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Analysis of methane emissions from natural gas and oil systems: 1990-2010

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ABSTRACT

The concentrations of anthropogenic emissions of greenhouse gases (GHG) in the atmosphere have considerably increased in recent years. This has caused to an increase in the greenhouse effect. Methane (CH_4), one of the greenhouse gases, is emitted from a variety of sources and its concentration in atmosphere has increased dramatically over the last few centuries. Natural gas and oil systems are one of the important sources of methane emissions whose concentration in atmosphere has rapidly increased. It is, therefore, highly important to determine the primary sources of emissions in terms of regions and countries. This paper examines the methane emissions from natural gas and oil systems from 1990 to 2010. It analyses the changes in methane emissions on the basis of geographic scale. Results indicate that the non-European Union nations had the biggest share in global methane emissions. Between these nations, Russian Federation was the highest emitter and its natural gas emissions dominate the region's emissions. Following the non-European Union nations, OECD countries and current members of the European Union were the next biggest contributors to the emissions. The United States was responsible for the majority of emissions in this group. Results also showed that these emissions can be decreased by nearly 100% using technology or equipment upgrades, improving management practices and operational procedures to reduce venting, enhancing management practices.

Doğal gaz ve petrol sistemlerinden kaynaklanan metan emisyonlarının analizi: 1990–2010

Anahtar Kelimeler:
Doğal gaz, Petrol, Metan emisyonu, Azaltım

ÖZET

Antropojenik sera gazı emisyonlarının atmosferdeki konsantrasyonları, son yıllarda önemli ölçüde artmıştır. Bu artış, sera gazı etkisinin de artmasına yol açmıştır. Sera gazlarından biri olan metan (CH_4), çeşitli kaynaklardan açığa çıkmakta olup, atmosferdeki konsantrasyonu son birkaç yüzyılda çarpıcı bir biçimde artmıştır. Doğal gaz ve petrol sistemleri, atmosferdeki konsantrasyonu hızla artan metan emisyonlarının önemli kaynaklarından biridir. Bu nedenle, bölgesel ve ülkeler bazında metan emisyonlarına sebep olan birincil kaynakların belirlenmesi önem arz etmektedir. Bu çalışma, doğal gaz ve petrol sistemlerinden kaynaklanan metan emisyonlarının 1990–2010 yılları arasındaki değişimi incelemektedir. Çalışma, metan emisyonlarındaki değişimi coğrafik ölçekte analiz etmektedir. Sonuçlar, Avrupa Birliği'ne üye olmayan ülkelerin küresel metan emisyonlarına sebep olan ülkeler içerisinde en büyük paya sahip olduğunu göstermektedir. Bu ülkeler içerisinde, en yüksek paya sahip olan ülkenin Rusya Federasyonu olduğu ve bu ülkenin bölgedeki metan emisyonları değişimi açısından baskın ülke olduğu belirlenmiştir. Avrupa Birliği'ne üye olmayan ülkelerin ardından, OECD ve Avrupa Birliği'ne üye ülkeler metan emisyonlarına en fazla sebep olan ülkelerdir. Bu gruplar içerisinde, Birleşik Devletler emisyonların çoğunluğundan sorumludur. Çalışmanın sonuçları ayrıca; doğal gaz ve petrol sistemlerinden kaynaklanan metan emisyonlarının, kullanılan ekipmanların yenilenmesi, yönetim prosedürlerinin iyileştirilmesi, havalandırmanın azaltılması gibi yöntemlerle neredeyse % 100 oranında azaltılabileceğini göstermiştir.

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1. Introduction

Anthropogenic emissions of greenhouse gases (GHG) have led, over the past 100 years, to a considerable increase in the concentration of these gases in the atmosphere [1]. The increase causes the greenhouse effect that is the sum of the interactions between the heat that is attempting to escape from earth to space and the molecules of various gases that trap the heat, reradiating it within the atmosphere, and impeding its loss to space. Without the greenhouse gases, the surface of the Earth would be as cold as the surface of the Moon (about -18 degrees Celsius or °C) [2]. Measurements taken from all over the world, however, have shown that the global climate is changing. In the last 100 years the atmosphere has warmed up by about half a degree Celsius. Also during the time humans have been emitting extra greenhouse gases, which are the result of burning fossil fuels (like coal, oil and gas) including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (NO_x) [2,3,4].

Methane is emitted from a variety of anthropogenic (human-induced) and natural sources and accounts for 16% of global GHG emissions (Fig.1). Human-induced sources include landfills, natural gas and oil systems, agricultural activities, coal mining, stationary and mobile combustion, wastewater treatment, and certain industrial processes. Approximately 60% of methane emissions come from these sources and the rest are from natural sources. Over the last two centuries, methane concentrations in the atmosphere have increased more than doubled [5]. Compared to carbon dioxide, methane is relatively short-lived and its atmospheric perturbation lifetime is 12 years [6]. As methane is a much more short-lived greenhouse gas than CO_2, it has high reduction potentials and high impacts on radioactive forcing within short time periods. On the other hand, methane has a higher global warming potential (GWP) than CO_2, controlling for its shorter atmospheric lifetime. GWP of methane is 21 relative to CO_2 on a 100 year time horizon (see Table 1) [7].

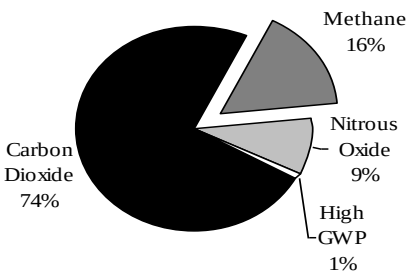

Fig.1. Contribution of Anthropogenic Emissions of Greenhouse Gases to the Enhanced Greenhouse Effect [8].

Table 1. Global Warming Potentials of greenhouse gases [8].

Gas	*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

Following the enteric fermentation, the oil and natural gas sector is the second biggest anthropogenic methane source releasing 1354.42 $MtCO_2eq$ (Million ton carbon dioxide equivalent) of methane to the atmosphere in 2010. It is highly important to determine the biggest emitters on the regional or local levels and understand the reasons affecting methane emissions so that the emissions can be reduced.

2. Method

Current study evaluates the methane emissions from natural gas and oil systems on the regional and local level. Grouping used in the study is based on the classification presented by EPA [8]. The groups include countries in the following geographic or geopolitical classifications:

i. OECD 1990 & EU3 - all of the countries in the Organization for Economic Cooperation and Development (OECD) as of 1990, the 25 current members of the European Union (EU), and countries whose accession to the EU is scheduled for 2007,
ii. Africa,
iii. China and Centrally Planned Asia (China/CPA),
iv. Latin America,
v. Middle East,
vi. Non-European Union nations that are newly independent states from the former Soviet Union (non-EU FSU),
vii. Other non-EU nations in Eastern Europe (non-EU Eastern Europe), and
viii. South and Southeast Asia (S&E Asia).

