by comparing the IOMS prediction with the odour

TABLE 1: Number of samples analysed for training each IOMS for each class with the respective range of odour concentration.

Class	N° of samples analysed	Range Cod [ou_E/m^3]
Air	26	20 - 50
Biogas	44	25 - 810
Organic odour	100	28 - 690

TABLE 2: Number of samples analysed for the field verification by each IOMS for each class with the respective range of odour concentration.

Class	N° of samples analysed	Range Cod [ou_E/m^3]
Air	20	20 - 50
Biogas	17	26 - 720
Organic odour	23	35 - 590

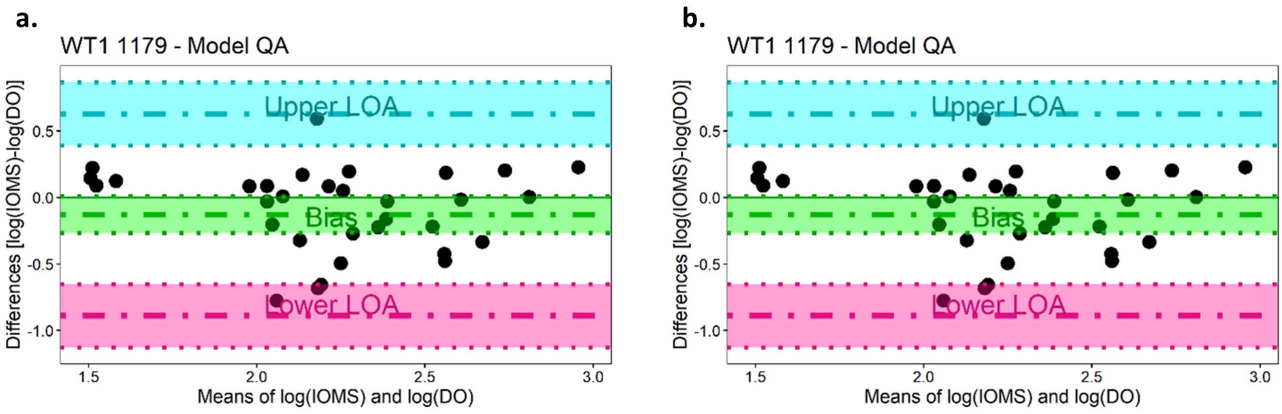

FIGURE 3: Data processing procedure adopted.

concentration assessed by dynamic olfactometry by means of a Bland-Altman model (Bland & Altman, 1999). For applying Bland-Altman test (Bland & Altman, 1999), which quantifies the agreement of two measurements in terms of mean difference (Bias) and Limits of Agreement (LoA), the logarithm of the odour concentration was considered.

2.3.4 Monitoring phase

The monitoring phase, during which the IOMS performed a continuous characterization of the ambient air, lasted about 1 year. IOMS monitoring data (i.e. continuous time series) were divided into 5 min timespans to be processed according to the procedure illustrated in Figure 3 to obtain an estimation of the odour class and concentration every 5 min.

IOMS qualitative predictions were then expressed in terms of frequency of detection of odours attributable to the different classes, with the aim of determining the odour impact, defined by the following equation, and the odour type most frequently detected at WTP fenceline.

$$\%\ odour\ impact = \frac{\sum IOMS\ detections\ of\ WTP\ odours}{\sum IOMS\ detections}$$

The odour concentration estimates, on the other hand, were used to evaluate the temporal trend of the concentration at the plant fenceline and evaluate the possibility to define an alarm threshold. The concentration values at the 95th and 98th percentiles were also calculated to determine the concentration values exceeded for 5% and 2% of the monitoring time, respectively.

Finally, a comparative evaluation between IOMS detections and odour reports by citizens living nearby the plant was carried out. Citizens' odour reports were collected by local municipality distributing questionaries to the population. For each odour event, the citizens were required to indicate the date and time of detection, the intensity (i.e., + perceptible odour, ++ strong odour, +++ very strong odour) and eventually notes regarding the odour type in the notes.

Given the significant influence of atmospheric conditions on the dispersion of odorous emissions, the wind speed and direction in force at the time of odour detection at the receptors were considered, as well.

