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Review

Sources and mitigation of methane emissions by sectors: A critical review

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ABSTRACT

The environmental community rightly recognizes global warming as one of the gravest threats to the planet. Methane (CH_4), one of the greenhouse gases causing global warming, is emitted from a variety of sources and its concentration in atmosphere has increased dramatically over the last few centuries. Therefore, the increasing concentrations of methane are of special concern because of its effects on climate and atmospheric chemistry. Anthropogenic sources of methane can be collected under the titles of agriculture, energy, waste and industry on the basis of sectors. This paper aims at examining the past trends in emissions, the sources and mitigation strategies of the methane. As a result of the study, it is determined that the agricultural sector is the biggest source of methane emissions among the sectors. The energy, waste and industry follow the agricultural sources respectively.

1. Introduction

Greenhouse gases from burning of fossil fuels, production, transportation, conversion and using of energy result in climate changes by affecting the atmosphere chemically in the long term [1,2]. Methane, which is an important greenhouse gas, constitutes 16% of greenhouse gas emissions [3,4]. Although the methane concentration has remained stable for thousands of years, it has doubled in atmosphere recently [5]. Although the changing rate is less than the carbon dioxide has, it affects climate change at least as much as carbon dioxide due to its global warming potential (GWP) (Table 1) [5,6].

Methane is formed as a result of decomposition of organic materials in an environment without oxygen. It is released from natural and anthropogenic sources. 40% of global methane emissions come from natural sources, whereas 60% of global methane emissions is released from anthropogenic sources.

Sources causing anthropogenic methane emissions grouped in Table 2 in sectoral bases [7]. These sectors include agriculture, energy, industry and waste. Fig. 1a shows the contribution of each sector to the total emissions. Additionally, methane release performances of the sectors between 1990 and 2010 respectively are depicted in Fig. 1b.

In this study, methane emissions from sectors are analyzed. Emissions and percentage contribution values presented in this study are calculated based on the average emissions between 1990 and 2010 and methane emissions from industry are not dealt since it is highly low (6.30 $MtCO_2eq$). The emissions raw data, used in this study, are taken from a report published by EPA (U.S. Environmental Protection Agency) [7]. Additionally, various strategies to mitigate methane emissions from each sector are mentioned.

2. Agriculture

Methane emissions from agricultural sources are projected to be 3135.75 $MtCO_2eq$ annually. This value makes the agricultural sector to be the biggest emitter that is responsible for the majority of methane emissions from anthropogenic sources. In other words, 50.63% of anthropogenic methane emissions are released as a result of agricultural activities. Methane emissions from enteric fermentation constitute 59.84% of emissions, followed by the emissions from rice cultivation, other agricultural activities and manure management respectively. Fig. 2a illustrates the trend of methane emissions related to the agricultural activities between 1990 and 2010. Percentage change of emissions is at higher level for agricultural activities than the emissions from other activities. These emissions have increased significantly after the year of 2000. China is the country that constitutes 15.47% of total emissions in this category. India, Brazil, the United States and other countries given in Fig. 2b follow China respectively in terms of their methane emission release performance. The top ten emitters are responsible for 54.59% of emissions from this category.

2.1. Sources

Sources causing methane emissions in agriculture sector can be ranged as enteric fermentation, manure management, rice cultivation and other agricultures sources.

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Table 1
Global warming potential of greenhouse gases.

Greenhouse Gases	GWP
Carbon Dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous Oxide (N_2O)	310
HFC-23	11.7
HFC-32	650
HFC-125	2,8
HFC-134a, HFC-4310mee	1.3
HFC-143a	3.8
HFC-152a	140
HFC-227ea	2.9
HFC-236fa	6.3
CF4, C2F6, C4F10, C6F14	6.5–9.2
SF6	23.9

Enteric fermentation is a description of being fermented of foods whereby microbes in an animal's digestive system [8]. As a result of this process, methane is released by exhaling of animals as a byproduct. Domesticated ruminants such as cattle, buffalo, sheep, goats, and camels account for the majority of methane emissions in this sector [9,10]. Other domesticated non-ruminants such as swine and horses also produce methane as a byproduct of enteric fermentation, but emissions per animal species vary significantly. Total methane emissions from this kind of sources are related to livestock population and especially quantity, quality and type of feed effect the methane emissions from enteric fermentation [7,11,12].

When manure is stored or treated in liquid systems such as lagoons, ponds or pits, anaerobic conditions will be developed and the methane emissions result from decomposition process [13]. The amount of methane from manure varies with respect to the storage type, ambient temperature for storage and composition of manure. Additionally, further methane emissions can be released in an environment with higher ambient temperature and moisture conditions. Moreover, the composition of manure is directly related to the animal types and diets [14]. As a consequence, a combination of all these factors effects the actual methane emissions from manure management [7].