Changes of methane emissions by these groups from 1990 to 2010 were analyzed. Contribution and percentage change presented in this study were calculated based on the average emissions from 1990 to 2010. Natural gas and oil production and consumption

data were taken from BP Statistical Review of World Energy while the emission raw data are taken from a report published by EPA [8].

3. General outlook to world energy

World energy consumption increased from 8096.56 Mtoe in 1990 to 11164.3 Mtoe in 2009, with an annual increase rate of 2%. About 90% of the primary energy is currently supplied by fossil fuels (Fig.2a). Fossil fuel consumption increased from 1990 to 2010 as a result of increasing population which caused an increase in energy demand (Fig. 2b). Although renewable energy use increased, any critical changes have not been observed in its share of word energy consumption. The share of renewable energy in energy consumption was around 11% in 1990 and 12% in 2009 [9].

It is expected that an increase will be occurred in energy demand with an increasing role of natural gas mainly in electric power generation in the next two decades [10]. The share of oil and natural gas in word energy consumption was on average 69% from 1990 to 2009. Oil and natural gas consumption showed almost the same trend. Their consumption increased from 1990 to 2009, with a slight increase from 1990 to 1995, increasingly positive growth from 1995 to 2005 and little increase between 2005 and 2009, as shown in Fig 2b.

Production/Consumption (P/C) ratio is an indicator of energy transportation between the regions. Changes in both exports and imports of natural gas and oil are important to understand the changes in emissions because methane is released both production and transportation [11]. From 1990 to 1995, the P/Cs of Russian Federation and Canada for oil quickly rose up to 3.96 and 1.61, respectively. The oil production of Russian Federation in 2009 was 0.96 times of year 1990, while its consumption decreased 0.5 times. The oil production of Canada in 2009 was 168% of year 1990, while its consumption was 122%. The P/Cs of China, Mexico, Venezuela, Iran, Saudi Arabia, United Arab Emirates and United States decreased up to 0.47, 1.72, 4.56, 2.42, 3.77, 0.91 and 0.08, respectively (Table 2). P/Cs of Venezuela, Saudi Arabia and United Arab Emirates was extremely high (Fig 2c).

There was not any critical increase or decrease in natural gas production and consumption of countries that are responsible for majority of the emissions. The natural gas P/Cs of China, Mexico, Venezuela, Iran, Saudi Arabia and United Kingdom were around one in 1995. Russian Federation, the United States and Canada are the main natural gas producers of the world. The natural gas production of Russian Federation in 2009 was 0.89 times of year 1990, while its consumption increased 1.05 times. The natural gas production of the United States had generally increased in the period (Table 3). The natural gas production and consumption of the United States in 2009 was 117% of year 1990, while its consumption was 119% (Fig 2d).

4. Methane emissions from natural gas and oil systems

The oil and gas sector is the most complex source category. The high emissions of methane are connected with oil and gas production; crude oil transportation and refining, and natural gas processing, transportation and distribution [12, 13, 14, 15]. A more detailed breakdown of natural gas and oil industry is provided in Table 4.

Oil and natural gas are found as stored in porous and highly permeable reservoir rock, trapped under low permeability cap rock. Within the reservoir, oil and gas are arrayed vertically according to their densities, oil at the greatest depths and natural gas above. Natural gas is also usually found dissolved in the oil. The natural gas held in rock reservoirs typically contains between 70% and 100% methane. Methane in both oil and gas is produced during the thermal degradation of organic matter in sedimentary rocks [16]. Oil and gas are withdrawn from underground formations using on-shore and offshore wells. Gathering lines are used to bring the crude oil and raw gas to one or more collection point(s) within a production field [17, 18]. Because methane is the major component of natural gas, leaks or venting from these systems result in methane emissions [19].

Venting from crude oil storage facilities that hold the oil before it is piped or trucked to refineries is the largest contributor to methane emissions from the oil sector. The methane that is in solution vaporizes and is vented from the storage tanks directly to the atmosphere, unless it is captured by vapor recovery units. Some emissions occur as crude is transferred in tankers and pipelines for shipment to refineries. Refineries break crude oil down into its various components such as gasoline and kerosene. Refineries are responsible for only about 2% of the emissions from the oil sector [19, 20].

During processing, natural gas is dried and most of the heavier hydrocarbons or condensate is removed from the gas. Processed gas is then injected into the natural gas transmission system and the heavier hydrocarbons are marketed separately.