3. RESULTS AND DISCUSSION

3.1 Field performance verification

IOMS predictions relevant to field testing were organized in confusion matrixes, reported in Table 3. The classification performance was assessed in terms of recalls and accuracy, whose value for both IOMS are summarized in Figure 4. Results achieved by both IOMS proved, with classification accuracies above 95%, their very good capability to accurately detect the odour presence and recognize the odour class. Based on these results, it is possible to state that real-time odour monitoring by adequately trained IOMS enables effective identification of the odour sources that may generate odour events outside the WTP, and thus helps undertaking rapid counteracting interventions.

The quantification performance was assessed by comparing the WT1 estimations of the odour concentrations performed on field test samples with the results of dynamic olfactometry according to EN 13725:2022, which is the reference method for odour quantification. Figure 5 illustrates Bland-Altman plots obtained for both IOMS: the x-axis reports the arithmetic mean of the logarithm of the two measurements, while the y-axis reports their difference.

TABLE 3: Confusion matrix for assessing the IOMS classification performance: a. WT1 1179, b. WT1 1180.

a.WT1 1179		**Reference**			**b.WT1 1180**		**Reference**		
		Air	**Biogas**	**Organic odour**			**Air**	**Biogas**	**Organic odour**
Prediction	Air	20	0	0	Prediction	Air	20	0	0
	Biogas	0	10	1		Biogas	0	9	0
	Organic odour	0	0	19		Organic odour	0	1	15

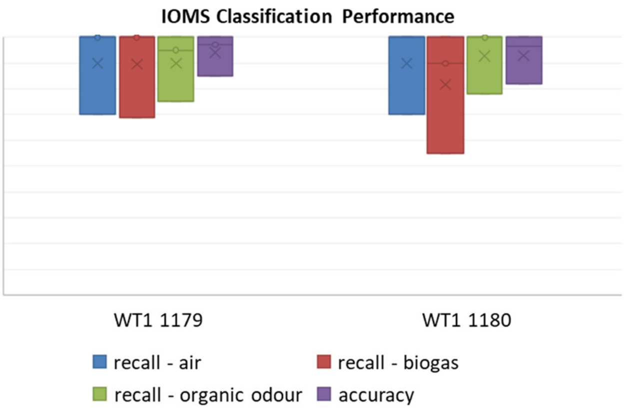

FIGURE 4: Summary of recalls and accuracy achieved by WT1 1179 and WT1 1180 on field testing.

The B&A plots illustrates the field measurements (black points), the bias (green dash-dot line), the Upper Limit of Agreement (LoA, blue dash-dot line), the Lower LoA (pink dash-dot line) and their relative 95% confidence intervals (delimited by the corresponding colour dot lines).

The visual inspection of the B&A plots proves a good agreement between IOMS and dynamic olfactometry: measurements are all comprised between the upper and lower LoA for both IOMS tested.

With the purpose of evaluating the IOMS quantification performance, the intermediate precision criterion reported in EN 13725:2022 for two consecutive measurements performed by olfactometry was used as reference, even if this is not directly defined for IOMS estimations. According to the intermediate precision criterion, the factor expressing the difference between two consecutive odour concentration measurements in 95% of cases (i.e., 1.96 * standard deviation) should not be larger than 3. In this case, factors slight above 3 were obtained for both IOMS (i.e., 3.56 for WT1 1179 and 3.74 for WT1 1180), thus proving the capability of properly trained IOMS to provide accurate estimations of the odour concentration at the WTP fenceline. Such results pointed out the potential of IOMS as tools for the real-time monitoring of the odour concentration and boost further developments in this field.

3.2 Monitoring phase

3.2.1 Processing and interpretation of IOMS outcomes

During the monitoring phase, the WT1 1179 and WT1 1180 detected the presence of WTP odours for about 7% and 11% of the monitoring period, respectively. Both instruments mostly detected odours attributed to the organic odour class. For a deeper analysis of the monitoring data, the frequency of odour detection was also calculated for each monitoring month. Figure 6 summarizes the odour impacts assessed by WT1 1179 and 1180 over the monitoring period, respectively.