The decomposition of organic materials in an environment without oxygen in flooded rice field causes to release methane. When the rice fields are flooded, decomposition of organic materials gradually consumes the oxygen which is available in soil and water. Once the oxygen in the environment is consumed, methanogenic bacteria release methane. The amount of methane from rice paddies is under the control of several factors including the quantity of organic materials and water management [15,16].

Other agricultural sources causing methane emissions can be ranged as open burning of biomass, savanna burning, agricultural residue burning, and open burning from forest clearing [7].

2.2. Mitigation

The strategies for reducing CH_4 emissions from enteric fermentation can be broadly focused in two main areas (i) improving the rumen fermentation efficiency and (ii) increasing the productivity of dairy animals thereby reducing the number of less productive/unproductive animals [17]. Detailed mitigation options of methane emissions from enteric fermentation are presented in Table 3.

2.2.1. Improving rumen fermentation efficiency

The production of CH_4 is particularly high in ruminant animals like cattle, buffalo, sheep, goat etc. due to their unique digestive system comprising of rumen. CH_4 is produced by the methanogenic archaebacteria located mainly in the rumen. The growth of Rumen microbes is affected by diet and other nutritionally related characteristics such as level of intake, feeding strategies, quality of fodder and fodder concentrate ratios. The workers have used a number of nutritional technologies to reduce the CH_4 production like, direct inhibitors, feed additives, propionate enhancers, methane oxidizers, probiotics, defaunation, diet manipulation and hormones [18,19].

2.2.2. Increasing the productivity of dairy animals

Enhancing the milk yield of dairy animals is seen as another approach for reducing enteric emissions. However, productivity improvement would result in reduction of total enteric emissions only if the quantity of milk produced is kept constant by decreasing the animal numbers [18,20].

Reduction strategies for manure management focus on emissions from liquid systems because these systems have large methane emissions that can be feasibly reduced or avoided. Two general options exist for reducing emissions from liquid systems: (1) switching from liquid management systems to dry systems; or (2) recovering methane and utilizing it to produce electricity, heat or hot water. Each option is described below [21,22].

2.2.3. Switch to dry manure management

Methane production is minimal in dry, aerobic conditions. Switching from liquid to dry management systems would reduce methane emissions produced in liquid systems.

2.2.4. Recover and use methane to produce energy

With the use of liquid-based systems, the only feasible method to reduce emissions is to recover the methane before it is emitted into the air. Methane recovery involves capturing and collecting the methane produced in the manure management system. This recovered methane can be flared or used to produce heat or electricity. Electricity generation for on-farm use can be a cost effective way to reduce farm operating costs [21].

Research has recently revealed that the methane emissions from wet rice can be decreased through multiple drainages of the fields during the growing season to keep down the reducing capacity of the soil. Another option is the continuous percolation of water over the fields [23]. This measure keeps methane emissions low as a result of methane oxidation in the water. Other options are related to soil characteristic [24]. Methane emission can also be curtailed by reducing the organic matter content of the soils [25].

Table 2
Activities caused anthropogenic methane emission.

Sectors causing methane emission			
Energy	Industry	Agriculture	Waste
■ Coal Mining Activities	■ Chemical Production	■ Manure Management	■ Landfilling of Solid Waste
■ Natural Gas and Oil Systems	■ Iron and Steel Production	■ Enteric Fermentation	■ Wastewater
■ Stationary and mobile combustion	■ Metal Production	■ Rice Cultivation	■ Waste Combustion
■ Biomass Combustion	■ Mineral Products	■ Other	■ Use of Solvent and Other Products
	■ Petrochemical Production		
	■ Silicone Carbide Production		

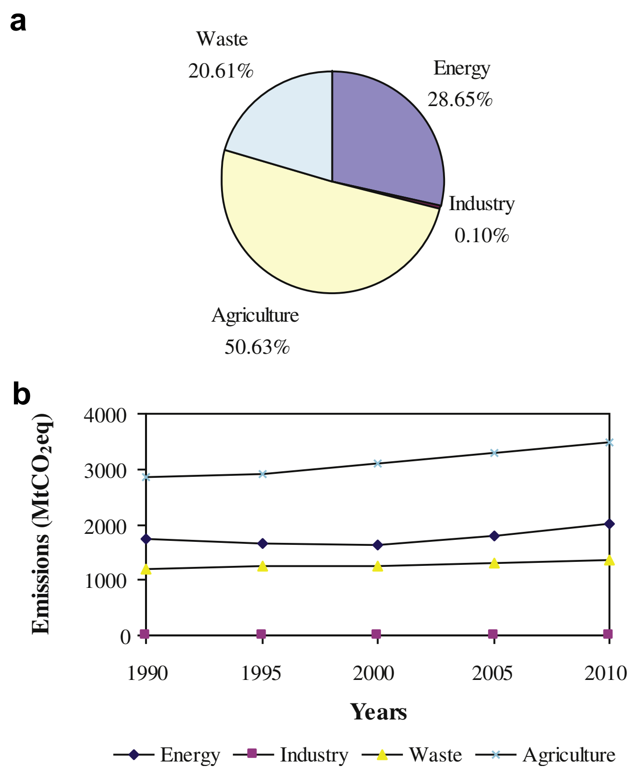

Fig. 1. a) Contribution of sectors to anthropogenic methane emissions, b) trends in methane emissions by sectors.