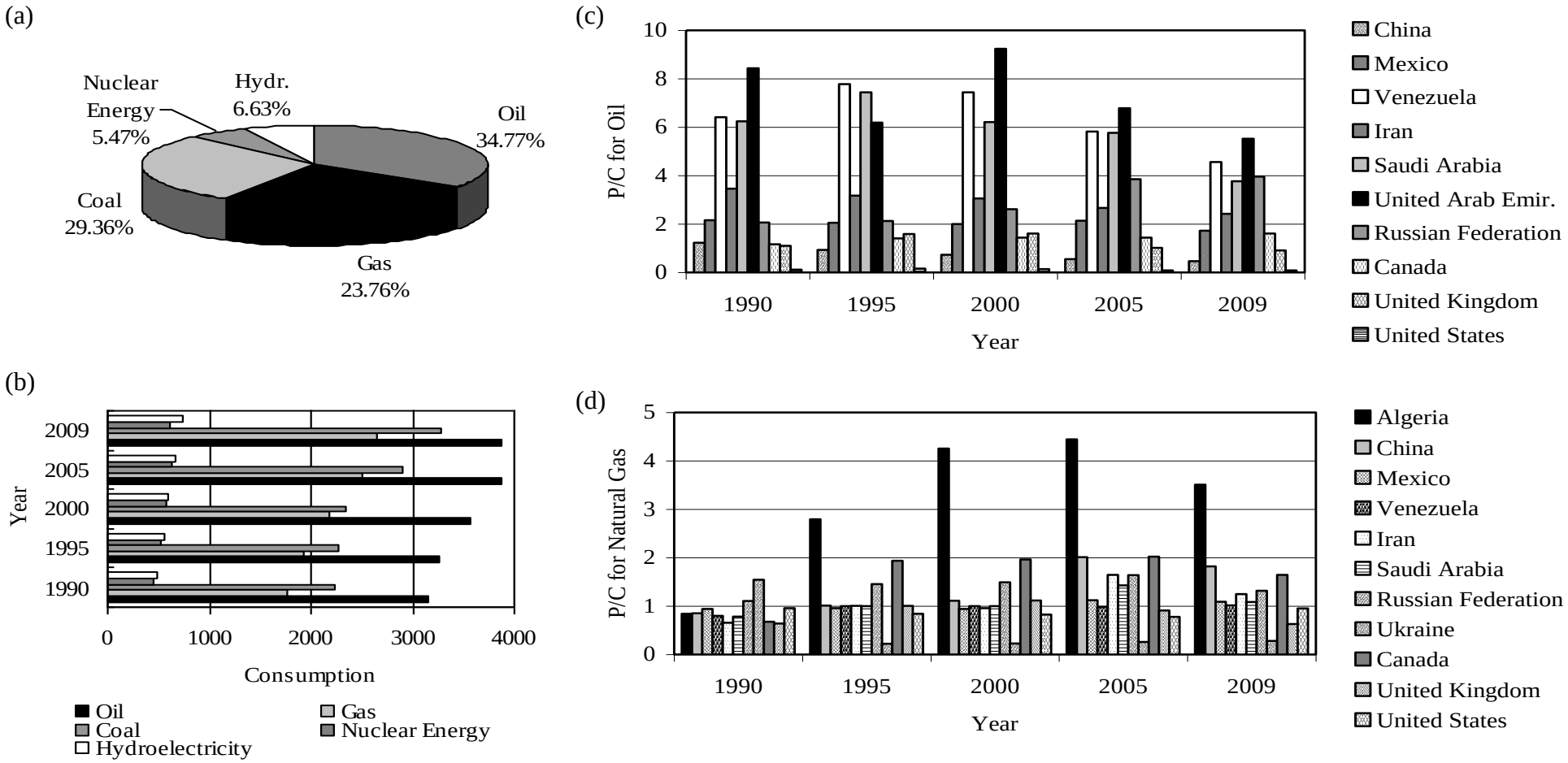

Fig. 2. General outlook of world energy: Primary energy sources and their share in word energy (a); their consumption between 1990-2009 (b); P/Cs for main oil (c) and natural gas (d) producer/consumers

Note: * In this figure, primary energy comprises commercially traded fuels only. Excluded, therefore, are fuels such as wood, peat and animal waste which, though important. Also excluded are wind, geothermal and solar power generation.

Table 2. Oil production and consumption of the countries accounting for majority of methane emissions in each region (Million tones equivalent oil)

Group	Production (Mt)							Consumption (Mt)						
	Country	1990	1995	2000	2005	2009	2009 share of total	Country	1990	1995	2000	2005	2009	2009 share of total
Africa	Algeria	57.5	56.6	66.8	86.4	77.6	2.03							
	Angola	23.4	31.2	36.9	69	87.4	2.29	Algeria	9.2	8.4	8.5	11.0	14.9	0.38
	Egypt	45.5	46.6	38.8	33.9	35.3	0.92	Egypt	23.8	23.3	27.2	29.8	33.7	0.87
	Libya	67.2	67.9	69.5	81.9	77.1	2.02	South Africa	16.6	20.0	22.0	24.3	24.3	0.63
	Nigeria	91.6	97.5	105.4	122.1	99.1	2.59							
China/CPA	China	138.3	149	162.6	180.8	189	4.95	China	112.9	160.2	223.6	327.8	404.6	10.42
	Vietnam	2.7	7.7	16.2	19.4	16.8	0.44							
Latin America	Argentina	25.4	37.5	40.4	36.2	33.8	0.88	Argentina	18.3	19.5	20.3	19.7	22.3	0.58
	Brazil	32.3	35.5	63.2	84.6	100.4	2.63	Brazil	64.3	76.1	91.6	89.5	104.3	2.69
	Colombia	22.3	29.5	35.3	27.3	34.1	0.89	Colombia	9.2	11.8	10.5	10.3	8.8	0.23
	Ecuador	14.9	20.1	20.9	27.6	25.2	0.66	Ecuador	4.2	5.1	5.8	7.5	9.9	0.25
	Mexico	146.3	150.5	171.2	187.1	147.5	3.86	Mexico	67.8	73.3	85.7	87.7	85.6	2.20
	Venezuela	117.8	155.3	167.3	151	124.8	3.27	Venezuela	18.4	20.0	22.5	25.9	27.4	0.71
Middle East	Iran	162.8	185.5	191.3	206.3	202.4	5.30							
	Iraq	105.3	26	128.8	90	121.8	3.19							
	Kuwait	46.8	104.9	109.1	129.3	121.3	3.17	Iran	47.1	58.5	62.5	77.3	83.6	2.15
	Oman	34.2	42.8	46.4	37.4	38.5	1.01	Kuwait	5.4	6.5	11.8	17.4	19.2	0.49
	Qatar	21.1	21.8	36.1	47.3	57.9	1.52	Saudi Arabia	54.9	58.9	73.4	91.4	121.8	3.14
	Saudi Arabia	342.6	438.4	456.3	526.8	459.5	12.03	United Arab Emir.	12.8	18.0	12.9	19.0	21.8	0.56
	Syria	20.2	29.6	27.3	22.4	18.7	0.49							
	United Arab Emir.	107.5	111.1	119.3	129.0	120.6	3.16							
	Yemen	8.7	16.7	21.3	19.6	14.0	0.37							
Non-EU Former Soviet Union	Azerbaijan	12.5	9.2	14.1	22.4	50.6	1.32	Azerbaijan	8.5	6.6	6.3	5.4	2.8	0.07
	Kazakhstan	25.8	20.6	35.3	62.6	78	2.04	Belarus	24.8	10.4	7.0	7.1	9.4	0.24
								Kazakhstan	21.6	12.0	7.4	11.0	12.0	0.31
	Russian Federation	515.9	310.7	323.3	470.0	494.2	12.94	Russian Federation	249.7	146.1	123.5	121.9	124.9	3.22

