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RISK MANAGEMENT IN BIOGAS PLANTS BASED ON NEW NORM ISO 31000:2018

Abstract

Biogas plays an important role in renewable energy production. Biogas plants are small-scale energy plants, facing numerous risks in daily operations. Production of biogas may cause danger for life and health by suffocation or poisoning due to presence of hydrogen sulphide (H_2S) and explosion of reactor. The current literature study revealed that there are no universal and comprehensive management tools designed only for biogas plants for risk management. Therefore, the aim of this paper is application of new ISO 31000:2018 on risk management in biogas plants. For this, three crucial technical criteria: Organic loading rate (OLR), Hydraulic retention time (HRT) and Technical performance of a biogas plant were taken into account. These criteria have been analysed to present how the methodology of risk management norm can be applied in any other area. Further research is needed to develop additional criteria in technical, environmental, economic and social issues.

Keywords: risk management, ISO norm 31000, biogas plants

Introduction

Biogas plants are source of renewable energy needed by modern economies on one hand and on the other hand they are energy reactors and face similar problems and challenges as conventional energy production plants. In energy production units risk management has become a crucial issue due to technical, environmental, social and economic risks. In contrast to conventional energy production plants, biogas plants work with biological material and are posed to other challenges such as heterogeneity of input material, instability and seasonality of supply, change of calorific value of substrate due to decomposing processes, odour emissions etc. These aspects are difficult to manage by biogas plant operators because there are no universal and comprehensive management tools for risk management designed only for biogas plants. The literature review revealed that only limited risk aspects in renewable energies (including biogas plants) are analysed. Integrated concepts for risk management referring to biogas plants are not available. This is not sufficient for the biogas plants operators due to hazards aligned with ignoring of risk such as explosion of a plant or poisoning of working personal due to presence of hydrogen sulphide (H_2S). Therefore, based on new ISO 31000:2018 a systematic assessment tool can be designed for risk management in biogas plants. Due to limits of this paper only three chosen technical aspects have been presented.

1. Biogas as a source of energy

According to Statistical Review of World Energy (BP, 2016), energy is one of the crucial issues for sustainable development. Currently, conventional sources of energy still remain the main source of energy for the world. However the amount of sources of fossil fuel does not increase. According to definition given by Ellabban (2014), renewable energy sources are energy sources whose use does not involve a long-term deficit, as their resources are being rebuilt in a short period of time. Such sources include bio-energy, wind, solar radiation, rainfall, tidal, wave and geothermal energy. Their opposites defined by Rincón-Mejía and de las Heras (2008) are non-renewable sources of energy also called a finite resource, i.e. sources whose resources recover very slowly or not at all like crude oil, coal, natural gas or uranium (see Table 1).

Table 1. Division of energy

Non-renewable energy		Renewable energy	
Fossil fuels	Crude oil	Wind power	
	Coal	Hydropower	
	Natural gas	Solar energy	
	Lignite	Geothermal energy	
Nuclear energy	Uranium	Bio-energy	Solid biomass
			Sewage biomass
			Biogas
			Biofuel

Source: (own elaboration)

According to Smith and Cheesema (2009), biogas is considered a renewable energy source because its production and consumption cycle is continuous and does not involve net production of carbon dioxide. The organic matter used in biogas production increases with the use of carbon dioxide in a repeatable, lossless cycle. The same amount of dioxide is absorbed from the atmosphere as is emitted during the combustion of biogas.

The biogas mixture consists primarily of methane (50–75 vol. %) and carbon dioxide (25–50 vol. %). Biogas also contains small quantities of pollutants such as hydrogen, hydrogen sulphide, ammonia and other trace gases (see Table 2). These substances must be later removed in the process of gas drying and washing.