Over the monitoring period, a decreasing trend of the odour impact assessed by the WT1 1179 was recorded. The reduction of odour detections from about 11% down to 4% can be explained considering that after the start-up of a new plant, it progressively reaches a regime condition.

A similar trend was also registered for the other IOMS, i.e., WT1 1180, from February to October 2022. Conversely, in the last two months of the monitoring period, an increase of the odour detection frequency up to about 21% was recorded. The increase in the frequency of odour events at fenceline in November and December combined with the analysis of the IOMS qualitative predictions allowed identifying a malfunction in the ventilation system of the OFWMS storage buildings, which resulted in increased fugitive odorous emissions impacting on the monitoring site at the eastern corner of the plant.

The odour concentrations measured at the WTP fenceline over the monitoring period were also analysed. Odour concentrations ranging from ca. 60 eq_ou$_E$/m^3 up to 350 eq_ou$_E$/m^3 were mostly measured by WT1 1179 and up to 280 eq_ou$_E$/m^3 by WT1 1180. Some spikes up to 1000 eq_ou$_E$/m^3 were recorded by the WT1 1179, installed in the proximity of the emergency flare in March and October. These anomalous concentrations were associated to the stop of the upgrading section of the plant devoted to the reefing of the biogas produced by anaerobic digestion.

The analysis of odour concentration trends at the WTP fenceline aimed at evaluating the possibility to define an alarm threshold for the odour concentration. Such alarm threshold should enable the prompt identification of plant malfunctions that could result in odour events in the proximity of the WTP. As first approximation, this threshold can

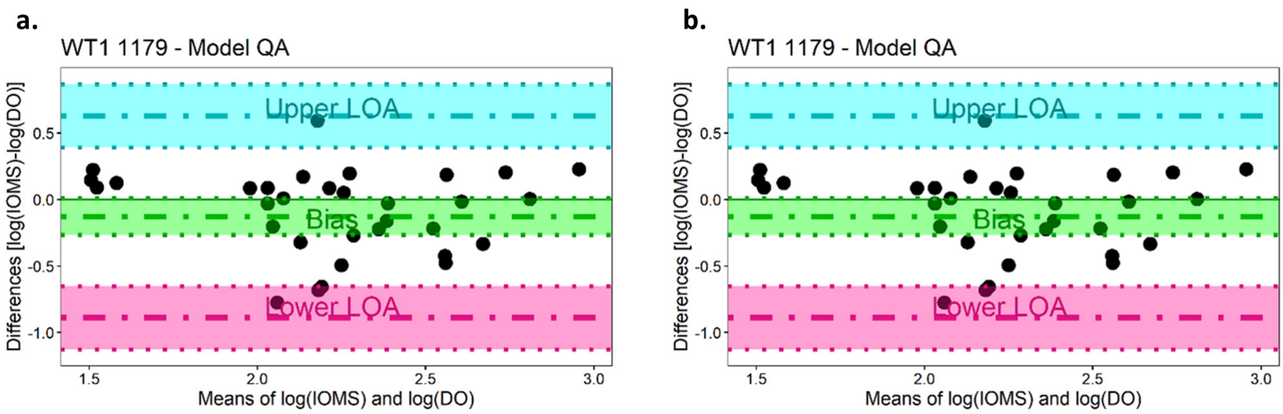

FIGURE 5: Bland-Altman plots obtained for WT1 1179 (a.) and (b.) WT1 1180 field testing results.