Table 2. Continued

up	Production (Mt)							Consumption (Mt)						
	Country	**1990**	**1995**	**2000**	**2005**	**2009**	**2009 share of total**	**Country**	**1990**	**1995**	**2000**	**2005**	**2009**	**2009 share of total**
South & South. Asia	India	34.2	36.6	34.2	34.6	35.4	0.93	S. Korea	49.5	94.9	103.2	105.4	104.3	2.69
	Indonesia	74.4	76.5	71.5	53	49	1.28	Thailand	19.7	35.0	36.7	47.0	44.2	1.14
								Australia	31.6	35.3	37.7	39.8	42.7	1.10
								Canada	79.8	79.8	88.1	100.3	97.0	2.50
								France	89.4	89.0	94.9	93.1	87.5	2.25
	Australia	28.8	25.4	35.3	24.5	23.6	0.62	Germany	127.3	135.2	129.8	122.4	113.9	2.93
	Canada	92.6	111.9	126.9	144.9	155.7	4.08	Italy	93.6	95.5	93.5	86.7	75.1	1.94
	Norway	82.1	138.4	160.2	138.2	108.3	2.83	Japan	247.7	267.6	255.5	244.1	197.6	5.09
OECD1990 & EU	United Kingdom	91.6	129.9	126.2	84.7	68	1.78	Netherlands	35.9	39.0	42.7	50.8	49.4	1.27
	United States	91.6	129.9	126.2	84.7	68	1.78	Spain	48.7	56.4	70.0	78.8	72.9	1.88
								Turkey	22.1	28.4	31.1	30.2	28.9	0.74
								United Kingdom	82.9	81.9	78.6	83.0	74.4	1.92
								United States	781.8	807.7	897.6	951.4	842.9	21.71
Total		**3171.7**	**3283.1**	**3609.0**	**3898.6**	**3820.5**			**3150.9**	**3150.9**	**3266.1**	**3562.1**	**3877.8**	

Table 3. Natural gas production and consumption of the countries accounting for majority of methane emissions in each region (Million tones equivalent oil)

Group	Production (Mtoe)							Consumption (Mtoe)						
	Country	1990	1995	2000	2005	2009	2009 share of total	Country	1990	1995	2000	2005	2009	2009 share of total
Africa	Algeria	44.3	52.8	76.0	79.4	73.3	2.97	Algeria	18.2	18.9	17.9	20.9	24.0	0.90
	Egypt	7.3	11.3	18.9	38.3	56.4	1.09	Egypt	7.3	11.3	18.0	28.4	38.3	1.44
	Nigeria	3.6	4.4	11.3	20.2	22.4	0.57							
China/CPA	China	13.8	16.2	24.5	44.4	76.7	1.43	China	13.7	16.0	22.1	42.1	79.8	3.01
	Vietnam		0.1	1.4	6.2	7.2	0.11	Cambodia	13.7	16.0	22.1	42.1	79.8	3.01
Latin America	Argentina	16.1	22.5	33.7	41.1	37.2	1.36	Argentina	18.3	24.3	29.9	36.4	38.8	1.46
	Brazil	2.8	4.6	6.7	9.9	10.7	0.32	Brazil	2.8	4.6	8.5	17.4	18.3	0.69
	Mexico	24.4	25.9	34.0	40.5	52.4	1.59	Mexico	24.8	27.0	36.2	48.0	62.7	2.36
	Venezuela	19.8	24.8	25.1	24.7	25.1	1.12	Venezuela	19.8	24.8	25.1	24.7	26.8	1.01
Middle East	Bahrain	5.2	6.5	7.9	9.6	11.5	0.36	Iran	20.4	31.7	56.6	94.5	118.5	4.47
	Iran	20.8	31.8	54.2	93.2	118.1	2.66	Kuwait	3.8	8.4	8.6	11.0	12.1	0.45
	Kuwait	3.8	8.4	8.6	11.0	11.3	0.37	Saudi Arabia	30.2	38.6	44.8	64.1	69.7	2.63
	Qatar	5.7	12.2	21.3	41.2	80.4	1.26	United Arab Emir.	15.2	22.3	28.3	37.9	53.2	2.00
	Saudi Arabia	30.2	38.6	44.8	64.1	69.7	2.21	Qatar	5.7	12.2	8.7	16.8	19.0	0.72
	United Arab Emir.	18.1	28.2	34.5	43.0	44.0	1.55	Russian Federation	366.8	330	318.6	360.2	350.7	13.22
Non-EU Former Soviet Union	Russian Federation	531.0	479.3	475.7	522.1	474.8	22.82	Turkmenistan	8.6	7.0	11.0	14.5	17.8	0.67
	Turkmenistan	71.5	26.3	38.3	51.3	32.7	1.92	Ukraine	111.6	66.5	63.9	62.1	42.3	1.59
	Ukraine	22.9	14.8	14.6	16.7	17.3	0.74	Uzbekistan	32.2	37.0	41.1	38.4	43.9	1.65
	Uzbekistan	33.2	39.5	45.9	48.6	58.0	2.02	India	10.8	16.9	23.7	32.1	46.7	1.76
South & South. Asia	India	10.8	16.9	23.7	26.7	35.3	0.99	Indonesia	15.2	25.3	26.8	29.9	33.0	1.24
	Indonesia	39.5	54.6	58.7	64.1	64.7	2.61	Pakistan	11.0	14.0	19.4	32.0	34.1	1.29
	Pakistan	11.0	14.0	19.4	32.0	34.1	0.97	Thailand	5.9	10.2	19.8	29.3	35.3	1.33
	Thailand	5.9	10.2	18.2	21.3	27.8	0.74							

Table 3. Continued

Group	Production (Mtoe)							Consumption (Mtoe)						
	Country	1990	1995	2000	2005	2009	2009 share of total	Country	1990	1995	2000	2005	2009	2009 share of total
OECD1990 & EU	Australia	18.7	26.8	28.0	33.4	38.1	1.29	Australia	18.7	26.8	28.0	33.4	38.1	1.29
	Canada	97.7	143.8	164.0	168.7	145.3	6.76	Canada	97.7	143.8	164.0	168.7	145.3	6.76
	Netherlands	54.9	61.0	52.3	56.3	56.4	2.53	Netherlands	54.9	61.0	52.3	56.3	56.4	2.53
	Norway	22.9	25.0	44.8	76.5	93.1	2.28	Norway	22.9	25.0	44.8	76.5	93.1	2.28
	United Kingdom	40.9	63.7	97.5	79.4	53.7	3.25	United Kingdom	40.9	63.7	97.5	79.4	53.7	3.25
	United States	461.8	480.9	495.5	467.6	541.8	22.20	United States	461.8	480.9	495.5	467.6	541.8	22.20
Total		**1790.3**	**1909.7**	**2178.0**	**2509.1**	**2696.0**			**1769.3**	**1924.1**	**2175.5**	**2498.3**	**2653.1**	

Major methane emissions sources in the gas processing are compressor fugitives, compressor exhaust, vents, pneumatic devices, and blowdown. Most fraction of the gas is transported through transmission and distribution pipelines while a small amount of gas is shipped by tanker as liquefied natural gas (LNG). Transmission pipelines are large diameter, high pressure lines that transport gas from production fields, processing plants, storage facilities, and other sources of supply over long distances to local distribution companies, or large volume customers. Major methane emissions sources are chronic leaks, compressor fugitives, compressor exhaust, vents, and pneumatic devices in transmission pipeline [20-21].