3. Energy

Energy sector is the second largest contributor to methane emissions. Methane emissions from energy are annually projected to be 1774.50 $MtCO_2eq$. This value constitutes 28.65% of the total methane emissions. 62.22% of emissions from energy sector results from natural gas and oil systems, followed by the emissions from coal mining, biomass combustion and stationary and mobile combustion respectively. Methane emissions from natural gas and oil, stationary and mobile combustion and biomass combustion increased, whereas the emissions from coal mining decreased between 1990 and 2010 (Fig. 3a). The rate of increase is at the highest level in the emissions from natural gas and oil systems. This can be explained by increase in demand for natural gas especially after 2000. Russian Federation constitutes 14.61% of the total emissions in this category, followed by the United States, China, Ukraine, India, Mexico and the other countries given in Fig. 3b respectively. The top six emitters account for 52.45% of the methane emissions from energy sector.

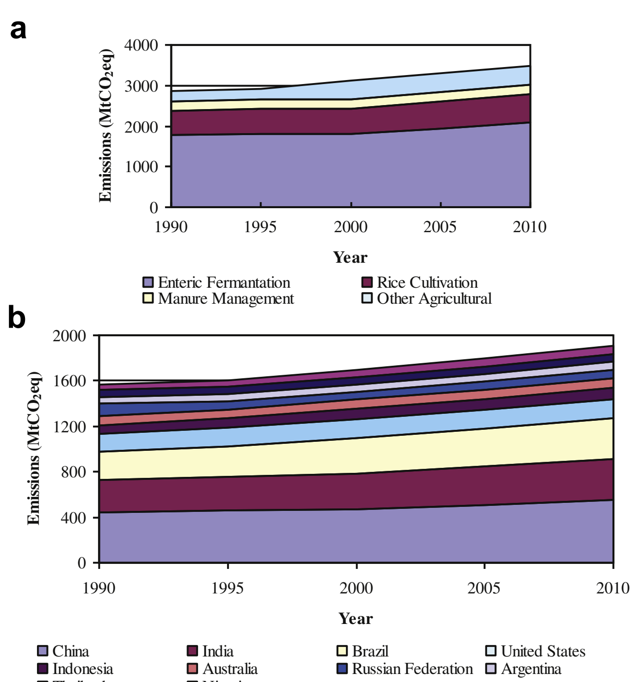

Fig. 2. a) Emissions trends of activities in agriculture sector and b) methane release performances of top ten emitters during study period.

3.1. Sources

Activities causing methane emissions in energy sector are natural gas and oil systems, coal mining, stationary and mobile combustion and biomass combustion.

Methane is the principal component (95 percent) of natural gas and is emitted from natural gas production, processing, transmission and distribution. Oil production and processing can also emit methane in significant quantities since natural gas is often found in conjunction with petroleum deposits [26]. In both oil and natural gas systems, methane is a fugitive emission from leaking equipment, system upsets, and deliberate flaring and venting at production fields, processing facilities, transmission lines, storage facilities, and gas distribution lines [3,27].

Methane emissions are released as a result of extraction processes of coal in both surface and underground coal mining. The methane released during the coal production, is diluted by using ventilation fans and emitted to the atmosphere in underground coal mines, whereas it is directly emitted to atmosphere in surface coal mines. Methane emissions from surface coal mines are less than emissions from underground coal mines owing to the low pressure and coal rank [28]. Coal rank and permeability, depth of seam, geologic parameters and the amount of production are among the factors that affect the quantity of methane released [29].

Carbon dioxide and water are developed when complete combustion is occurred in ideal conditions. It can be observed the incomplete combustion due to insufficient oxygen in spontaneous combustions. This kind of combustions results in methane emissions. The quantity of emission varies with respect to the content and combustion conditions of fuels However; combustion is a relatively minor contributor to overall methane emissions [30].

Methane is released as a result of incomplete biomass combustion. Fuel wood, charcoal, agricultural residues, agricultural waste, and municipal waste combustion are the major contributors to methane emissions within this category [31]. The amount of emission is related to the combustion conditions and content of fuel [3,32].

