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Analysis of accidents in biogas production and upgrading

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ABSTRACT

In the last 10 years biogas production tripled, resulting in an increasing number of related facilities. The present study addresses safety issues of such activity on the basis of past accident analysis. A database of accidents related to biogas supply chain was created and data on 169 accidents were collected from different literature sources. Trends, causes of accidents, scenarios, and consequences were analysed also using Multi Correspondence Analysis to obtain correlations between causes of accidents and scenarios. The study showed that almost 12% of the past accident analysed can be classified as major accidents. The number of accidents is growing faster than biogas production. A risk assessment was carried, based on the analysis of accident frequencies and consequences. A non-negligible risk profile, typical of ALARP zone, was obtained for this industrial sector, revealing an emerging risk issue. The main lessons learnt are the need of developing and adopting specific safety standards and of improving the safety culture and risk awareness in the biogas production sector.

1. Introduction

The role of biogas is becoming crucial in the panorama of sustainable development. In fact, the worldwide bioenergy demand is strongly increasing in recent years [1], and the forecast indicates a further increase up to 2035, as a result of the support strategies for the reduction of air pollution implemented by several governments around the world [2]. As an example, in Italy the number of biogas production sites more than doubled in 2013, growing from 521 to 1264 [3], thanks to the incentives for small-scale facilities allocated by the Ministry of Economic Development [4].

In general, the contribution of all types of biomass to energy production is increasing its importance [5]. Although solid biomasses are still leading the market of bioenergy production, biogas is quickly developing in several countries [3]. Indeed, even if Europe is the most important producer of biogas, the biogas sector is of great interest also in the U.S., with 2200 installed plants in 2013, and it is developing in Latin America, Asia, and Africa [3]. In China and India, the biogas sector is quickly emerging.

Even if an accurate estimation is not available for worldwide biogas production [3], data can be found for the European market, where more than 13800 biogas plants were running at the end of 2012, with a corresponding installed capacity of 7.5 GW. The leading country for biogas production in Europe is Germany [6].

Despite the widespread installation of biogas plants, the safety of such energy supply was not specifically addressed to date and there is a lack of dedicated safety standards aiming at the control of hazards and risks associated to biogas production and upgrading. Most of the biogas production plants are of small or medium scale, therefore falling below the thresholds for the application of legislation aimed at the control of major accident hazard, as the Seveso Directive [7]. Recent studies in the literature aimed at the exploration of biogas safety issues [8–10] suggest the need for specific and harmonized international standards for biogas production and upgrading [11].

Several authors remarked the progress that process safety in the biogas sector could achieve thanks to the sharing of experience, feedback and results of accident investigations [12–14]. This may also contribute to improve the safety culture in the biogas field, that is presently limited as pointed out in different studies [8,12,15].

Learning from past accidents and raising the risk awareness in this emerging energy sector is crucial for a safe and sustainable exploitation of such a renewable resource. In this perspective, the present study focused on the collection and analysis of accidents in the biogas sector. The analysis was carried out aiming at the

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characterization of the possible accident scenarios, of their causes and of their consequences.

Multiple Correspondence Analysis [13,16] was applied to better understand the causes of the different accident scenarios. The accident trends were also examined, in order to understand the safety of the biogas sector and to obtain some indications on the current risk figures.

2. Methodology

2.1. The database

The first step of the study was the collection of data on past accidents in the biogas sector. This was carried out consulting the following sources:

- scientific literature;
- specific sources and accident databases, such as the Loss Prevention Bulletin (IChemE) [17], the ARIA Database [18], the MHIDAS Database [19], OSHA web site [20], the eMARS Database [21] and the ZEMA Database [22];
- information reported on the web, in particular on newspaper websites.

Specific criteria were defined to search accident records. In particular, the keyword "biogas" was associated (logical "AND") to one of the following keywords: "accident", "incident", "explosion", "fire", and "release". The search was carried out translating the terms in several European languages (i.e. English, Italian, French, German, and Spanish).

