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Aerosol exposure and risk assessment for green jobs involved in biomethanization

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ABSTRACT

Anaerobic digestion is a consolidated biotechnology able to produce renewable energy from biomasses. In the European countries, quick growth of biogas production from different organic matrices including wastes has been observed. In relation to the characteristics and quantity of the anaerobic digestion of feedstock, there are different technologies, advantages and criticisms. An accurate occupational risk assessment and development of management tools for green jobs involved in the anaerobic digestion plants are due. The aim of this work is to assess the aerosol exposure for such workers, focusing on the bioaerosol risk. Full scale plants for the treatment of organic municipal waste, waste water treatment sludge, agro zootechnical and food producing byproducts were involved for this purpose. The bioaerosol levels were monitored during activities through culturing and biomolecular methods; moreover, the sub-fractionated PM10 and carried endotoxins were measured in different plant areas. Global microbial contamination is higher (> 5000 UFC/m^3) in the area where organic wastes are handled and pretreated, both for organic municipal waste plants - with a bacterial prevalence - and agro zootechnical plants - with a fungi prevalence. Moreover, the microbial contamination is higher where organic municipal waste is present in respect to other biomasses (ANOVA $p < 0.01$). Numerous pathogens are carried by the aerosol. HAdV-4 presence is lower than LOQ (50 gene copies/m^3) in all the samples. Environmental PM10 reached the 280 μg/m^3 level including PM3 for 78%. Endotoxin pollution overtakes the 90 EU/m^3 limit sporadically. Personal PM4.5 reached 10 mg/m^3 only for maintenance technicians in the pretreatment area for organic municipal waste. The risk can be evaluated under a quantitative and qualitative point of view highlighting risk management improvement for anaerobic digestion plants.

1. Introduction

Green Jobs refers to all occupational employment - from agriculture to administration and services - that sharply contributes to preserve or to restore environmental quality in terms of pollution impact removal, reduction or mitigation. The green jobs diffusion is in line with the stimulus to adopt more ecological production methods to limit global warming and to avoid irreversible climate change (WHO, 2014). Moreover, both increasing energy needs and the price of raw materials have been factors in the diffusion of such jobs. It has been estimated that in 2016, approximately 8 million people worldwide worked in renewable bioenergy (IRENA, 2017), and by 2020, 120,000 new net jobs are expected in the whole-EU bio-anaerobic sector (IEA, 2017).

Biomethanization consists of the production of methane from biomasses through a biological anaerobic process. The environmental advantage of such biotechnology includes the wide spread of biomethanization, particularly in the agro-zootechnic and waste treatment sectors. Anaerobic digestion is a process in which microorganisms breakdown organic biomasses in anaerobic or micro-aerophilic conditions (Díaz et al., 2011). This process leads to the production of biogas, a mixture mainly composed of methane and carbon dioxide with other trace compounds (Ali Shah et al., 2014). According to qualitative standards of the European certification, it has recently become possible (after an upgrading process and a cleaning phase) to turn biogas into

Abbreviations: WWTP, Waste Water Treatment Plant; AD, anaerobic digestion; OFMSW, Organic Fraction Municipal Solid Waste; ALB, agricultural and livestock biomasses; FFbP, food and feed producing by-products; COPD, Chronic Obstructive Pulmonary Disease; GIMC, Global Index of Microbial Contamination; IMC, Index of Mesophilic bacteria Contamination; PNOC, Particulate Not Otherwise Classified

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biomethane; this can be used for vehicle fuels, natural gas net introduction, residential heating and so on (Scholz et al., 2013). Moreover, in many countries, including Italy, a subsidy is recognized for specific end uses and for specific biomasses such as wastes and production by-products (Wall et al., 2017). There are > 6000 active biogas plants in modern Europe (European Bioplastics, 2015), within which various occupational and environmental risks can be identified; these include explosive, chemical and biological risks (ECORYS, 2012). In general, there are not new risks, but risks with different magnitudes in relation to the source and to the quantity of the input biomasses. Such peculiarity is relevant, especially for biological agents and bioaerosols, which are generally underestimated in the occupational settings (Douglas et al., 2017). Bioaerosols include particles with a biological origin such as microorganisms, microorganism fragments such as endotoxins and biological-derived particles such as animal fur (ACGIH, 2006). They can produce adverse human health effects, such as transmissible diseases, decline of lung functionality and respiratory symptoms (De Vizcaya-Ruiz et al., 2006). On the other hand, bioaerosol compositions are not well-known, and surveillance data are weak to describe the real human health impact on groups generally composed of few individuals. (Douglas et al., 2016; Walser et al., 2015; Wéry, 2014). Furthermore, biomass treatments produce much fine particulate matter, which is also correlated to relevant effects on human health. Some of these effects – such as, primarily, COPD and cardiovascular diseases - are also correlated to bioaerosol exposure.

