A WSN Energy-aware Approach for Air Pollution Monitoring in Waste Treatment Facility Site: A Case Study for Landfill Monitoring Odour

Lelio Campanile, Mauro Iacono, Roberta Lotito and Michele Mastroianni
Dipartimento di Matematica e Fisica, Università Degli Studi della Campania "L. Vanvitelli", Italy

Keywords: WSN, Sensor, Energy, Monitoring, Landfill, Odour, LoRaWAN.

Abstract: The gaseous emissions derived from industrial plants are generally subject to a strictly program of monitoring, both continuous or one-spot, in order to comply with the limits imposed by the permitting license. Nowadays the problem of odour emission, and the consequently nuisance generated to the nearest receptors, has acquired importance so that is frequently asked a specific implementation of the air pollution monitoring program. In this paper we studied the case study of a generic landfill for the implementation of the odour monitoring system and time-specific use of air pollution control technology. The off-site monitoring is based on the deployment of electronic nose as part of a specifically built WSN system. The nodes outside the landfill boundary do not act as a continuously monitoring stations but as sensors activated when specific conditions, inside and outside the landfill, are achieved. The WSN is then organized on an energy-aware approach so to prolong the lifetime of the entire system, with significant cost-benefit advancement, and produce a monitoring-structure that can answer to specific input like threshold overshooting.

1 INTRODUCTION

Anthropogenic environmental pollution is one of the greatest problems that is faced and is going to be faced by the actual generation. The pollution derived from industrial activities is related not only to the hazardous and/or accidental event (like oil spill) but also to the regular process procedures. Indeed, almost all the human activity emits heterogeneous pollutant into the environment: the magnitude depends on the emission rates and on the chemical composition of the effluent. In such complex scenario, in order to decrease the impact and restore the environmental quality, worldwide governments and environmental agencies have introduce, in their permitting protocols, procedures and threshold limits based on the Best Available Techniques (BAT) that have to be respected by industrial plant (European Commission, 2010).

Apart from this imposition, monitoring the results obtained by developing a Pollution Monitoring Program (PMP) for the operating time is also important. The PMP is edited according to the industrial plant process and specific pollutant emission rate: it is approved as part of the permitting procedure and applied during the industrial lifetime. Usually the monitoring process is performed at specific time and location at the emitting source (i.e. x chemical compound, every six months, to be measured at the stack). Otherwise, to establish the impact at near receptors, mathematical models are commonly used: the input data for these systems are real data gathered after a specific event occurred. In both cases, if during the monitoring there is a non-conformity between the threshold authorised and the value measured, the plant managers must perform any procedures to reduce the impact. In the worst-case scenario, the plant is shutted down until the permitting revision.

Nowadays the necessity to have a continuous monitoring system is raised by the plant managers, not only to cope with the administration and local population but also to be able to perform the necessary procedures ahead of time. A typical example is the one regarding the waste treatment facilities: these plants are not well approved by the near population that suffers of the so called Not In My Backyard (NIMBY) syndrome (Xu and Lin, 2020), so people understand the necessity to complete the integrated waste management system, and are willing to pay the service, but they do deny the proximity of these plants to their homes. Therefore, the manager and plant operators are called to demonstrate the respect of the imposed limits, and so their impact, even outside the PMP time.

In this needing scenario of an efficient monitoring

Campanile, L., Iacono, M., Lotito, R. and Mastroianni, M.
A WSN Energy-aware Approach for Air Pollution Monitoring in Waste Treatment Facility Site: A Case Study for Landfill Monitoring Odour.
DOI: 10.5220/0009819005260532
In *Proceedings of the 5th International Conference on Internet of Things, Big Data and Security (IoTBDS 2020)*, pages 526-532
ISBN: 978-989-758-426-8

system, ta Wireless Sensor Network (WSN) can be employed. A WSN is a network formed by dislocated nodes, linked between them by wireless transmissions, so as to collect data from the surrounding environment according to installed sensors (Aiswariya Jonsi et al., 2018; Bonastre et al., 2012). Its use in the environmental field is quite appealing, although some problems have been found for real applications. Indeed, if in the field of waste management systems most of the works focused on the development of a smart bins collecting system in order to avoid the storage overtime and find the best collecting routes (Narendra Kumar, 2014; Hannan et al., 2015), the use of WSN for air quality monitoring developed in the last decade shows various results according to the developed architecture and sensors technical characteristics. Consequentially, the marriage between WSN and the Waste Pollution Monitoring Program (wPMP) is not always a happy-ending one. On one hand there is the facility manager who wants a perfect system, with specific characteristics such as cost-contained and fast-answer capabilities, on the other hand, a WSN-based system has to cope with problems like energy supply and network modulability. Hence, the efficiency of a WSN-based system depends on its capability to identify or predict a pollutant event, report it to the facility manager and apply emergency procedures on tight deadlines.