Table 2. Average composition of biogas

Constituent	Concentration
Methane (CH_4)	50–75 vol. %
Carbon dioxide (CO_2)	25–45 vol. %
Water (H_2O)	2–7 vol. % (20–40^{o}C)
Hydrogen sulphide (H_2S)	20–20000 ppm < 2 vol. %
Nitrogen (N_2)	< 2 vol. %
Hydrogen (H_2)	< 1 vol. %
Ammoniac (NH_3)	< 1 vol. %
Trace gases	< 2 vol. %

Source: (Swedish Gas Technology Centre, 2012; Ecofys, 2013)

The organic matter is decomposed in a number of steps in collaboration between several different types of microorganisms – bacteria. The composition of the gas is essentially determined by the substrates, the fermentation (digestion) process and the various technical designs of the plants. The efficiency of the biogas production depends on how suitable the conditions are for the microorganisms and the composition of substrate (Swedish Gas Technology Centre, 2012).

Figure 1 below presents the biogas production at different stages.

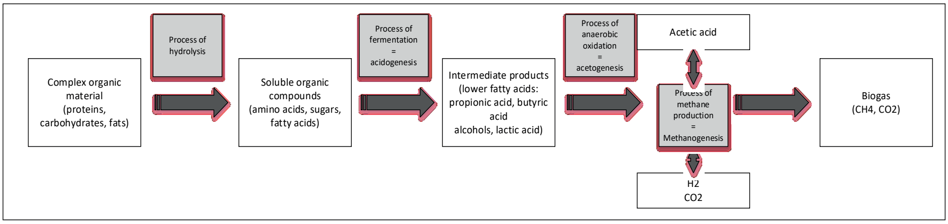

Figure 1. Biogas process at different stages
Source: (own elaboration)

1) Process of hydrolysis – is a process of breaking down of complex compounds of the starting material (such as carbohydrates, proteins and fats) into simpler organic compounds (e.g. amino acids, sugars and fatty acids) with use of hydrolytic bacteria.
2) Process of acidogenesis (fermentation) – is a further process decomposing of intermediate products by fermentative (acid-forming) bacteria to form lower fatty acids (acetic, propionic and butyric acid) along with carbon dioxide and hydrogen Tiny quantities of lactic acid and alcohols are also formed.

3) Process of acetogenesis (anaerobic oxidation) – is a process where fermentation products are converted by acetogenic bacteria into precursors of biogas (acetic acid, hydrogen and carbon dioxide).
4) Process of methanogenesis (methane production) – is the last process in biogass process. Acetic acid, hydrogen and carbon dioxide are converted into methane by strictly anaerobic methanogenic archaea. The hydrogenotrophic methanogens produce methane from hydrogen and carbon dioxide, whereas the acetoclastic methane-forming bacteria produce methane by acetic acid cleavage.

To achieve the biogas quality of natural gas, biogas must be upgraded. That means the majority of the carbon dioxide and other pollutants are removed. The gas density is increased. The product of this process is bio-methane. The process of biogas upgrade can be performed with different technologies (Swedish Gas Technology Centre, 2012). The most common technologies for purification of raw biogas to bio-methane quality are presented in Table 3 below[1].

Table 3. Gas upgrade technologies

Technique	Function	Regeneration
Pressure Swing Absorption (PSA)	Absorption of carbon dioxide on activated carbon	Depressurisation
Water scrubber	Absorption of carbon dioxide in water	Depressurisation and counter flow air
Chemical absorption	Chemical reaction between carbon dioxide and amine – based solvents	Heating
Membrane	Separation through a membrane that is permeable for carbon dioxide	–
Cryogenic separation	Cooling until condensation or sublimation of the carbon dioxide	–

Source: (Swedish Gas Technology Centre, 2012)

Biogas/biomethane and process products – digestate – can be used in many ways. Typical applications include (see Figure 2):

- digestate: use in agriculture as fertiliser or compost;
- biogas: use for heat production via combustion in a boiler; heat is used to heat the digester and nearby buildings or be exchanged on a local district heating network;
- biogas: use for production of Heat/Power (CHP) in stationary engines, typically Otto or diesel engines, or gas turbines;
- biomethane: use in vehicle (cars, buses and trucks), providing it is upgraded by removing carbon dioxide, water and hydrogen sulphide; the gas must also be odourised and pressurised to around 200 bar before it can be used as vehicle fuel;
- biomethane: use in the national gas grid for different applications;
- biomethane: use as a storage of energy.