3.2. Mitigation

The methane emissions from natural gas and oil systems and coal mining constitute 86.35% of the total emissions in the energy sector. Thus, it is highly important to reduce methane emissions from energy sector.

Methane emissions from natural gas and oil systems can be reduced to 4–100% based on abatement options. These options are given below.

i. *Install Vapor Recovery Units and flare systems:* During crude oil storage, light hydrocarbons vaporize out of solution and vent

Table 3
Summary of methane mitigation strategies for dairy cows (Boadi et al., 2004).

Strategy	Potential CH_4 reduction	Technology availability/feasibility	Cost/production benefits
Improving animal productivity	20–30%	Feasible and practical	Increased feed cost increased milk production use of fewer animals less feed per kg of milk
Increasing concentrate levels at high levels of intake	25% or more	Feasible, for high producing cows, but may increase N_2O and CO_2 emissions	Increased feed intake increased feed cost, machinery/fertilizer use increased milk production
Processing of forages, grinding/pelleting	20–40%	Feasible	Increased cost of processing improved feed efficiency increased milk production
Forage species and maturity	20–25%	Feasible	Increased feed efficiency increased milk production
Rotational grazing of animals/early grazing	9% or more	Feasible	Increased cost of fencing increased management of animals increased feed intake increased milk production
Managed intensive grazing vs. confined feeding		Feasible needs more investigation	Cheaper feed cost may need supplements reduced milk fat/protein content higher net return
Use of high-quality forages/pastures	25% or more	Feasible	Increased feed intakeincreased milk production
Preservation of forage as silage vs. hay/additivesAddition of fats	up to 33% (model prediction)	Feasible Feasible and practical, but usage limited to 5–6% in diet	Limited studies Increased cost of diet increased or no effect on milk production may or may not affect milk fat
Use of ionophores, e.g., monensin, lasolocid	11–30%	Feasible, but not long lasting public concerns	Increased feed efficiency decreased feed intake increased milk production
Use of probiotics	10–50% (in vitro)	Feasible, needs more investigation	May increase feed intake may increase milk production or no change
Use of essential oilsUse of bovine somatotropin (bST)Protozoa inhibitors	8–14% (in vitro)9–16%20–50% (in vitro and in vivo)	Feasible, needs more investigation Not approved for use in Canada Not available for practical use	Not quantified Reduced feed cost Practicability and cost to be assessed
Propionate enhancers (fumarate, malate)	5–11% (in vitro)up to 23% (in vivo)	Possible microbial adaptation to fumaric acid	Economic feasibility ruminal adaptation and level of inclusion need to be evaluated
Use of acetogens	not quantified	Not available, needs more investigation	Needs further investigation
Use of bacteriocins, e.g., Nisin, bovicin HC5	up to 50% (in vitro)	May provide alternatives to ionophores needs more investigation	Production effects are to be evaluated
Use of methane inhibitors, e.g., BES, 9,10-anthraquinone	up to 71% (in vitro)	No compounds registered for use No long lasting effects identified	Increased cost of chemicals production effects not established
Immunization	11–23%	Not available, needs more investigation	May increase cost of production increased gain
Genetic selection (Use of high Net Feed Efficiency animals)	21%	Long term feasibility	Decreased feed intake increased feed efficiency

to the atmosphere. Vapor recovery units capture these vapors for fuel or sales. Flaring devices burn vented gas, thus converting methane to carbon dioxide. Applicable to onshore and offshore gas wells.

ii. *Install Plunger Lift System:* Instead of "venting" gas wells to the atmosphere to expel accumulated well bore fluids, a plunger lift uses the well's energy to efficiently push the fluids out of the well.
iii. *Green Completions:* After drilling new wells, instead of venting the well to remove debris (i.e., fluids, sand, and cuttings) from around the well bore, green completions use additional separator traps and dehydrators to route gas to sales [33,34].
iv. *Install Flash Tank Separators in Production:* Flash tank separators are used to recover methane from tri-ethylene glycol for fuel or sales, minimizing venting with water vapor.
v. *Install Flash Tank Separators in Processing and Transmission:* Flash tank separators are used to recover methane from tri-ethylene glycol for fuel or sales, minimizing venting with water vapor.
vi. *Replace High Bleed Pneumatics with Low Bleed Devices:* Natural gas powered pneumatic devices are designed to emit (bleed) natural gas as part of their normal operations. Such systems can be replaced with low bleed pneumatics.
vii. *Replace High Bleed Pneumatics with Instrument Air Systems:* Natural gas powered pneumatic devices can be replaced with compressed, dried air systems, eliminating methane emissions [35,36].
viii. *Composite Wrap Repairs:* For non-leaking damaged pipelines, composite wrap repairs can be implemented with the pipeline in service, preventing the need to shutdown and vent gas from the pipeline.
ix. *Portable Evacuation Compressor for Pipeline Venting:* This practice uses an in-line portable compressor to remove gas and lower pipeline pressure before venting.
x. *Fuel Gas Retrofit for Blowdown Valve:* Installing a connection to fuel gas, the methane that is typically vented during a compressor blowdown is recovered to supplement fuel [37,38].