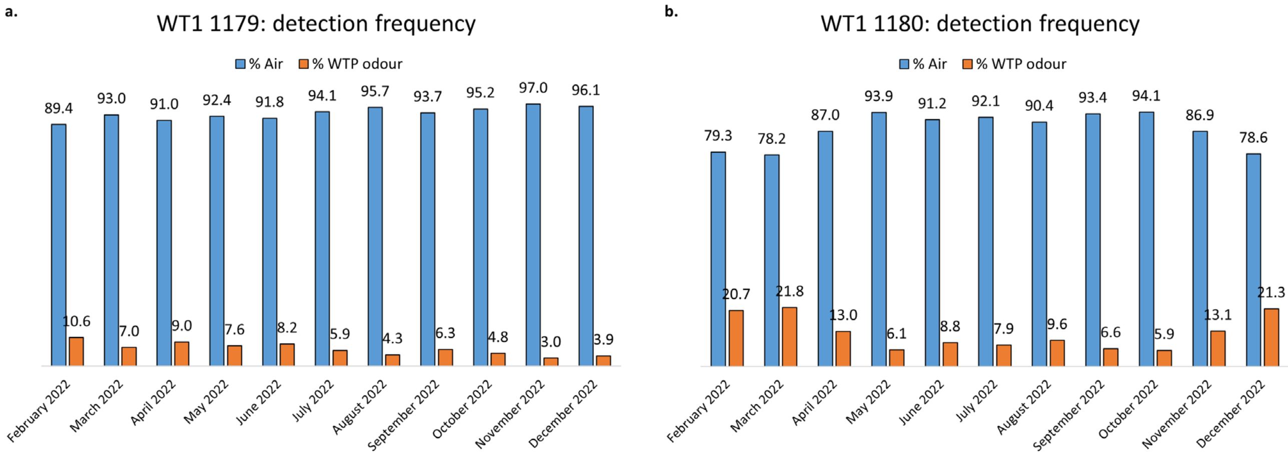

FIGURE 6: Odour impact assessed over the monitoring period: a. WT1 1179 and b. WT1 1180.

be defined in terms of a given percentiles of the odour concentration values assessed by the IOMS. Table 4 summarizes the 95th and 98th percentiles obtained on monitoring data. It is worthy to highlight that results here presented should be considered as preliminary, since the definition of a solid threshold for the odour concentration requires the analysis of IOMS predictions in combination with the meteorological conditions occurring during the monitoring phase. Moreover, the reports made by citizens should be considered to verify the existence of a correspondence between the odour nuisance perceived outside the WTP with the odour events detected at the plant fenceline.

3.2.2 Comparison of IOMS outcomes with citizens' odour reports

With the purpose of further validate IOMS predictions relevant to the monitoring period, the IOMS monitoring outcomes at the fenceline were compared with odour events reported by citizens living nearby the plant.

During the monitoring period, 37 odour events were reported by the citizens involved. In general, the reports of odours at the receptors located near the biodigester were recorded in the morning between 7 a.m. and 10 a.m. in conditions of calm winds or weak winds, which are like to worse the odour dispersion into the atmosphere.

Before performing the comparative analysis, citizens' odour reports were purged of odour events occurred under incompatible meteorological conditions (wind speed and direction not likely to favour the detection of odours from the plant at the reporting sites). Thus, 30 out of 37 odour events, listed in Table 5, were analysed. For each odour event, Table 5 reports the duration of the event indicated by citizens, the IOMS outcomes in terms of odour class detected and odour concentration, and a consideration about the agreement between IOMS and citizens' reports.

TABLE 4: 95th and 98th percentiles obtained on monitoring data recorded by WT1 1179 and WT1 1180 from February to December 2022.

IOMS	98° percentile [eq_ou$_E$/m^3]	95° percentile [eq_ou$_E$/m^3]
WT1 1179	201	174
WT1 1180	182	132

In general, the analysis pointed out a good correlation between the IOMS predictions at the plant fenceline and the odour events reported by citizens outside the plant. Indeed, only in 3 cases out of 30 odour events, both IOMS did not detect any odour in correspondence of odour events signalled by citizens. Thus, the odour events could be likely associated to external odour sources. Conversely, in most of the cases, at least one of the two instruments detected at the fenceline the presence of odours attributed to the WTP under exam, thereby confirming citizens' complaints. It is worthy to highlight that most of the times the IOMS provided information about the cause of the odour presence, thereby allowing a prompt intervention. As an example, in correspondence of odour events numbered from 8 to 12 in Table 5, both IOMS reported the highest odour concentrations at the fenceline (i.e., close to 300 eq_ou$_E$/m^3), which turned out to be a consequence of the malfunction of the ventilation system in the building devoted to the storage and pre-treatment of wastes. Therefore, properly trained IOMS can serve not only as system for controlling odorous emissions from WTP plant, but also as useful tools for the plant management.