Table 4. Sources of methane emissions from natural gas and oil systems [14]

Categories	Segment	Major Emission Sources	Other Possible Emission Sources
Oil and Gas Production	Oil and Gas Wells Gathering lines Treatment facilities	Venting Normal operations: fugitive emissions; deliberate releases from pneumatic devices and process vents	Flaring, maintenance, system upsets and accidents
Crude oil transportation and Refining	Pipelines Tankers Storage tanks Refineries	Normal operations: fugitive emissions; deliberate releases from process vents at refineries, during loading and unloading of tankers and storage tanks	Flaring, maintenance, system upsets and accidents
Natural Gas Processing, Transportation, and Distribution	Gas Plants Underground storage reservoirs Transmission Pipelines Distribution Pipelines	Normal operations: fugitive emissions; deliberate releases from pneumatic devices and process vents	Flaring, maintenance, system upsets and accidents

5. Analysis of the emissions from natural gas and oil systems

Methane is released from activities conducted in energy, waste, agriculture, and industry sector. Energy sector following the agricultural sources was the second biggest contributor to global methane emissions. It was responsible for 29% (1774.50 $MtCO_2eq$) of anthropogenic methane emissions (Fig.3a). These emissions increased from 1990 to 2010, especially after 2000. Percentage change was 17% (Fig.3b). Although there were many reasons causing the increase in emissions from energy sector, main factors can be ranged as follows:

i. the economic restructuring in the Eastern Europe and the Former Soviet Union,
ii. a shift from coal to natural gas as an energy source in several regions,
iii. restructuring in several key coal mining countries and
iv. expansive growth in energy consumption in less developed regions [8, 12].

Natural gas and oil systems are a significant source of global methane emissions from energy sector [13]. The source emitted approximately 1104.03 $MtCO_2eq$ annually and constituted 62% of methane emissions from energy sector (Fig.3c). In other words, 18% of global anthropogenic methane emissions were released from the activities in natural gas and oil systems. Emissions from this source increased between 1990 and 2010, with a slight decrease between 1990 and 1995, increasingly positive growth between 1995 and 2010, as shown in Fig.3d. The non- EU FSU economic transition, the mild growth in production in parts of the OECD, and the accelerated growth in energy production and demand in all other regions (especially Asia) affected the overall trend in the emissions.

Emissions over the period of 1990-2010 increased in all regions except the non-EU FSU, as shown in Table 5. Although the rank order of the regions did not change during the study period, each region's contribution to global emissions changed dramatically. Non-EU FSU and OECD90 & EU's total emissions accounted for the majority of anthropogenic methane emissions from natural gas and oil systems (Fig.4a). These regions were followed by Middle East, Latin America, SE Asia, Africa, China/CPA and Non-EU Eastern Europe. Changes in emissions by these groups are shown in Fig.4b.

Non-EU FSU was the biggest emitter and the only group where methane emissions decreased. Russian Federation, Ukraine, Uzbekistan, Turkmenistan and Azerbaijan were the countries having big share in emissions from the group (Fig.5a). Only Russian Federation is responsible for 55% of these emissions. Natural gas emissions by Russian Federation dominate this region's emissions. Economic transition of Russia Federation caused a short term decline in the production

and use of natural gas and oil, which leads to a sharp decrease in emissions from 1990 to 2000 [8]. Following Russian Federation, Ukraine was the important emitter in the group. Methane emissions from Ukraine accounted for 22% of emissions by group and have increased by 20% in study period. Other countries in the group emit low methane, respectively (Table 5).

After the non-EU FSU, OECD90 & EU was the next biggest emitter of methane. The share of this group in global methane emissions was 25%. United States, Canada, Turkey, Romania, England and Germany were the major countries releasing methane (Fig.5b). Among the country in the group, just the United States released about 52% methane. During the period of 1990-2010, United States has decreased its methane emissions by about 142.37 $MtCO_2eq$. Although the consumption of natural gas and oil in the United States has increased, methane emissions by this country has decreased (Table 5). This can be explained by the decrease in oil production and mature natural gas and oil industries with stabilized or limited growth in production sectors. Turkey's methane emissions were the second biggest share (14%) in total emissions. Canada, following Turkey was one of the big emitters in the group and accounts for 13% of emissions by the group. Methane emission from this country has increased by 49% from 1990 to 2010. Other countries in this group emit low methane compared to countries given above. Many OECD countries have instituted air quality and safety rules that have the ancillary benefit of reducing methane emissions. However, it is likely that there will be a continued and growing demand for natural gas in the OECD, which may result in increased emissions in the distribution and transmission sectors [8].

Table 5. Numerical evaluation of regional methane emissions from natural gas and oil systems

Group	Country	Average Emissions between 1990 and 2010 ($MtCO_2eq$)	Share 2010 over 1990		Percentage Change between years %				
			Local %	Cumulative %	90-95	95-00	00-05	05-10	90-10
Africa	Nigeria	36.94	57	57	38	113	30	21	362
	Algeria	13.69	21	78	14	40	1	21	95
	Others	7.90	12	90	6	14	10	20	59
	Egypt	6.60	10	100	52	46	21	21	222
	Total	**65.14**			**26**	**70**	**20**	**21**	**211**
China/ CPA	China	5.07	96	96	18	57	54	62	364
	Vietnam	0.19	4	100	1400	60	17	4	2800
	Total	**5.26**			24	57	52	60	375
Latin America	Mexico	65.33	50	50	7	36	27	33	147
	Venezuela	39.89	30	80	17	8	20	12	70
	Argentine	13.29	10	90	37	36	0	12	109
	Others	13.03	10	100	22	42	25	32	184
	Total	**131.54**			**15**	**27**	**21**	**25**	**120**
Middle East	Iran	44.43	34	34	48	16	64	30	268
	Others	44.43	34	68	40	23	16	22	143
	United Arab Emirates	34.14	26	94	40	83	12	22	249
	Kuwait	7.96	6	100	8	58	-2	22	103
					-5	16	-4	22	28
	Total	130.98			**36**	**39**	**25**	**25**	**196**
Non-EU Eastern Europe	Albania	0.06	4	4	-89	0	50	33	-79
	Croatia	1.26	75	78	-8	1	20	17	31
	Others	0.37	22	100	371	-70	8	38	112
	Total	**1.68**			**24**	**-29**	**18**	**21**	**26**
Non-EU FSU	Russian Fed.	219.09	55	55	-28	-31	4	4	-47
	Ukraine	86.62	22	77	4	6	4	4	20
	Uzbekistan	35.29	9	86	11	15	14	12	63
	Turkmenistan	35.78	9	95	-14	46	90	56	270
	Azerbaijan	7.97	2	97	-16	-28	37	25	3
	Others	10.50	3	100	-31	18	34	30	43
	Total	**395.25**			**-20**	**-15**	**13**	**13**	**-14**
SE Asia	Indonesia	43.45	46	46	30	4	10	2	53
	Others	16.95	18	64	30	32	35	4	141
	India	19.72	21	85	56	26	63	38	345
	Pakistan	5.53	6	91	34	32	-1	4	82
	Thailand	5.85	6	97	30	84	12	4	181
	South Korea	3.12	3	100	183	98	26	49	948
	Total	**94.62**			**36**	**20**	**24**	**13**	**126**
OECD90 & EU	United States	144.00	52	52	3	-2	-15	12	-4
	Others	30.09	11	63	-3	-6	13	13	16
	Canada	35.39	13	75	34	9	0	2	49
	Turkey	39.44	14	90	41	34	30	12	176
	Romania	12.22	4	94	-43	-27	11	29	-40
	England	8.94	3	97	-6	-17	-4	-4	-28
	Germany	7.46	3	100	8	-3	5	0	10
	Total	**277.53**			**4**	**1**	**-2**	**10**	**14**
World Totals			**1104.03**		**-2**	**5**	**13**	**16**	**36**