On the basis of these requirements, Low Power Wide Area Networks (LPWAN) acquire great importance as emerging approach to Internet of Things (IoT) and WSN: its main objective is to provide energy efficiency, extended coverage and scalability for end user devices such as sensors and actuators.

LPWAN seems to be a logic choice for the aim of this work as it provides wireless connectivity and long range transmissions using a star topology in the sub-Ghz frequency bands, with the major advantage of a low power consumption which should ensure a long sensor lifespan without the need to recharge the battery.

Among the LPWAN technologies for IoT, there is a growing interest for Long Range Wireless Area Network (LoRaWAN), since it is a long range (from 3-5Km in urban scenarios to 15Km in rural scenarios), low power wide area network operating in the license free sub-GHz bands (Centenaro et al., 2016).

This work presents a proof-of-concept architecture for monitoring gaseous pollutants from waste facility plants, based on a case studio, using the LoRAWAN standard. The main contribution of this architecture is an evaluation of the application of LoRAWAN in such systems to obtain better network performances in term of robustness, reliability and sensor battery life.

After this introduction, the paper is divided in five sections. Section 2, namely Related Works, analyzes what has been done in this specific field. Section 3 states out the motivation that drove us and a particular case study for which we describe a specific system architecture in section IV. Finally, conclusions are drawn in section 5. A list of the used acronyms is provided at the end of this paper.

2 RELATED WORKS

The application of the WSN technology to air monitoring is widely studied but not yet fully developed. Indeed, the field applications of a specific system have to face various problems like cost and energy supply (Lee et al., 2012). According to the confronted problem, the scientific literature is wide (Idrees and Zheng, 2020).

In terms of environmental industrial monitoring, a first distinction can be made between on-site and off-site monitoring. The on-site monitoring procedures are described as the monitoring protocol performed inside the plant boundary: sensors are so deployed near the emitting sources or around product units. This system is used to qualify and quantify the local concentration and to develop secondary procedures according to the emission characteristics. Some examples of this kind of system are those related to landfill sites in which both non-continuous (Mélo et al., 2019) and continuous systems have been studied (Beirne et al., 2010).

The off-site monitoring concerns the evaluation of the impact generated by a specific source near sensitive receptors, like city centers and natural environment. In this group works are included about air quality monitoring from a smart cities point of view (Pauchuri, 2018; Alejandro et al., 2015; Carminati et al., 2019).

Overall, both types of monitoring systems share some common characteristics, like the large number of nodes deployed, and the problem of prolonging network lifetime due to energy consumption. On this last perspective, some works introduced core network nodes into the system with a method based on a jointly energy-efficient development (Fadi M. Al-Turjman, 2015) or by the use of modified algorithms based on nodes clustering (Behera et al., 2020).

3 WORK MOTIVATION AND CASE STUDY SETUP

One of the newest problems that has to be handled by the industrial facility manager is the odour impact generated by the normally conducted process. This is particularly true with the waste treatment facilities where, from the collecting procedures to the process itself, there is a high probability of emission of volatile organic compounds (VOCs) and other chemicals, like hydrogen sulphide, with a low detection threshold.

The odour detection threshold (DT) is the concentration at which nearly 50% of the population can detect the chemical odour, so that people have a sensing answer to it. Most of the time the limit imposed by the permitting license overcomes the DT limit: in this case, even if the facility is consistent with the license, it still impacts the surrounding human environment.

The actual odour monitoring, based on the chemical approach, concerns the application of a compliance system and the use of specific sensors.