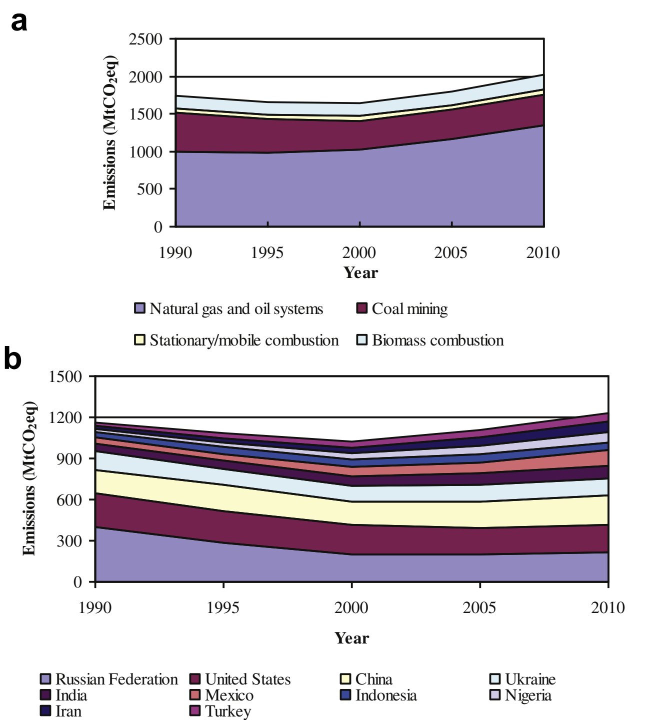

Fig. 3. a) Emissions trends of activities in energy sector and b) methane release performances of top ten emitters during study period.

xi. *Directed Inspection & Maintenance (DI&M) at Compressor Stations:* Conduct leak detection surveys of facilities to identify and repair leak sources that are cost effective.

xii. *DI&M at Gate Stations and Surface Facilities:* Conduct leak detection surveys of facilities and equipment to identify and repair leak sources [3].

It is possible to reduce methane emissions from coal mining. Methane has to be firstly captured from coal mines to use in some applications. In these applications, methane is converted carbon dioxide and its greenhouse effect would be decreased 20 times [39].

A general classification process for coal mine methane (CMM) mitigation and utilization technologies is illustrated in Fig. 4. Gas having high methane content in coal seams has to be recovered in order to both maintain the production activities efficiently and use in diverse areas of industries as long as no supply continuity problem of providing. Table 4 presents a description of degasification methods, efficiency of each methods and gas quality that can be recovered by these methods. The recovered gas may contain methane up to 95% [40] (Table 5).

While drained gas having methane concentration more than 30% could be used in diverse areas of industry, it is so difficult that the utilization of ventilation air containing very low methane as the air volume is large and variable in methane concentration. In order to not reduce only the effect of greenhouse gas but use it also in different areas, methane concentration of ventilation air has to be increased. Effective technology for increasing methane concentration is yet not available but is being developed and majority of works has been concentrated on the oxidation of methane in ventilation air. Methane is transformed to carbon dioxide by oxidation and energy production can be possible with the heat got out. As a result of oxidation, the effect of methane on climate changes can be reduced almost 20 times [41–43].

Oxidation technologies of methane may be classified as thermal and catalytic oxidation from the standpoint of the kinetic combustion mechanisms. Ventilation air methane is used as ancillary and principal fuel in these oxidation technologies [44,45].

3.2.1. *Principal uses of ventilation air methane*

Ventilation air can be used as principal fuel in combustion processes for mitigation and utilization of methane in vented air [46,47]. However, principal uses of ventilation air (VA) may not be possible for some technologies in terms of methane concentration for the operational requirement [48,49]. Mitigation and utilization technologies of ventilation air methane as a principal fuel are presented in Table 4. Ventilation air could be used in thermal and catalytic flow reverse reactors, catalytic-monolith reactors, lean burn gas turbines, concentrators [50,51].

3.2.2. *Ancillary uses of ventilation air methane*

The captured ventilation air can be used as an ancillary fuel to increase the combustion performance in combustion processes. Basic applications utilizing ventilation air methane as ambient air are pulverised coal-fired power stations, hybrid waste/coal methane combustion unit, gas turbines and internal combustion engines. An assessment of ancillary uses technologies of ventilation air is presented in Table 6 with respect to the main operational parameters such as combustion method, technical feasibility and engineering applicability [52,53].