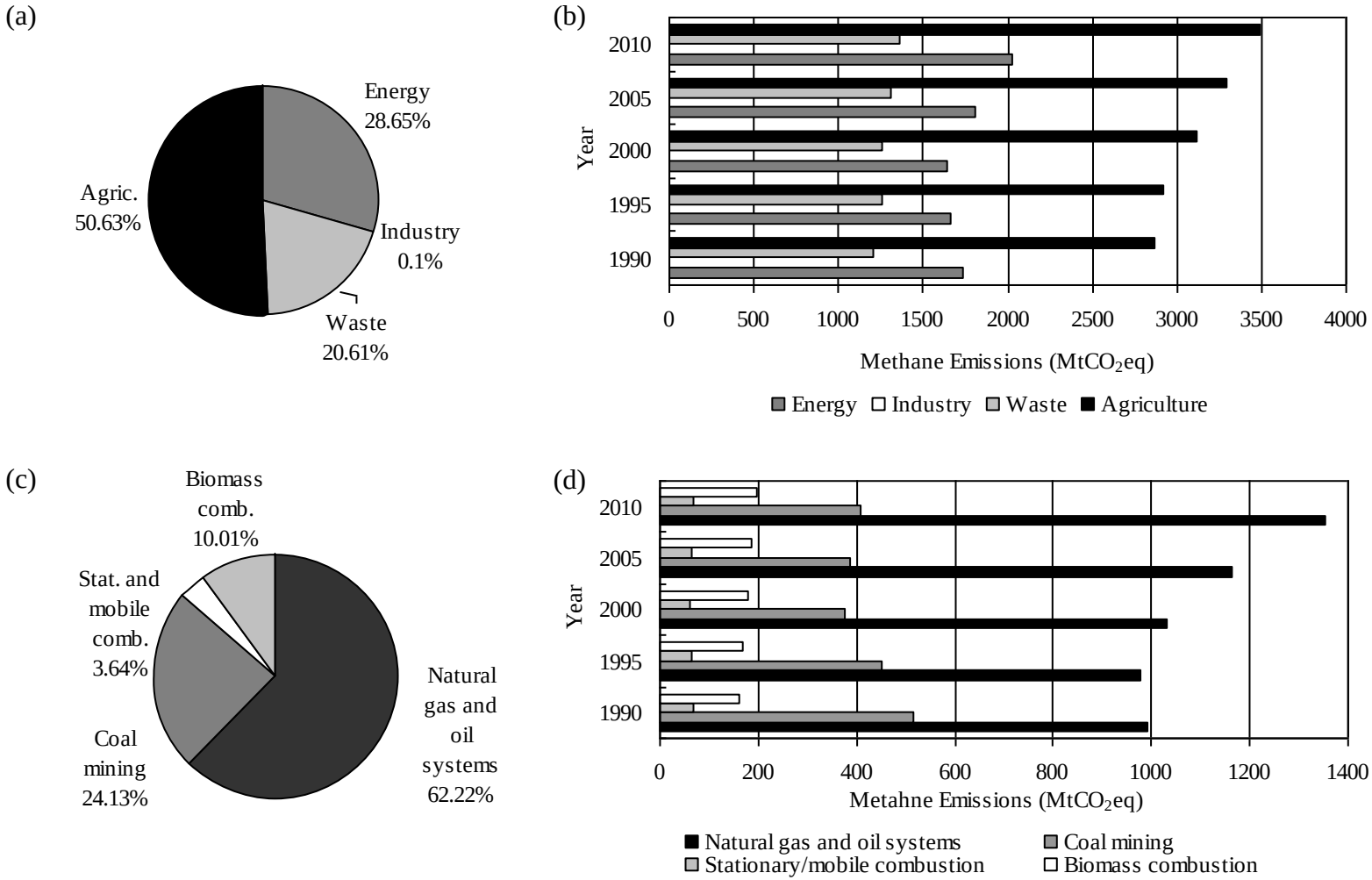

Fig. 3. General outlook of methane emissions from natural gas and oil systems: Sectoral contribution to methane emissions (a) and change in emissions by sectors between 1990 and 2010 (b); contribution of activities in energy sectors to energy-related emissions (c) and changes of emission by the activities defined in defined period (d).