The information gathered was organized in a specifically developed database whose structure is summarized in Fig. 1. Some fields of the database were filled in as free text fields (such as date, summary, documentation, links, …), whereas others are categorical variables (i.e. cause, scenario, number of injuries or fatalities, marked in red in Fig. 1). Multiple Correspondence Analysis was applied to the latter fields, as explained in the following.

A total of 169 accidents entries were collected and included in our database. Table 1, reporting the content of the summary field for the events for which a more detailed description was available, provides an example of the content of the database.

2.2. Multiple Correspondence Analysis

As already mentioned, in the database several variables are categorical (qualitative, e.g. "Cause" and "Scenario") and in order to analyse possible correlations between them, a Multiple Correspondence Analysis (MCA) was performed.

MCA is a statistical method for multidimensional analysis used to correlate and visualize different nominal categorical data of a data set [13,16,23]. The result is usually provided in the form of a map of points (*factorial map*) that represent the similarity, in terms of proximity in the plot, between the variables chosen for the analysis. In the present study, the causes of accidents and the final scenarios were selected and analysed.

Some basic parameters need to be defined in order to understand the resulting plots:

- *profile* (i.e. frequency, calculated as number of events divided by the total number of events) of variables forming rows and columns of the contingency table. At this step of the analysis, the categorical variables were organized in a numerical form, in other words, a *contingency table* was created. In the present analysis, the columns of the table were the types of causes of accidents (as discussed in the following) and the rows were the scenarios.
- *centroid*, representing the weighted average position (i.e. weighted average of the profiles);
- *chi-square distance*, measuring the relative proximity between points in the factorial map;
- *inertia*, which is the weighted average of the chi-square distances to the centroid (calculated as chi-square distance divided by the total number of events).

The details needed to carry out the calculations needed to obtain the above parameters can be found elsewhere [16,23].

Entry No.	Date of the accident	Source of information	Geographical Information
Cause	Scenario	Location in the plant	
Injuries	Fatalities	Environmental Damage	Asset Damage
Summary	Documentation	Links	

Fig. 1. Simplified structure of the database used to organize the information on accidents in biogas production and upgrading. In red: categorical variables used in multi-correspondence analysis. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Results and discussion

3.1. Distribution of accidents and comparison with biogas production trend

The search resulted in the identification of 169 accidents related to biogas supply chain occurred in the last 20 years, from 1995 to 2014 (Fig. 2). The time distribution of collected events seems important. Focussing on the five years period 2007–2011, the number of accidents in the biogas sector has increased more than five times, a growth that is higher than the one experienced by the number of biogas installations [3,24]. The reduction in the number of accident files collected in the following three years (period 2012–2014) is likely a consequence of deficiencies and delays in reporting rather than the consequence of an improvement in process safety in biogas facilities. Actually, almost the totality of the studies concerned with past accident analysis show a decreasing trend in the documented events in the last two-three years of the study [8,25–27].

The plot in Fig. 2 shows that within the events documented, some accidents fall under the definition of major accidents according to Annex VI of the Seveso III Directive [7]. These are 20 events over 169, representing almost 12% of the events in the database.

Considering the geographical distribution of events included in the database, 96% of the accidents retained for the analysis took place in Europe (163 over 169). Most of the events took place in Germany (76%), while a lower amount were documented in France (11%), Italy (6%), and UK (2%) (Fig. 3). These data can be explained considering that Germany is leading the European biogas market and is, in fact, the country where the highest number of plants is operating [3]. For the same reason, awareness about risks related to biogas production is deeper in Germany than in the rest of Europe.

Fig. 4 reports the number of accidents with respect to time compared to the biogas production in Europe. The trends show that both the number of documented accidents and the production of energy from biogas are increasing in recent years. However, it is evident that the number of accidents is growing faster than biogas production. This is clearly shown considering both the data on Europe (Fig. 4-(a)) and the detail available on Germany (Fig. 4-(b)).