4. CONCLUSIONS

The paper describes the realization of an IOMS network at the fenceline of a WTP plant for the real-time monitoring of its odorous emissions. Results obtained by means of validation tests in the field proved the reliability of the IOMS outputs, thus pointing out the potential of IOMS as tools for the real-time measurement of the odour concentration at plant fencelines. Indeed, IOMS predictions turned out to be in line with the odour concentration assessed by the reference technique for odour quantification, i.e., dynamic olfactometry (EN 13725:2022).

The analysis of the odour concentration trends measured at the WTP fenceline and the comparison of IOMS outcomes with meteorological conditions preliminarily proved the possibility to define an alarm threshold for the odour concentration at the fenceline, whose exceedance could

TABLE 5: Summary of odour events reported by citizens during the monitoring phase.

Citizens' odour report	Odour event duration [min]	WT1 1179 outcomes (type, concentration)	WT1 1180 outcomes (type, concentration)	Agreement
1	60	Organic, 160 eq_ou_E/m^3	Organic, 120 eq_ou_E/m^3	Yes
2	40	Organic, 150 eq_ou_E/m^3	Organic, 190 eq_ou_E/m^3	Yes
3	180	Organic, 200 eq_ou_E/m^3	Organic, 110 eq_ou_E/m^3	Yes
4	60	Air, 30 eq_ou_E/m^3	Biogas, 60 eq_ou_E/m^3	Yes
5	120	Air, 30 eq_ou_E/m^3	Biogas, 80 eq_ou_E/m^3	Yes
6	70	Organic, 120 eq_ou_E/m^3	Organic, 120 eq_ou_E/m^3	Yes
7	120	Organic, 120 eq_ou_E/m^3	Organic, 120 eq_ou_E/m^3	Yes
8	90	Organic, 280 eq_ou_E/m^3	Organic, 280 eq_ou_E/m^3	Yes
9	50	Organic, 170 eq_ou_E/m^3	Organic, 230 eq_ou_E/m^3	Yes
10	30	Organic, 170 eq_ou_E/m^3	Organic, 230 eq_ou_E/m^3	Yes
11	15	Organic, 180 eq_ou_E/m^3	Organic, 220 eq_ou_E/m^3	Yes
12	240	Organic, 180 eq_ou_E/m^3	Organic, 220 eq_ou_E/m^3	Yes
13	45	Air, 50 eq_ou_E/m^3	Organic, 110 eq_ou_E/m^3	Yes
14	30	Organic, 180 eq_ou_E/m^3	Organic, 100 eq_ou_E/m^3	Yes
15	20	Air, 30 eq_ou_E/m^3	Air, 20 eq_ou_E/m^3	No
16	140	Air, 30 eq_ou_E/m^3	Air, 20 eq_ou_E/m^3	No
17	90	Organic, 190 eq_ou_E/m^3	Organic, 110 eq_ou_E/m^3	Yes
18	15	Organic, 190 eq_ou_E/m^3	Organic, 110 eq_ou_E/m^3	Yes
19	20	Organic, 200 eq_ou_E/m^3	Organic, 120 eq_ou_E/m^3	Yes
20	120	Organic, 150 eq_ou_E/m^3	Organic, 90 eq_ou_E/m^3	Yes
21	60	Organic, 150 eq_ou_E/m^3	Organic, 90 eq_ou_E/m^3	Yes
22	120	Organic, 200 eq_ou_E/m^3	Biogas, 100 eq_ou_E/m^3	Yes
23	90	Organic, 210 eq_ou_E/m^3	Biogas, 30 eq_ou_E/m^3	Yes
24	120	Organic, 180 eq_ou_E/m^3	Air, 20 eq_ou_E/m^3	Yes
25	100	Organic, 150 eq_ou_E/m^3	Air, 20 eq_ou_E/m^3	Yes
26	80	Organic, 150 eq_ou_E/m^3	Air, 20 eq_ou_E/m^3	Yes
27	30	Organic, 150 eq_ou_E/m^3	Air, 20 eq_ou_E/m^3	Yes
28	150	Organic, 200 eq_ou_E/m^3	Air, 30 eq_ou_E/m^3	Yes
29	15	Air, 30 eq_ou_E/m^3	Air, 20 eq_ou_E/m^3	No
30	90	Organic, 200 eq_ou_E/m^3	Air, 30 eq_ou_E/m^3	Yes