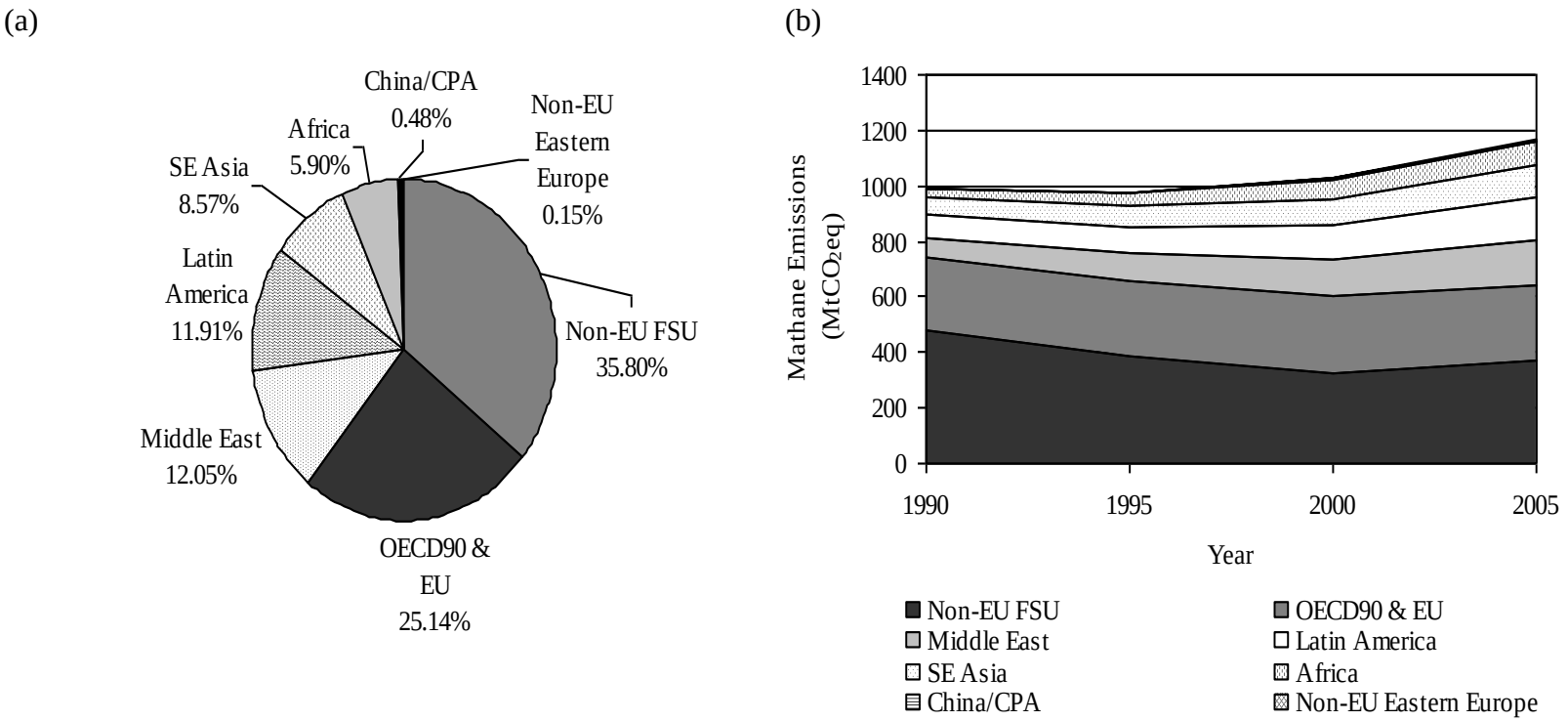

Fig 4. Share of emissions by the groups in global methane emissions (a) and changes in these emissions between 1990 and 2010 (b).

Middle East was the third biggest emitter of methane and responsible for 12% of the emissions. Iran, United Arab Emirates and Kuwait were the countries releasing majority of methane in the group (Fig.5c). The share of Iran and United Arab Emirates in methane emissions was 79%. Percentage change of emissions by these countries was 267.82 and 143.49 respectively. These were caused by the increase in oil and natural gas production of the countries. Oil production of Iran and United Arab Emirates increased from 162.8 Mtoe and 107.5 Mtoe to 202.4 Mtoe and 120.6 Mtoe between 1990 and 2009, respectively (see Table 2). Similarly, natural gas production of Iran and United Arab Emirates increased from 20.80 Mtoe and 18.10 Mtoe to 118.10 Mtoe and 44.00 Mtoe, respectively (see Table 3).

Latin America followed Middle East as emitter that was responsible for 12% emissions of methane. Mexico, Venezuela and Argentine were the countries accounting for majority of emissions in the group (Fig.5d). Mexico was the biggest emitter and its share in methane emissions by group was 50%. These emissions have dramatically increased by 147% from 1990 to 2010. Methane emission by Venezuela was 39.89 $MtCO_2eq$ that makes it be responsible for 30% of emissions. On the other hand, these two countries released 80% of the group emissions. Argentine followed these countries with a share of 10% (see Table 5).

94.62 $MtCO_2eq$ of methane released by SE Asia. These emissions have a share of 9% in the emissions and dramatically increased by 126% between 1990 and 2010. Indonesia, India, Pakistan, Thailand and South Korea were the main emitters in the group (Fig.6a). Indonesia is the biggest share in the emissions by the group and accounted for 46% of the emissions. The highest increase was observed in the emissions by Indonesia from1990 to 1995. Percentage change of these emissions between in study period was 53%. India has also big share in methane emissions and emission from this country has increased between the studied period where the percentage change of emission extremely high (344.93%) (see Table 5).

Africa released 65.14 $MtCO_2eq$ methane and these emissions dramatically increased especially from 1995 to 2000 (Fig.6b). Overall percentage change of emissions in study period was 211%. Nigeria, Algeria and Egypt were the primary emitters in the group. Only Nigeria released 57% of methane emissions by the group. Algeria and Egypt followed Nigeria with contributions rate of 21% and 10%, respectively. These three countries account for 88% of methane emissions released by this group (see Table 5).

China/CPA shows the largest rate of growth in emissions at 375%; however, it still accounts for only 5% of the global total emissions since it relies more heavily on coal than oil and gas production for its energy needs (Fig.6c; Table 5). Non-EU Eastern is the lowest emitter between the groups and only responsible for 2% of global methane emission (Fig.6d).