Energy recovery from these technologies may be certain. Main issue is the safe connection of these units to mine shafts. But, this is a site specific and has not been fully examined [42,54,55].

4. Waste

The quantity of methane from waste is projected to be 1276.32 $MtCO_2eq$ annually. This emissions account for 20.61% of the anthropogenic methane emissions. The emissions from landfilling of solid waste (59.07%) and wastewater (40.81%) are two largest sources of emissions in this sector. Emissions from landfilling of solid waste showed a slightly decrease although the emissions from the other categories increased (Fig. 5a). The United States is the country that is the largest emitter in this sector. Its share in emissions related to waste is 13.82%. China, India and the other countries releasing relatively low methane emissions follow the United States respectively (Fig. 5b).

4.1. *Sources*

Main sources causing methane emissions in waste sector, are landfilling of solid waste, wastewater, human sewage, and other activities. The two largest sources of emissions within the waste sector are landfilling of solid waste and wastewater.

The oxygen in an environment is rapidly consumed by microorganisms in closed landfilling of solid waste and gases in the storage constitute stabilized wastes together with the percolating waters that have high pollutive concentrations [56,57]. Methane gas, one of the storage gases and constituting approximately 50% of storage gases, can be produced as a result of anaerobic decomposition of organic materials in landfilling of solid wastes. Principal parameters controlling the emissions from these wastes vary depending on the quantity of organic material, the duration of anaerobic decomposition and usability of methane in diverse areas [58,59].

Methane is emitted both incidentally and deliberately during the handling and treatment of municipal and industrial wastewater. The organic material in the wastewater produces methane when it decomposes anaerobically [60,61]. Most developed countries rely on centralized aerobic wastewater treatment to handle their municipal wastewater, so that methane emissions are small and incidental. However, in developing country areas with little or no collection and

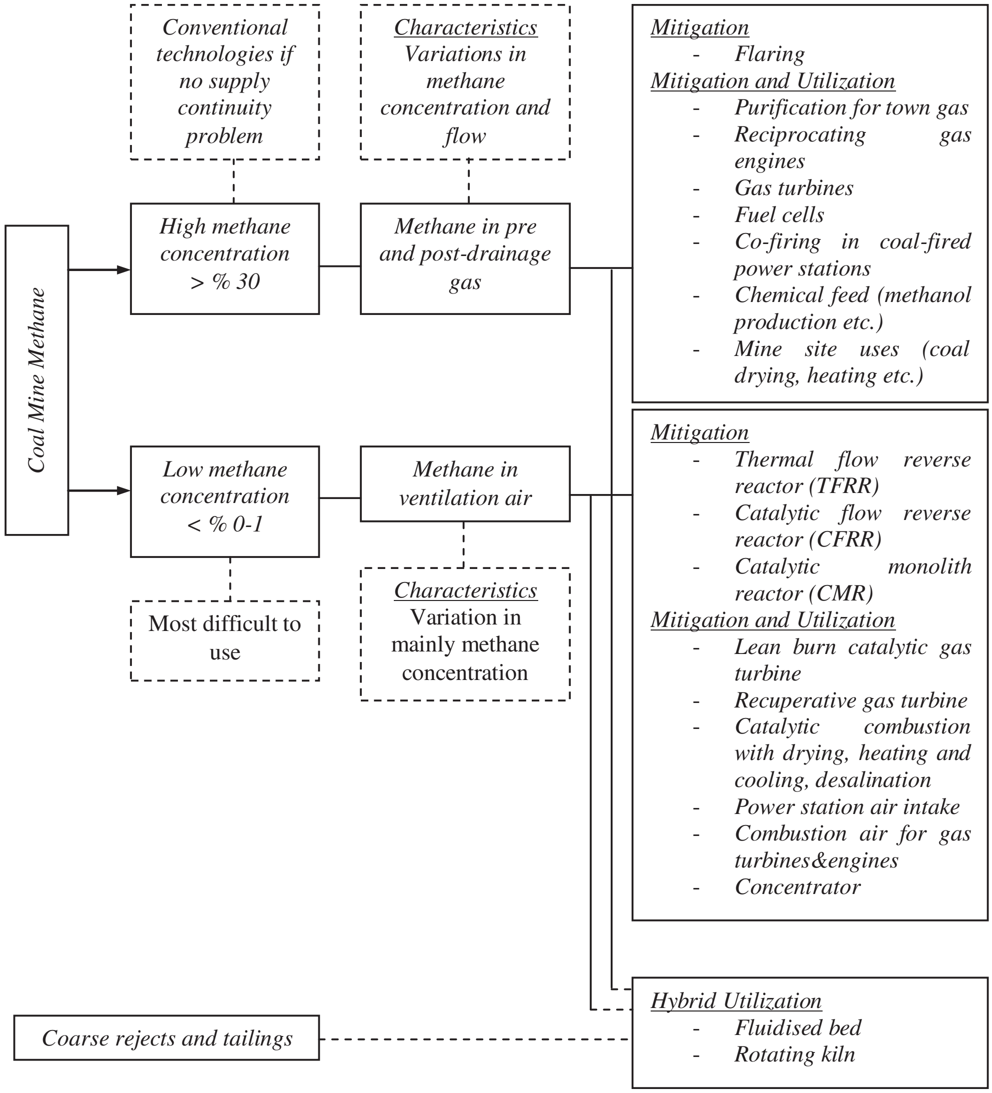

Fig. 4. Classifying of coal mine methane mitigation and utilization technologies.