be related to the occurrence of odour events outside the plant that may generate an odour nuisance problem. However, the definition of a robust and representative threshold (which may not necessarily be a fixed value but may vary with meteorological conditions to account for atmospheric dispersion) requires deeper investigations. Future developments of the project should also evaluate the stability over time of the monitoring network and consider the implementation of specific drift compensation models.

ACKNOWLEDGEMENTS

This research has carried out within the MUSA – Multilayered Urban Sustainability Action – project, funded by the European Union – NextGenerationEU, under the National Recovery and Resilience Plan (NRRP) Mission 4 Component 2 Investment Line 1.5: Strenghtening of research structures and creation of R&D "innovation ecosystems", set up of "territorial leaders in R&D.

REFERENCES

Bax, C., Sironi, S., & Capelli, L. (2020a). Definition and application of a protocol for electronic nose field performance testing: Example of odor monitoring from a tire storage area. Atmosphere, 11(4). https://doi.org/10.3390/ATMOS11040426

Bax, C., Sironi, S., & Capelli, L. (2020b). How can odors be measured? An overview of methods and their applications. In Atmosphere (Vol. 11, Issue 1). MDPI AG. https://doi.org/10.3390/atmos11010092

Bland, J. M., & Altman, D. G. (1999). Measuring agreement in method comparison studies.

Brancher, M., Griffiths, K. D., Franco, D., & de Melo Lisboa, H. (2017). A review of odour impact criteria in selected countries around the world. In Chemosphere (Vol. 168, pp. 1531–1570). Elsevier Ltd. https://doi.org/10.1016/j.chemosphere.2016.11.160

Cortes, C., Vapnik, V., & Saitta, L. (1995). Support-Vector Networks Editor. In Machine Leaming (Vol. 20). Kluwer Academic Publishers.

De Vito, S., Karatzas, K., Bartonova, A., & Fattoruso, G. (n.d.). Environmental Informatics and Modeling Environmental Informatics and Modeling Air Quality Networks Data Analysis, Calibration & Data Fusion.

John, A. T., Murugappan, K., Nisbet, D. R., & Tricoli, A. (2021). An outlook of recent advances in chemiresistive sensor-based electronic nose systems for food quality and environmental monitoring. In Sensors (Vol. 21, Issue 7). MDPI AG. https://doi.org/10.3390/s21072271

Kursa, M. B., & Rudnicki, W. R. (2010). Feature Selection with the Boruta Package. In JSS Journal of Statistical Software (Vol. 36). http://www.jstatsoft.org/

Oliva, G., Zarra, T., Pittoni, G., Senatore, V., Galang, M. G., Castellani, M., Belgiorno, V., & Naddeo, V. (2021). Next-generation of instrumental odour monitoring system (IOMS) for the gaseous emissions control in complex industrial plants. Chemosphere, 271. https://doi.org/10.1016/j.chemosphere.2021.129768

Panzitta, A., Bax, C., Lotesoriere, B. J., Ratti, C., & Capelli, L. (2022). Realisation of a Multi-Sensor System for Real-Time Monitoring of Odour Emissions at a Waste Treatment Plant. Chemical Engineering Transactions, 95, 139–144. https://doi.org/10.3303/CET2295024

Prudenza, S., Bax, C., & Capelli, L. (2023). Implementation of an electronic nose for real -time identification of odour emission peaks at a wastewater treatment plant. Heliyon, 9(10). https://doi.org/10.1016/j.heliyon.2023.e20437

Smola, A. J., Sch¨olkopf, B., & Sch¨olkopf, S. (2004). A tutorial on support vector regression *. In Statistics and Computing (Vol. 14). Kluwer Academic Publishers.