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Sustainable Mitigation of Methane Emission by Natural Processes

Zrównoważone ograniczanie emisji metanu z wykorzystaniem naturalnych procesów

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Abstract

It has been observed that employing the natural processes occurring in the Earth's ecosystem for mitigating the greenhouse gases emission is sustainable. One of the main sources of methane emission is agriculture (rice cultivation and livestock raising). Limiting the cultivation of rice would not be sustainable, as it is the basic source of alimentation for a large share of human population. On the other hand, introducing feed additives which limit the methane production in rumens can be considered sustainable. Another significant source of methane emission are landfills. Utilizing this gas for energy purposes is the most sustainable solution. However, as only part of methane can be used as the source of energy, the natural process of methane oxidation by methanotrophic bacteria occurring in soil may contribute to sustainable reduction of its emissions from landfills.

Key words: green gases emissions, methane emission, sustainable development, reduction of green gases emissions

Streszczenie

W artykule zwrócono uwagę, że wykorzystanie naturalnych procesów istniejących w ekosystemie ziemi do zmniejszenia emisji gazów cieplarnianych jest zrównoważone. Jednym z głównych źródeł emisji metanu jest rolnictwo (uprawa ryżu i hodowla bydła). Ograniczenie upraw ryżu nie byłoby zrównoważone, ponieważ ryż jest głównym źródłem żywności dla dużej części populacji ludzkiej. Natomiast wprowadzenie suplementów do paszy bydła ograniczających tworzenie się metanu w żwaczach można uznać za działanie zgodnie z zasadą zrównoważonego rozwoju. Innym znaczącym źródłem emisji metanu są składowiska odpadów. Najbardziej zgodne z zasadą zrównoważonego rozwoju jest wykorzystanie tego gazu do celów energetycznych. Ponieważ tylko część metanu daje się wykorzystać do celów energetycznych zwrócono uwagę, że zastosowanie naturalnego procesu zachodzącego w glebie, jakim jest utlenianie metanu przez bakterie metanotroficzne może przyczynić się do zrównoważonej redukcji emisji metanu ze składowisk odpadów.

Słowa kluczowe: emisja gazów cieplarnianych, emisja metanu, rozwój zrównoważony, redukcja emisji gazów cieplarnianych

Introduction

Sustainable development is development that meets the needs of the present without compromising the possibilities of meet their needs by future generations (WCED, 1987). This is related to ecological, economic and social issues.

Human beings are social people, however to expand their social behaviour, they need i.e. stable environment.

The most important challenge for the present state of the biosphere is connected with climate changes and anomalies. They are caused by huge logging of forests, especially tropical forests, and impressive emissions of different greenhouse gases.

Climatic changes foreseen by IPCC seem to be one of the greatest threats for the implementation of the basic sustainable development paradigm, which is preserving the environment for future generations. Remedial measures, especially in the European Union, focus on cutting the CO_2 emission from anthropogenic sources, particularly in the energy generation processes. Switching to so called low emission energy generation technologies is an extremely costly venture, which has a negative impact on the economic development and may significantly hinder the implementation of another important sustainable development paradigm, namely the intra-generational justice. On the other hand, other methods of mitigating CO_2 concentration in the atmosphere remain under-appreciated. While approximately 10 billion tons of CO_2 are emitted annually from anthropogenic sources, mainly fossil fuel combustion and cement production, roughly 120 billion tons of CO_2 are emitted simultaneously from the Earth's biosphere. If the emission from ecosystems were reduced by 10%, it would mitigate the total emission from anthropogenic sources. Similar situation occurs in the case of methane, which is another important greenhouse gas.

On Earth, methane exists in deposits. It was created through two kinds of processes:

- in thermal processes. Organic matter decomposed in elevated temperature, producing methane and higher hydrocarbons. It is believed that both shale gas and crude oil were created in thermal processes.
- in biological processes. Methanogenic bacteria process organic matter into methane in anaerobic conditions. Methane produced in this way is found in conventional gas deposits, clathrates, and arctic permafrost.

The most important parameter, when considering the impact on greenhouse effect, is the content of methane in the atmosphere, which is continuously on the rise since the onset of Industrial Revolution. Its concentration in the atmosphere equalled 700ppb prior to 1750, reached 1745ppb in 1998 and amounted to 1775ppb (IPCC, 2001) in 2014. According to Fung et al. (1991), Lelieveld et al. (2002), Sapart et al. (2012), methane is emitted into the atmosphere both from natural sources such as swamps (115-145 Mt/year), termites (10-20 Mt/year), seas and oceans (5-10 Mt/year), as well as from anthropogenic ones such as fuel industry emissions (75-100 Mt/year), municipal landfills emissions (40-70 Mt/year), or rice cultivation (60-200 Mt/year).