treatment of wastewater, anaerobic systems such as latrines, open sewers, or lagoons are more prevalent [7].

This category includes emission sources as fugitives from solid fuels, miscellaneous waste handling practices, solvent and other product use and waste combustion. These sources encompass several different sectors, but are placed in the waste sector because waste combustion emissions dominate these miscellaneous sources.

4.2. Mitigation

A wide range of mature technologies is available to mitigate GHG emissions from waste. The mitigation of GHG emissions from waste relies on multiple technologies whose application depends on local, regional and national drivers for both waste management and GHG mitigation [62].

Table 4
Comparison of degasification methods (Bibler and Carothers, 2001; EPA-1, 1999).

Technique/parameter	Gas drained from gob area	Gas drained from coal seam
Recovery Techniques	- cross-measure boreholes - gob wells	- vertical wells - horizontal boreholes
Recovery Support Equipment	- In-Mine Drills and/or Surface Rigs - Compressors and pumps	- In-Mine Drills and/or Surface Rigs - Compressors and pumps
Gas quality	Medium (11–30 GJ/103m^3) (300-800 Btu/cf) (approx. 30–95% CH_4)	High (35–37 GJ/103m^3) (950-1000 Btu/cf) (above 95% CH_4)
Use Options	- On-Site Power Generation - Natural Gas Pipeline Injection (after upgrading) - Direct Use (on-site, utility, industry, etc.	Chemical Feedstocks In addition to those uses listed for Gob Gas
Availability	Currently Available	Currently Available
Applicability	Widely Applicable Site Dependent	Technology, Finance, and Dependent

* Utilization as combustion air is commercially successful, but use of flow-reversal reactors which convert methane in ventilation air to heat and power may require further demonstration prior to commercial use.

Table 5
Mitigation and utilization technologies of ventilation air methane as principal fuel (Su and Agnew, 2006).

Technology	Oxidation Mechanism	Principal	Application
Thermal flow reverse reactor (TFRR)	Thermal	Flow reverse reactor with regenerative bed	Mitigation: demonstrated Utilization: not demonstrated yet
Catalytic flow reverse reactor (CFRR)	Catalytic	Flow reverse reactor with regenerative bed	Mitigation: demonstrated Utilization: not demonstrated yet
Catalytic-monolith combustor	Catalytic	Monolith reactor with a recuperator	Mitigation: demonstrated Utilization: not demonstrated yet
Catalytic lean burn gas turbine	Catalytic	Gas turbine with a catalytic combustor and recuperator	Mitigation: combustion demonstrated Utilization: being developed in a lab scale unit
Recuperative gas turbine	Thermal	Gas turbine with a recuperative combustor and recuperator	Mitigation: combustion demonstrated Utilization: demonstrated in a pilot scale unit but needed further modification
Concentrator	N/A, Adsorption	Multi-stage fluidised/moving bed using adsorbent, and a desorber	Mitigation and utilization: under development.

Table 6
Mitigation and utilization technologies of ventilation air methane as an ancillary fuel (Su and Agnew, 2006).

Technology	Oxidation Mechanism	Principal	Application Status
Combustion air for conventional power station	Thermal	Combustion in power station boiler furnace	Mitigation/Utilization. In a pilot scale unit but, large scale unit studies under consideration.
Combustion air for gas turbines	Thermal	Combustion in conventional gas turbines combustor	Mitigation Utilization-studied
Combustion air for gas engine	Thermal	Combustion in a gas engine combustor	Mitigation Utilization-demonstrated
Hybrid waste coal/methane combustion in a kiln	Thermal	Combustion inside a rotating combustion chamber	Mitigation Utilization-being tried in a pilot scale unit.
Hybrid waste coal/methane combustion in a fluidised bed	Thermal	Combustion inside a fluidised bed	Mitigation Utilization-being proposed as a concept.