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[1] Further upgrade of gas density is called gas condensation in the process of cryogenic cooling – liquefaction. Cooling is done by using a working fluid (in cryogenics this is almost always helium) and making it undergo a closed thermodynamic cycle that removes heat at low temperature and rejects the heat at room temperature. The product from the process is Liquefied Biogas. The common abbreviation is LBG. In this form LBG can be transported on long distances.

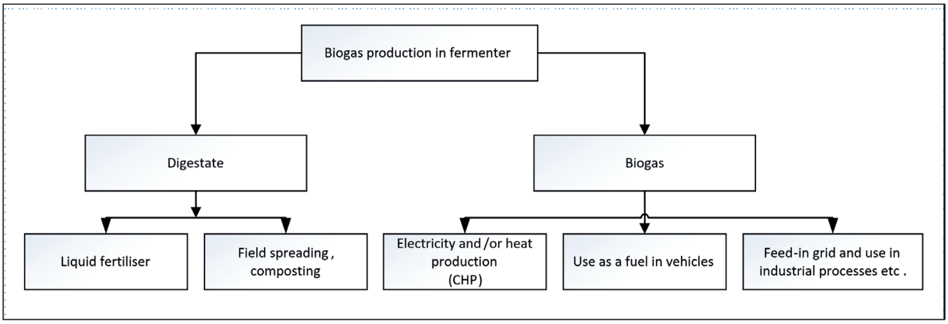

Figure 2. Use of biogas and its products
Source: (own elaboration)

2. Role of risk management in biogas projects

According to Sgroi et al. (2015), risk management in term of biogas projects mostly concentrate on financial risk. It is hard to foresee entrepreneurial risks, which arise due to market fluctuations in supply and dedicated energy crops price volatility. It is significant, to try to estimate them on the phase of planning, due to build economically viable installation.

On the other side, according to Casson Moreno et al. (2018), there is a high technical risk in biogas installations. Emerging risks are issues that are perceived to be potentially significant. Unfortunately they cannot be entirely understood and assessed. In effect it is hard to develop risk management options with confidence. In the biogas case, situation is deteriorated not only by the lack of built standards, but also by limited technical experience. It affects many companies operating on the field.

In case of biogas, variety of potential dangers is present on the daily basis. NFU Mutual (2018) mentions the following as the most important:

- danger to life and health by suffocation or poisoning due to presence of hydrogen sulphide (H_2S); methane (CH_4), and carbon dioxide (CO_2);
- health risks from fermentation by-products;
- explosion by ignitable gas/air mixture;
- fire hazards – plant rooms;
- electrical hazards – plant rooms and generator;
- build-up of condensation through cooling of gas/water mixture in pipes and subsequent freezing/blockage of pipes;
- corrosion of components and subsequent failure caused by aggressive parts of the gas mix e.g. ammonia or hydrogen sulphide.

Therefore, in risk management concept, the risk analysis should take place with appropriate attention to functional safety regulations. A process of hazard identification and the risk assessment, according to Barnert et al. (2014) determines if the safety related actions should be implemented in the analyzed object.

The properly built control and protection system can considerably reduce the risk of human, environmental and financial loses.

However safety instrumented systems usually require more complex technologies and higher financial support. Other way to manage and avoid technical risk is to train employees. A well trained operator may have a larger influence on the risk reduction in this kind of plants.