The compliance system works on a call-after-impact model. Firstly, when a nuisance event occurs, the impacted receptors call the facility administration giving information following the what-where-when scheme, as so to rely data about what kind of odour they smelled, where they sensed it and when. The second step is to match the compliance with wind speed and direction: if the match succeeded, the compliance is accepted. When a facility receives consecutively compliance, it has to apply all the procedures in order to reduce the emission even if these procedures have a high cost. In the worst-case scenario, the facility is closed by the local authorities until the whole industrial process and PMP is reviewed. Obviously, this strategy is applied after the odour event occurred without any possibility for warning the population nor activating air control protocols to overthrow the pollutant concentrations. Since the Air Pollution Control technologies (APC) are usually time-cost depending and their application on large surfaces can be cost relevant in term of maintenance, and their use can also produce a large amount of waste that has to be disposed later on, the use of specific-APC has to be accurate and time-specific in order to be effective, efficient and cost-contained.

Another way of odour monitoring is the use of specific sensors called electronic nose (E-nose): nowadays these sensors are used as a continuous monitoring station deployed along the facility boundary. The sensors are calibrated, during a so-called training procedure, on the basis of specific pollutants emitted under control by the source (industrial emission footprint). When they record a concentration above an imposed limit, the recording hour is labelled as *odour peak event*. One of the problems related to the use of E-noses is their failure in distinguishing the background concentration – defined in this case as the environmental concentration not correlated to the emitting source – and the concentration derived from the facility.

The contribution of this paper consists in the presentation of a WSN system that can answer the facility management needs to have a secure and efficient system that can automatically activate the APC protocol only when a specific odour event occurs and before the pollutants can reach the near sensitive receptors. For this reason, we set up a case study for a generic landfill that still accepts organic waste, so that it produces VOC with low DT during the normal working procedures. The landfill site is equipped with a common meteorological station – normally used for the odour compliance system – with a logging period of 1h. The nearest city is located 3 km far from the site at the most frequent wind direction. To reduce variables, there is no other industrial plant that can emit the same pollution footprint as the landfill: nonetheless, local facilities or artisans impact the air quality by producing some of the same chemical compounds. In this situation, the odour nuisance can be produced either from the landfill or from other emitting sources.

In this scenario, the WSN needs to discern the impact due to the landfill and the impact due to other sources, so that the APC protocols are activated only when a confirmed odour-process is performed inside the landfill and before the pollution reaches the receptors.

4 SYSTEM ARCHITECTURE

The entire system is composed of three layers, characterized by different nodes and roles, that exchange information with each other and have different energy consumption profiles. The first layer is composed by the base station and three nodes, equipped with different sensors, continuously recording data of compound X concentration at the emitting source $[X]_s$, the wind characteristics $W_{direction}$ and W_{speed}, and the compound X background concentration $[X]_{bk}$: for this layer energy supply is guaranteed by the plant itself, so that the death of a node can be only related to actual faults.

The second layer is formed by head cluster nodes that, apart from the normal sensing procedures, have the role to activate clustered nodes (third level) when needed and collect acquired data. Hence, each head