Gas collection, by vertical wells and horizontal trenches, typically begins after a portion of a landfill, called a cell, is closed. Vertical wells are most commonly used for gas collection, while trenches are sometimes used in deeper landfills, and may be used in areas of active filling. The collected gas is routed through lateral piping to a main collection header. Ideally, the collection system should be designed so that an operator can monitor and adjust the gas flow if necessary. Once the landfill methane is collected, it can be used in a number of ways, including electricity generation, direct gas use (injection into natural gas pipelines), powering fuel cells, or compression to liquid fuel.

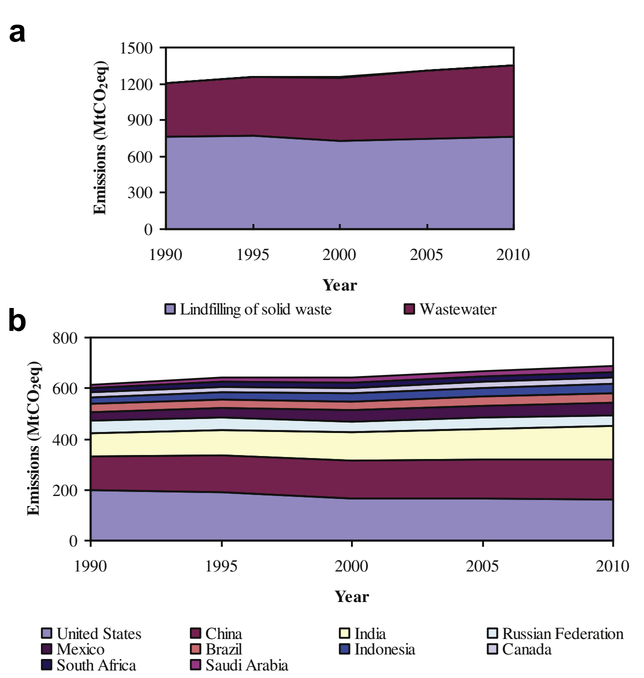

Fig. 5. a) Emissions trends of activities in waste sector and b) methane release performances of top ten emitters during study period.

4.2.1. *Electricity generation*

LFG collected at the landfill site is used for electricity generation. The gas is pumped out and then underwent pretreatment to remove CO_2 and yield CH_4. LFG collecting and processing plant requires a flare station to burn the excessive methane production. Energy from LFG can be transformed into cogeneration system or supplied to power plant and natural gas pipeline. LFG power generation engine is varied and each of them has benefits and drawbacks. Brief reviews of some traditional and current technologies are depicted in the following [63].

4.2.2. *Direct gas use*

Landfill gas is used as a medium- Btu fuel for boilers or industrial processes, such as drying operations, kiln operations, and cement and asphalt production. In these projects, the gas is piped directly to a nearby customer where it is used as a replacement or supplementary fuel.

4.2.3. *Reduced landfilling*

Landfilling is reduced through recycling, waste minimization, and waste diversion to alternative treatment and disposal methods, such as composting and incineration [59].

4.2.4. *Other options*

Landfill gas can be sold to the natural gas pipeline system once it has met certain process and treatment standards. This option is appropriate in limited cases, such as when very large quantities of gas are available. Additionally, landfill gas is processed into liquid vehicle fuel for use in trucks hauling refuse to a landfill.

CH_4 emissions can be virtually eliminated if wastewater and sludge are stored and treated under aerobic conditions. Options for preventing CH_4 production during wastewater treatment and sludge disposal include aerobic primary and secondary treatment and land treatment. Alternatively, wastewater can be treated under anaerobic conditions and the generated CH_4 can be captured and used as an energy source to heat the wastewater or sludge digestion tank. If additional CH_4 is available, it can be used as fuel or to generate electricity. As a last resort, the gas may be flared, which converts the CH_4 to CO_2, with a much lower global warming potential [64,65].

High-rate anaerobic processes for the treatment of liquid effluents with high organic content (e.g., sewage, food processing wastes) can help reduce uncontrolled CH_4 emissions and are particularly suited to the warmer climates of most developing countries. Both Brazil and India, for example, have developed extensive and successful infrastructure for these technologies, which have lower hydraulic retention times than aerobic processes and therefore are much smaller and cheaper to build. More importantly, unlike aerobic processes, no aeration is involved and there is little electricity consumption [66,67].

5. Conclusions

Global warming is considered as one of the important environmental problems. Increasing use of fossil fuels and destruction of forests cause a significant increase in the anthropogenic greenhouse gas emissions leading to global warming. Among these gases, methane is responsible for approximately 16% of the greenhouse effect. As a result of this study, it was disclosed that agriculture and energy sector are the biggest sources of anthropogenic methane emissions. These are responsible for 50.63% and 28.65% of the emissions, respectively. Waste and industry sectors follow these emissions. Due to the increase in population and living standards, and growth in energy consumption, methane emissions have increased recently and are estimated to increase in near future. Many technologies and practices presented in the paper can be considered to reduce methane emissions from all sectors.

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