Literature search proved that risk management regarding renewable energies and especially biogas plants is limited to chosen aspects. In the Table 6 in the attachment different risks by renewable energies are presented. There are no integrated and comprehensive concepts for the whole process. Therefore, ISO 31000 norm can be a helpful instrument to design an assessment tool.

3. ISO 31000 norm as a support tool for risk management

The International Organization for Standardization (ISO) has developed and released a number of highly popular standards. The most notably are ISO 9000 for quality management, and ISO 14000 for environmental management. In 2011 a new norm for energy management systems 51000 was developed to help organisations reduce their energy consumption and increase energy efficiency.

ISO 31000 for risk management (RM) was originally published in 2009 and an updated version was published in February 2018. However, the overall purpose of ISO 31000 remains the same – integrating the management of risk into a strategic and operational management system (IRM, 2018). The ISO 31000 Risk Management Standard can be widely applicable across contexts and projects due to universal and generic concept of the norm. The structure of this standard consists of three main components:

1) Principles – the purpose of risk management is the creation and protection of value. It improves performance, encourages innovation and supports the achievement of objectives. Principles include the requirement for the risk management initiative to be (1) customised; (2) inclusive; (3) structured and comprehensive; (4) integrated; and (5) dynamic.
2) Framework – the purpose of the risk management framework is to assist with integrating risk management into all activities and functions. The effectiveness of risk management will depend on integration into governance and all other activities of the organisation, including decision-making. The Framework consists of issue of Leadership and commitment, Integration, Design, Implementation, Evaluation and Improvement.
3) Process – the risk management process involves the systematic application of policies, procedures and practices to the activities of communicating and consulting, establishing the context and assessing, treating, monitoring, reviewing, recording and reporting risk. The Process contains issue of Communication and consultation, Scope, context and criteria, Risk assessment, Risk treatment, Monitoring and review, Recording and reporting.

Although ISO 31000 covers the full scope of requirements for a management system, it is a task for the organisation to convert those requirements into a checklist and action plan. By doing so, the organization is given a flexibility to have a ccontinuous control of processes and procedures (of the system in a repeatable cycle as by Deming) by:

1) Deduction of improvements (Act),
2) Planning of measures (Plan),
3) Establishment of a working environment and realization of goals (Do),
4) Control of the success and the current situation (Check).

This leads to continuous and controlled improvements of the results of the organization and its efficiency, of the quality of its processes and of the quality of its products.

Huge disadvantage, according to Aven (2011) is lack of constructive and consistent definitions of key concepts and risk-related vocabulary. Leitch (2010) concludes, that norm is not precise and does not have mathematical background. The process is unclear, what is very surprising, according to fact, that norm was created by various professionals. Other disadvantage is lack of actual evidence to evaluate the effectiveness of the ISO 31000 standard. Also its potential for impact in industry is unknown.

For the purpose of this paper risk management has been limited to three main technical aspects in operation of biogas plants:

- organic loading rate (OLR);
- hydraulic retention time (HRT);
- technical performance of a biogas plant.

Aspects of Risk assessment, Risk treatment, Monitoring and review, Recording and reporting (as included in the Process part of the norm) for chosen parameters are presented.

Organic loading rate (OLR) – when assessing the degradation performance a crucial parameter is organic loading rate (OLR). ORL determines "how many kilograms of volatile solids (VS, or organic dry matter – ODM) can be fed into the digester per m^3 of working volume per unit of time" (DGIZ, 2010). The OLR is mathematically expressed in kg VS/(m^3 * d).

$$OLR = \frac{m \times c}{Vr \times 100}$$

m – amount of substrate added per unit of time (kg/d)
C – concentration of organic matter (volatile solids) (% VS)
Vr – reactor volume (m^3)

The measurement of the quantity and composition of the biogas produced in terms of methane and carbon dioxide content is of fundamental importance to evaluate the performance of the process. How important determining of OLR factor for the process is, has been presented in a study by Babaee Azadeh (2011) done for vegetable wastes.