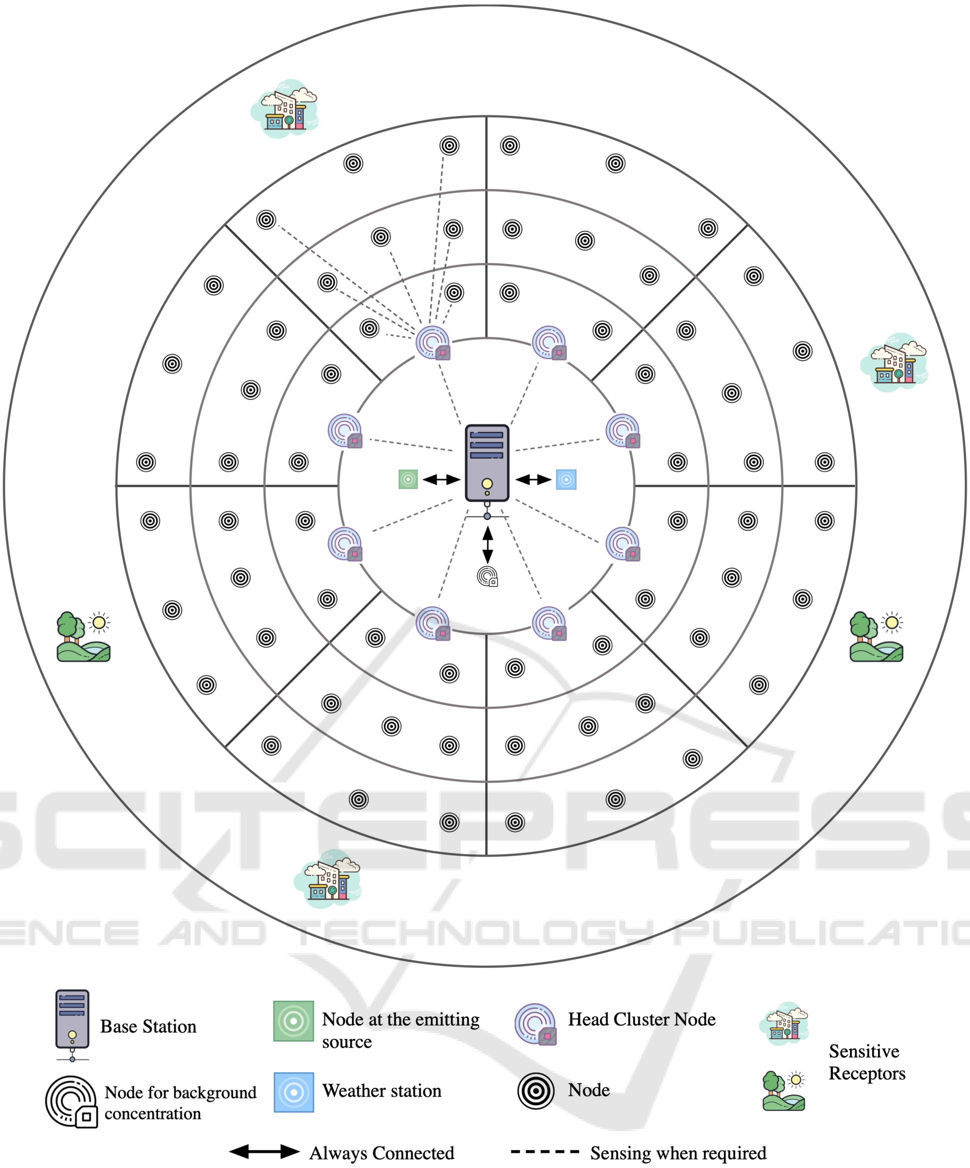

Figure 1: General view of the system.

cluster node HC and node N obtains a concentration of the X compound as $[X]_{HC}$ and $[X]_N$.

Figure 1 shows the network where the HCs are dislocated around the facility so to cover the preferential wind directions; Figure 2 shows a detail.

4.1 LoRaWAN Protocol

The LoRaWAN protocol is an open protocol based on the proprietary LoRa physical layer. The LoRaWAN protocol is developed by LoRa Alliance and described in (Sornin et al., 2015).

LoRaWAN networks are organized according to a star-of-stars topology, in which we can identify three main components:

- *End Devices* (*ED*);
- *Gateways* (GW);
- a *Network Server* (NS);

In this topology, represented in Figure 3, each ED transmits messages to one or multiples GWs and each GW is connected to the NS by a stable high bandwidth link. The responsibility of filtering duplicate messages from the EDs, through the GWs, is in charge to the NS.

In our architecture HCs and N correspond to Lo-

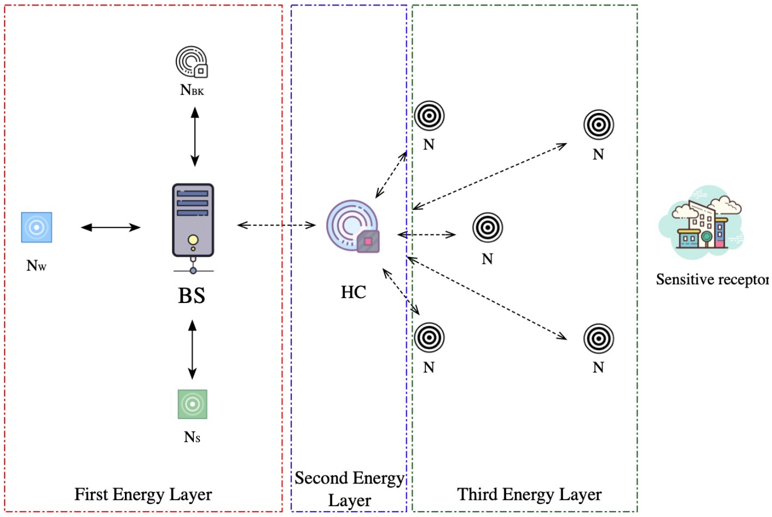

Figure 2: Detail view of the system.