Rice paddy fields can be compared to man-made wetlands which are characterized by high moisture content and oxygen depletion. These factors combined with high content of biomass and nutrients, create conditions for methane formation. Production of 1 Mg of rice corresponds to the emission of 100 kg of methane. Other sources of methane emission include livestock raising (80-115 Mt/year), biomass combustion in domestic stoves (30-50 Mt/year) and municipal wastewater treatment plant (~10Mt/year). According to IPCC estimations (IPCC2013), total annual methane emission from all the sources adds up to 598 Mt.

Simultaneously, methane is removed from the atmosphere. The most important sources include: oxidation in the troposphere (~506Mt/year), oxidation in the stratosphere (~40 Mt/year), and oxidation by methanotrophic bacteria in soil (30Mt/year). According to these estimations, methane content in the atmosphere increases annually by ~20Mt. Climate stabilization mainly necessitates inhibition of increasing methane content in the atmosphere. Limiting its emission to the degree which causes a drop in its concentration in the atmosphere would be beneficial. Taking into account the paradigms of sustainable development, which prescribe both to neutralize impact of methane on the greenhouse effect and to minimize the influence of taken actions on food production, a critical evaluation of possible methane emission mitigation methods will be carried out.

Sources of methane emission

Methane is the product of anaerobic organic matter decomposition. One of the main sources of methane emission is ruminants raising, especially cattle. This emission could be limited by reducing the beef production and substituting it with poultry and pigs, which are more neutral for the environment. Rice cultivation is another important source of methane. However, limiting its production would be difficult, as it is one of the diet basic components for almost half of the human population. Certain amount of methane is emitted from industrial processes such as extraction and distribution of natural gas (IPCC, 2013; Osborn et al., 2011; Rahm et al., 2012; Rozel and Reaven, 2011; Vidic et al., 2013) as well as coal mining (EIA, 2013). Biomass combustion in domestic stoves, especially in households, is yet another significant source of methane emission. Additionally, a lot of methane is emitted from wastewater treatment plants, especially the sewage discharged by growing cities, and from landfills. Emission from both sources is rapidly growing. Since the days of Industrial revolution, the concentration of methane in the atmosphere increases by 0.9% per year on average. In the Earth's ecosystem, there are various methane decomposing processes. One of the more important ones is methane oxidation in troposphere and stratosphere by $OH^{\bullet}$ radicals. Methane absorbed by soil is also decomposed by methanotrophic bacteria. Therefore, it is advisable to seek natural methods for mitigating its con-centration in the atmosphere.

Methods of mitigating methane emission

Mitigating methane emission from natural sources is relatively difficult. Practically, one should not interfere with the termite colonies existing in natural ecosystems. It is also hard to imagine any way of controlling the emission from seas and oceans. Theoretically, it would be possible to reduce methane emission from swamps by drying them. However, this is a significant interference in important natural earth ecosystems, which are habitats of many organisms. Drying swamps would decrease bio-diversity. Moreover, it leads to increased rate of organic matter mineralization, which in turn leads to the increase of another greenhouse gas – namely, carbon dioxide. Taking into account the above-mentioned consequences, the conclusion is that interfering with the natural methane-emitting processes would not conform to the principles of sustainable development.

Let us evaluate the anthropogenic processes. Relatively lot of methane is emitted during the extraction and processing of fuels. Actions aiming at curbing the emission, mainly through improved leachate control and reducing the emissions from coal mines are encouraged. In the latter case, degassing coal deposits prior to extraction is desirable, as it leads to the utilization of methane as a source of energy and increases the safety in the process of mining coal as well.

Rice paddle fields, which are a vital source of food, especially in Asia, also significantly contribute to the emission of methane. Hence, limiting the cultivation of rice would be against the sustainable development principle of providing access to food. In the case of livestock raising, cattle is mainly responsible for methane emission. To a certain extent, the raising of cattle for slaughter could be limited by substituting beef with pork and poultry, as the emission of methane is low in that case in that process. However, it is difficult to alter the dietary patterns of a large and wealthier part of population, which puts the reduction of livestock for meat production into question.

Approximately 3-12% of the energy consumed by cattle and sheep is converted to methane in the rumen and released to the atmosphere. This amount of energy is wasted and therefore is not used for growing of these animals. Therefore, minimization of the methane generation in rumen will contribute to better utilization of forages by farmers.

However, limiting methane emission from livestock raising by means of feed additives that mitigate the methane production in rumens should be considered. Rumensin™ is a product which significantly reduces this problem (Hook et al., 2010). Employing this additive would eliminate the negative impact of livestock raising on climatic changes and will improve utilization of feed in meat and milk production. Yet, this approach is not cost free. The production of this additive generates additional cost which should be balanced by an increase in forage utilization and decrease in the contribution of methane emission to greenhouse effect. Cutting the emission from cattle and sheep raising by 50% would inhibit the increasing methane concentration in the atmosphere. However, the problem consists in the lack of economic instruments which could be used to control the use of above-mentioned feed additives on a broader scale.