In this research the performance of the anaerobic digestion process when operated at different loading rates was determined. The reactor showed stable performance with highest methane yield (64%) during loading rate of 1.4 kg VS/(m^3 * d). When the loading rate was increased to 2 kg VS/(m^3 * d), the pH value dropped from 7.75 and reached to lower value of 7.3 but it was still above 7 which were in the methanogenic range. The overloading was marked by the fall in pH and gas yield and increase of carbon dioxide content in the biogas. The highest biogas and methane yield observed was 0.4 m^3 biogas/kg VS and 0.25 m^3 CH_4/kg VS in run 1 (1.4 kg VS/m^3 * d). How different substrates may influence OLR, biogas yield, methane content and degradation of volatile solids is presented in Table 4.

Table 4. Performance data of different anaerobic processes by substrate

Substrate	OLR (VS/m^3 * d)	Biogas yield (m^3 CH_4/kg VS)	Methane (%)	Degradation (% of VS)	References
Vegetable wastes	1.4	0.4	64	88	(Babaee Azadeh, 2011)
Organic fraction of municipal solid wastes	0.8	0.26	60	61	(Nguyen, Kuruparan, Visvanathan, 2007)
Municipal solid wastes	2.5	0.38	61	70	(Fruteau de Laclos, Desbois, Saint-Joly, 1997)
Fruit and vegetable wastes	0.3–1.3	0.3	54–56	67	(Rene Alvarez, 2008)
Fruit and vegetable wastes	1.6	0.47	65	88	(Mata-Alvarez, Cecchi, Llabrés, 1992)

Source: (Babaee Azadeh, 2011)

Hydraulic retention time (HRT) is another relevant parameter for deciding on the size of vessel. This is the length of time for which a substrate is calculated to remain on average in the digester until it is discharged. This parameter involves determining the ratio of the reactor volume (VR) to the volume of input substrate added per day. The hydraulic retention time is expressed in days (DGIZ, 2010).

$$HRT = \frac{Vr}{V}$$

Vr – reactor volume (m^3)
V – Volume of substrate added daily (m^3/d)

As OLR rises at stable composition of substrate, more material is fed into the digester and retention time is shortened consequently. At shorter retention time bacteria may not have sufficient time to decompose the material and methane yield may decrease. Therefore, the retention time must be adapted to the decomposition time of substrates. At known daily amount of substrates added to the digester, the required reactor volume can be calculated in conjunction with the decomposing time substrates. This parameter is important for slurry plants where large volumes appear with low content of degradable material (DGIZ, 2010).

Technical performance of a biogas plant can be measured by calculating productivity, yield and degree of degradation. Productivity is a quotient of daily gas production to digester volume. Productivity can be measured for biogas and methane production and is expressed as $Nm^3/(m^3 * d)$.

$$PCH_4 = \frac{VCH_4}{Vr}$$

VCH_4 – methane production (Nm^3/d)
Vr – reactor volume (m^3)

Yield is a relation of biogas or methane production to input material (amount of organic matter) and is expressed in Nm^3/t VS.

$$ACH_4 = \frac{VCH_4}{mTS}$$

VCH_4 – methane production (Nm^3/d)
mTS – Organic matter in loaded substrates

Degree of degradation or organic matter can be determined based on volatile solids (VS) or chemical oxygen demand (COD). Calculation of these parameters depends on composition input material (proportions of fats, proteins and carbohydrates), retention time of the substrates in the digester, the total solid content, fatty acid content and inhibitors, temperature, dry matter and water content. Also mixing of the material inside the digester is crucial for optimal formation of biogas and needs to be observed.

Conclusions

In the Table 5 the Risk assessment, Risk Treatment, Monitoring and review, Recording and reporting for three discussed technical performance criteria (Organic loading rate (OLR), Hydraulic retention time (HRT) and Technical performance) of a biogas plant are presented.