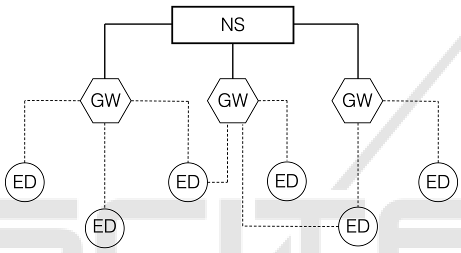

Figure 3: LoRaWan architecture.

RaWAN EDs, while the NS is located near the Base Station. The Gateways could be unique and also be placed close to the BS or, in more complex scenarios where more redundancy is needed, they could be placed close to the HCs.

All the EDs in our architecture are in *Class A* mode, which according to (Sornin et al., 2015) is the default operation mode for LoRaWAN devices. In this mode a ED transmits the packets coming from the upper layer on the wireless channel in an asynchronous way. After the transmission, the ED wait for any command or packet returned by the NS. Using this operational mode, devices should keep the radio transceiver off as long as possible to save battery power.

4.2 Activation Model

The condition for the activation procedure is described as following.

Inside the landfill, the first condition to activate the network is:

$$\begin{aligned} &[X]_s \geq DT \\ &t = 30\,min \end{aligned} \tag{1}$$

then BS activates the HC at the preferential wind direction at time t. The 30 minutes default-time is based on the definition of odour peak, namely odour-hour during which the odour is sensed by the population: the restrictive time is chosen as a *safety guard* procedure.

The HC activated at the specific direction $\alpha°$ at which the winds blows to and starts sensing the concentration, $[X]_{HC}^{\alpha°}$; therefore the second condition has to be achieved. If:

$$\begin{aligned} &[X]_{HC}^{\alpha°} - [X]_{bk} \geq DT \\ &t = 30\,min \end{aligned} \tag{2}$$

then, a further node at $\alpha°$ direction is activated, otherwise the procedure is stopped and the HC returns to its idle state until a new alert is stated.

The new activated nodes have to fulfill the second condition for t equal to the minimum amount of time needed for the pollutant to reach the receptor:

$$\begin{aligned} &[X]_{N}^{\alpha°} - [X]_{bk} \geq DT \\ &t = \frac{d}{W_{speed}} \end{aligned} \tag{3}$$

where d is the distance between the last deployed node and the sensitive receptor in that direction.

The procedure continues to activate nodes until the last is reached: if the third condition is satisfied, then the APC procedure at the landfill is activated. In the following the activation procedure described above in programming metalanguage:

```
X_s: float = 0
X_bk: float = 0
t: int = 30
X_hc: float = 0
X_n_th: float = 0
W_speed: float = 0
threshold: float = 10
distance_node: int  = 0
t_n: int = 0
wind_direction: [wdir] = None

wind_direction  = get_wind_direction
    ()
wind_speed = get_wind_speed()

while True:
    if X_s >= threshold:
        hc_nodes = get_hc_nodes(
    wind_direction)
        for hc_node in hc_nodes:
            activate(hc_node, t =
    30)
            X_hc =  get_sensor_value
    (HC_node)
            X_hc_th = X_hc - X_bk
            if X_hc_th >= threshold:
                nodes = get_nodes(
    wind_direction)
                for node in nodes:
                    distance_node =
    get_distance(node)
                    activate(node, t
     = distance_n/wind_speed)
                    X_n =
    get_sensor_value(node)
                    X_n_th = X_n -
    X_bk
                    if X_n_th >=
    threshold:

    activate_APC_procedure()
```

Listing 1: Activation Procedure.

5 CONCLUSIONS AND FUTURE WORKS

In this work we presented a proof-of-concept architecture for monitoring gaseous pollutants, specifically for odourant compounds, in the case study of a landfill site. The procedure of activation of each node is based on the fulfillment of three conditions to be acquired both on-site and out-site so to activate the air pollution control system to minimize the emission. The adopted network protocol is LoRaWAN in order to prolong the lifetime of the entire network and to satisfy the specific requirements. Future work will aim to simulate the architecture here proposed by using the ns-3 simulator, because it is widely used in WSN simulations as you can clearly see in (Campanile et al., 2020), so to understand its efficiency in terms of energy consumption and throughput.

ACKNOWLEDGEMENTS

This work has been partially funded by the internal competitive funding program “VALERE: VAnviteLli pEr la RicErca” of Università degli Studi della Campania “Luigi Vanvitelli”.