The increment of the air temperature rise recorded in the last years - 0.2 °C per decade (World Meteorological Organization, 2017) - worsens the potential bioaerosol burden in relation to human health effects.

The aim of this study was to evaluate the biological risk of biogas plants by identifying the green jobs involved, measuring the bioaerosol generated, assessing the worker exposure and finally proposing a semi-quantitative risk assessment method.

2. Material and methods

2.1. Anaerobic digestion plants

In Italy, the number of anaerobic digestion plants has overtaken 1550 units. Moreover, the volume of biogas produced in 2015 is 5-fold higher in respect to 2007. The increment is more marked in the last 5 years and for the production of the final product biomethane, including the cleaning and up-grading steps (Sun et al., 2015). There are 167 biogas plants local to Piedmont (ARPA Piemonte, 2017), and these involve approximately 800 green jobs exposed directly to biological risks (3.2 persons/100 km^2); moreover, in Italy, the future perspective accounts for a total 25.000 green jobs involved in AD processes. This is double the green jobs measured to be involved in such sectors during 2015 (Green Report, 2015). Biogas plants can use different kinds of biomasses, including agricultural and livestock biomasses (ALB), food and feed producing by-products (FFbP), waste water treatment sludge (WWTS) and the organic fraction of municipal solid waste (OFMSW). In this study, we considered 3 types of plants in relation to the origin of the biomasses introduced into the digester: 3 plants that use ALB (1 in thermophilic and 2 in mesophilic conditions), 1 plant that mainly uses WWTS (mesophilic) and 1 plant that mainly uses OFMSW and FFbP (thermophilic conditions). The process flowcharts of the three types of plant are reported in Supplementary data 1 (a-b-c).

In ALB plants, the input matrix (solid vegetal origin biomasses and liquid cattle manure) is located in a storage tank and loaded into the hopper, directly or with the tractor aid, where the biomasses can directly reach the digester. In this type of plant, the greatest part of the workplace is outdoors, though these conditions are partly influenced by the different distances of plants from highly populated areas. Generally, in ALB plants, few workers are involved in anaerobic digestion management: on average, 4 workers, ranging from 1 to 7 workers in relation to different plants. When there is only 1 worker in the workforce, a large number of operations are allocated to outsourcing. The ALB plants have a nominal installed electricity of 1 MW. All the ALB sampling sessions were conducted during the summer of 2016, involving 9 full sampling days. During each sampling day, we conducted samplings both in the morning and in the afternoon (Table 1).

In the WWTS plant, the AD input biomasses are sludge from primary and secondary sedimentation. In OFMSW treatment plants, solid biomasses are disposed of indoors in open tanks and then, mechanically pre-treated, from the unpacking to the grinding, mixing and heating. They reach the digester through pipes. Mechanical pre-treatment is generally only introduced for OFMSW, while for WWTS only thickening is included.

The number of AD workers in WWTS and OFMSW plants is on average 13, ranging from 7 to 20. The installed electrical capacity is on average 3 MW. The sampling session are conducted from August 2016 (OFMSW) to February 2017 (WWTS), involving 6 full sampling days. During each sampling day, we conducted samplings in the morning and in the afternoon, they are detailed on Table 1.

In all the involved plants, the produced biogas is recovered and piped in a co-generation system to obtain heat and electricity. System upgrades to produce biomethane were being implemented, even if they were not yet operative, during the sampling period.

The digested sludge can be used differently in relation to its hygienic characteristics (EU directive 1535/2015 and regulation EU 142/2011). In Italy, the latest law is the D.M. 5046 and the update of the D. Lgs. 75, both published on 2016. In the no-waste AD plants, sludges - often dewatered - can generally be used directly as fertilizer, taking into account the nitrate directives (European Commission, 1991) and the common agricultural policy (European Commission, 2010). On the other hand, when wastes are used, the output biosolids can be

Table 1
Description of the collected samples: sampling site, work shift, number of samples both in PM filters and microbiological plates.

Where		Work shift	N of filters*	N of plates[a]
OFMSW	Pre-treatment control room (INPUT)	Morning	1C	42
		Afternoon	1C	/
	Storage and loading, including pretreatment (INPUT)	Morning	5 A 1 B 3C	40
		Afternoon	5 A 1 B 2C	40
	Digestate OUTPUT	Morning	5A 1 B 3C	40
		Afternoon	5 A 1 B	40
ALB	Storage and loading (INPUT)	Morning	30 A 6 B	211
		Afternoon	15 A 3 B	85
	Digestate OUTPUT	Morning	25 A 5 B	248
		Afternoon	15 A 3 B	206
WWTP	Storage and loading (INPUT)	Morning	5 A 1 B 4C	42
		Afternoon	5 A 1 B	42
	Digestate OUTPUT	Morning	5 A 1 B 2C	42
		Afternoon	5 A 1 B	42

* A = PM subfractions; B = PM < 0.49; C = PM 4.5. Each C filter corresponds to a worker.
[a] Included LMA plates.