For example is case of Organic loading rate the plant operator – as responsible person in the process – needs to determine optimal organic load for substrates delivered for the process. This is crucial for the control of pH and gas yield achieved in the production. OLR is a parameter to be controlled constantly as mixture of substrates may change in time due to supply and decomposition of the organic material. This information should be recorded and reported daily for investigation of unexpected events in operation of the plant (see Table 5).

This methodology to control risk may be applied to any criterion defined as relevant in operation of a biogas plant, regardless whether of technical, environmental, social or economic nature. For a construction of a comprehensive assessment tool for risk management there is a need to further develop assessment criteria in technical, environmental, social or economic areas taking into account the methodology of ISO 31000.

Table 5. Risk management of technical aspects of a biogas plant

Aspect	Risk assessment	Risk Treatment	Monitoring and review	Recording and reporting
Organic loading rate (OLR)	Determining of optimal organic loading rate (OLR) for used substrate Identified risks: Fall in pH and gas yield, increase of carbon dioxide content in the biogas	Constant control of OLR in the process	Responsibility: Loading manager, technician	Daily reporting
Hydraulic retention time (HRT)	Determining of hydraulic retention time (HRT) for reactor volume Identified risks: Fall in gas yield due to short retention time	Control of HRT in the process	Responsibility: Loading manager, technician	Daily reporting
Technical performance of a biogas plant	Determining of optimal technical performance of a biogas plant Identified risks: Inefficient process, low methane production, high concentration of H_2S, resulting corrosion damage of CHP or heating boiler	Calculation of productivity, yield and degree of degradation, slowly rotating agitators exerting low shear forces	Responsibility: Plant manager	Daily reporting, Calculation on weekly, monthly basis

Source: (own elaboration)

Attachment

Table 6. Identification of risk in renewable energies

Kind of renewable energy	Investment risk	Social risk (acceptance)	Political risk	Administrative risk	Financing risk	Technical risk	Grid access risk	References
Renewable energies	–	Acceptance of investment	–	–	–	–	–	(Hitzeroth, Megerle, 2013)
Renewable energies	Market risk, credit risk	–	Addressed	–	Liquidity risks, operational risks	–	–	(Lee, Zhong, 2015)
Renewable energies	–	–	–	–	Risks associated with financing energy projects	Different risk exposure levels concerning energy supply, electricity generation, facility expansion, pollutant emission	–	(Nie et al., 2017)
Wind & Solar	–	–	Regulatory and policy risk	–	Energy price risk, resource risk, and inflation risk	–	–	(Gatzert, Vogl, 2016)
Wind & Solar	Planning	Planning	Planning, construction, operation	Planning	Planning, construction, operation	Construction, operation	Planning, construction, operation	(Angelopoulos et al., 2017)

Table 6. cont.

Kind of renewable energy	Investment risk	Social risk (acceptance)	Political risk	Administrative risk	Financing risk	Technical risk	Grid access risk	References
Wind	Risks to investments in renewable, Transport/ construction/ completion, Financing risks/ insufficient expertize/ insufficient management know-how	Insufficient public acceptance, Complex approval processes	Policy and regulatory risks	Liability/legal risk	Limited insurance solutions	Technology and innovation risk, General operation and maintenance risks, Damage due to natural hazards (severe weather)	Market/ sales risks, Counterparty risk	(Gatzert, Kosub, 2016)
Biogas	Addressed	–	–	–	Fluctuating availability and price volatility	–	Supply	(Sgroi et al., 2015)
Biogas	–	–	–	–	–	Addressed	–	(Benjamin, Tana, Razon, 2015)
Biogas	–	–	–	–	–	The risk of formation of an explosive atmosphere, explosions	–	(Casson Moreno et al., 2018)
Biogas	–	–	–	–	–	Addressed (mostly risk assessment)	–	(Barnert et al., 2014)

Source: (own elaboration)

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