REFERENCES

Aiswariya Jonsi, S., Rani, V., and Suseela, S. (2018). Challenge, technologies and components of Wireless Sensor Network. *n International Journal of Engineering Research & Technology*, Special Issue.

Alejandro, V., Ferrero, R., Gandino, F., Montrucchio, B., and Rebaudengo, M. (2015). On the design of distributed air quality monitoring systems. *AIP Conference Proceedings*, 1702(1):180014.

Behera, T. M., Mohapatra, S. K., Samal, U. C., Khan, M. S., Daneshmand, M., and Gandomi, A. H. (2020). I-SEP: An improved routing protocol for heterogeneous wsn for iot-based environmental monitoring. *IEEE Internet of Things Journal*, 7(1):710–717.

Beirne, S., Kiernan, B. M., Fay, C., Foley, C., Corcoran, B., Smeaton, A. F., and Diamond, D. (2010). Autonomous greenhouse gas measurement system for analysis of gas migration on landfill sites. In *2010 IEEE Sensors Applications Symposium (SAS)*, pages 143–148.

Bonastre, A., Capella, J., Ors, R., and Peris, M. (2012). In-line monitoring of chemical-analysis processes using Wireless Sensor Networks. *TrAC Trends in Analytical Chemistry*, 34:111 – 125.

Campanile, L., Gribaudo, M., Iacono, M., Marulli, F., and Mastroianni, M. (2020). Computer network simulation with ns-3: A systematic literature review. *Electronics*, 9(2):272.

Carminati, M., Kanoun, O., Ullo, S. L., and Marcuccio, S. (2019). Prospects of distributed Wireless Sensor Networks for urban environmental monitoring. *IEEE Aerospace and Electronic Systems Magazine*, 34(6):44–52.

Centenaro, M., Vangelista, L., Zanella, A., and Zorzi, M. (2016). Long-Range Communications in Unlicensed Bands: the Rising Stars in the IoT and Smart City Scenarios. *IEEE Wireless Communications*, 23.

European Commission (2010). Industrial emissions directive.

Fadi M. Al-Turjman, Hossam S. Hassanein, M. I. (2015). Towards prolonged lifetime for deployed WSNs in outdoor environment monitoring. *Ad Hoc Networks*, Volume 24, Part A:172–185.

Hannan, M., Mamun, M. A. A., Hussain, A., Basri, H., and Begum, R. (2015). A review on technologies and their usage in solid waste monitoring and management systems: Issues and challenges. *Waste Management*, 43:509 – 523.

Idrees, Z. and Zheng, L. (2020). Low cost air pollution monitoring systems: A review of protocols and enabling technologies. *Journal of Industrial Information Integration*, 17:100123.

Lee, K., Murray, D., Goodfield, D., and Anda, M. (2012). Experiences and issues for environmental engineering sensor network deployments. In *2012 6th IEEE International Conference on Digital Ecosystems and Technologies (DEST)*, pages 1–6.

Mélo, . C. A., Freire, R. C. S., Santana, E. E. C., Gurjão, E. C., and Bernardo, M. G. (2019). A low cost data acquisition system based on wireless sensor networks for environmental monitoring in landfills. In *2019 4th International Symposium on Instrumentation Systems, Circuits and Transducers (INSCIT)*, pages 1–5.

Narendra Kumar, G., C. S. N. K. (2014). Efficient garbage disposal management in metropolitan cities using VANETs. *Journal of Clean Energy Technologies*, 2(3):258 – 262.

Pauchuri, V.L., R. D. (2018). IoT for monitoring carbon monoxide (CO) emissions using wireless sensor networks in smart cities. *International Journal of Engineering & Technology*, 7:1045 – 1050.

Sornin, N., Luis, M., Eirich, T., Kramp, T., and Hersent, O. (2015). LoRaWAN specifications, LoRa Alliance, San Ramon, CA, USA.

Xu, M. and Lin, B. (2020). Exploring the "not in my backyard" effect in the construction of waste incineration power plants - based on a survey in metropolises of China. *Environmental Impact Assessment Review*, 82:106377.

LIST OF ACRONYMS

BAT. Best Available Techniques

PMP. Pollution Monitoring Program

NIMBY. Not In My Backyard

WSN. Wireless Sensor Network

wPMP. waste Pollution Monitoring Program

VOC. Volatile Organic Compound

DT. Detection Threshold

APC. Air Pollution Control

LPWAN. Low Power Wide Area Networks

LoRaWAN. Long Range Wireless Area Network