Landfills constitute another important source of methane emission to the atmosphere (Bogner and Spokas, 1993). Methane on landfills is created in the process of anaerobic organic matter decomposition by bacteria (methanogens). This process yield great amounts of methane (Hilpert et al., 2007; Fountoulakis et al., 2008; Hook et al., 2010; Wedlock et al., 2013) which is profitable in recovery and use for energy purposes.

Landfills are the third biggest anthropogenic source of methane, after rice cultivation and ruminants. 1200 Tg of waste is produced annually in the world, 70% of which is deposited on landfills. According to estimates 30-35 Tg CH_4/yr is emitted from landfills. It is projected that the amount of produced waste will increase twice till 2030. Therefore, cutting the emission from this source may significantly contribute to the mitigation of methane impact on the greenhouse effect.

In the USA alone, there are over 400 systems utilizing landfill gas, which are capable of generating more than 9 billion kWh of electricity. It is estimated that there are over 1000 such systems globally.

However, utilization of methane from landfills is possible when the production is intense, i.e. for a certain period. Attempts to intensify the methane production in order to utilize it for energy purposes are made (Pawłowska and Siepak, 2006), as they would allow for a more sustainable management of landfills. Nevertheless, methane will be produced on every landfill for decades, but after some time its concentration will be too low to be used as a source of energy. On the other hand, mitigating this emission is extremely important for preventing the global warming. While seeking the methods of mitigating methane emission, attention was drawn to methanotrophic bacteria living in soil, which are capable of oxidizing it.

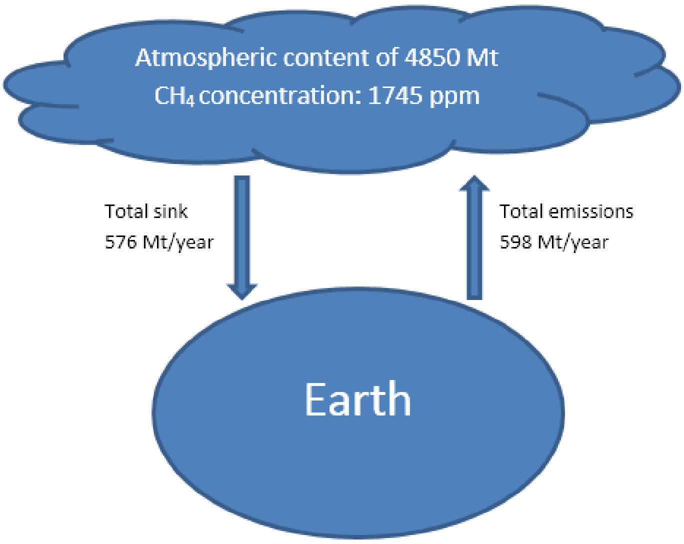

Figure 1. Simplified diagram of methane circulation in the Earth ecosystem (data based on direct flux measurements, IPCC 2007)

Methanotrophic bacteria are able to convert the methane to carbon dioxide, which has warming potential 25-times smaller than the methane.
Biofilters that employ these bacteria have been constructed (Pawłowska et al., 2011), and methods of creating landfill covers in which methanotrophic bacteria develop have been devised (Pawłowska et al., 2003: Pawłowska and Stępniewski, 2004, 2006: Czepiel et al., 1996; He et al. 2008; Chanton et al., 2011) (Fig. 1). In this way, methane emitted from landfills may be oxidized. Such biofilters and special covers allow for self-oxidation of methane and thus mitigate its emission.

Summary

There are two fields in which significant reduction of methane emission into atmosphere is possible. The first constitutes employing additives to the feed for cattle and sheep raising. This solution is beneficial from the point of view of sustainable development, as it leads to better fodder utilization, meaning that the same amount of feed would yield more milk and beef. However, it is difficult to convince the animal breeders to employ it. Although the reduction of methane emission from livestock raising through the addition of substances inhibiting the production of methane in rumens could relatively easily stop the increase of methane concentration in the atmosphere, no possibility of convincing the breeders to adopt this solution renders it practically non-viable.
Methane emission to the atmosphere could also be inhibited through the reduction of the emission from landfills by using biofilters or bioactive biocovers. Bearing in mind that biofilters and biocover may virtually operate autonomously, employing this method of methane emission mitigation is easier. It would be possible to introduce legal regulations enforcing the installation of biofilters or biocovers on landfills.
Employing the natural methods, such as methanotrophic bacteria, for the mitigation of methane emission from landfills is a good example of intensifying natural processes occurring in the environment to reduce the greenhouse gases emission. This is a classic example of a sustainable method.

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