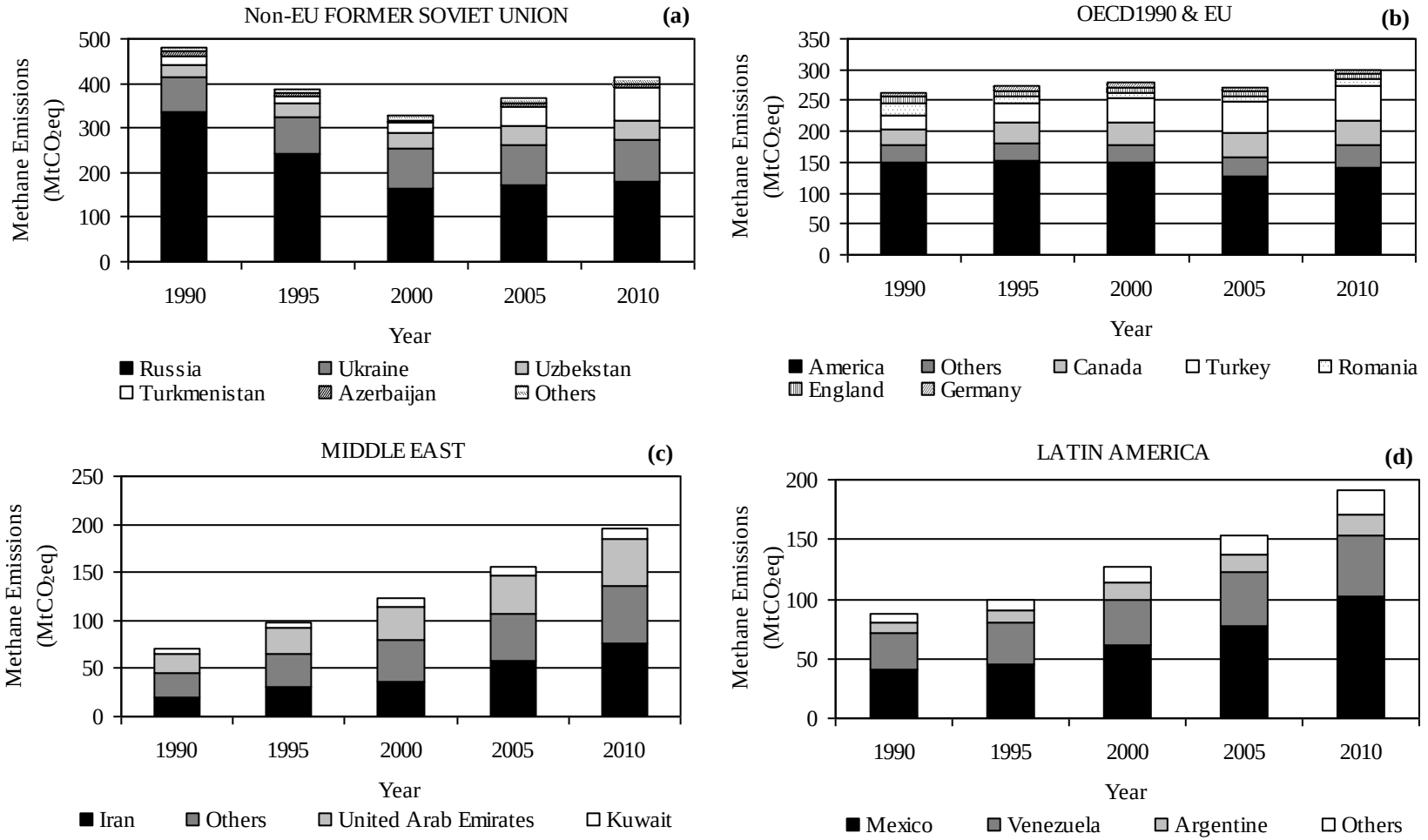

Fig. 5. Changes in methane emissions released by the biggest emitters in the groups of non-EU Eastern Europe (a), OECD1990 & EU (b), Middle East (c) and Latin America (d).

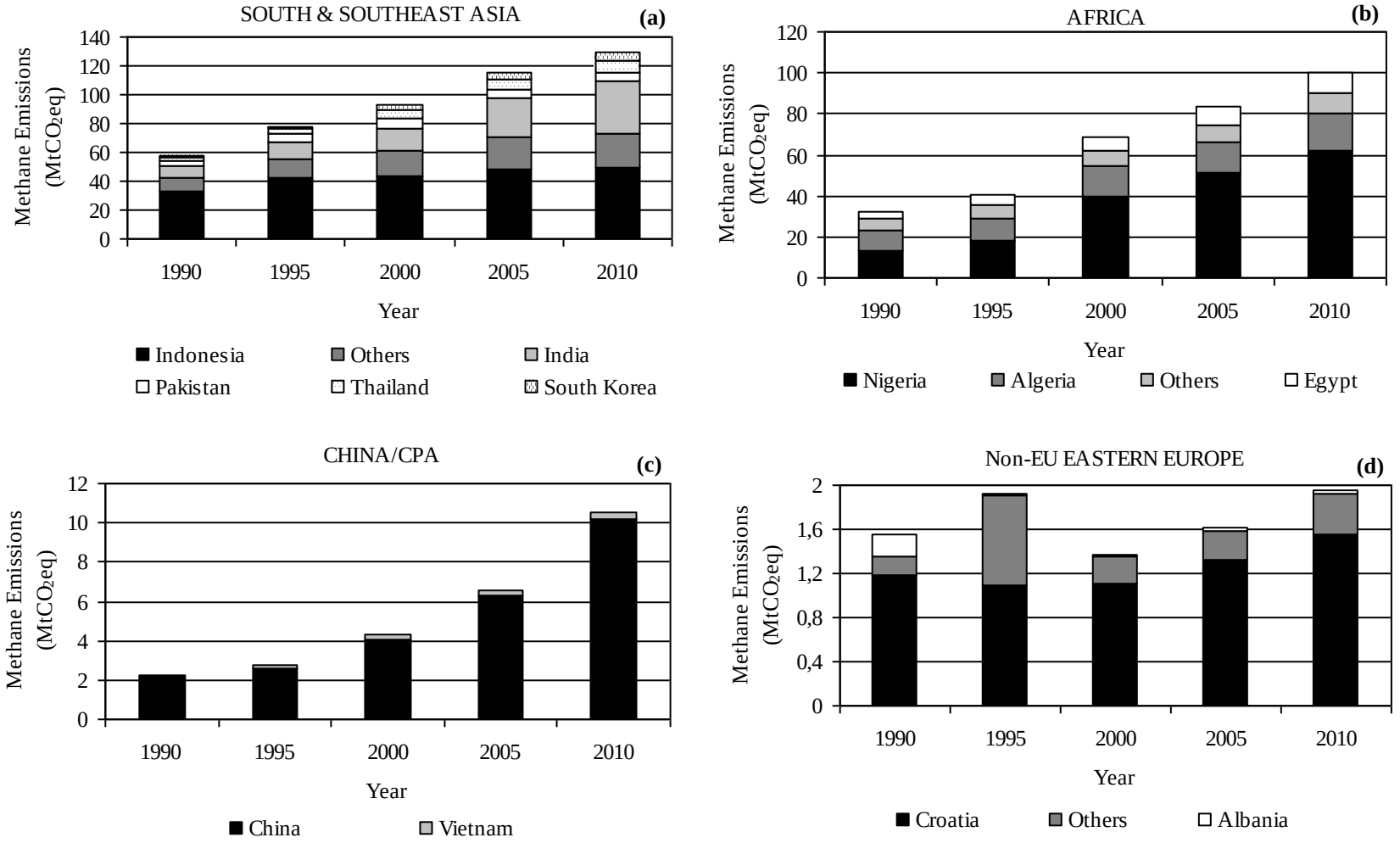

Fig. 6. Changes in methane emissions released by the biggest emitters in the group of South & Southeast Asia (a), Africa (b), China/CPA (c), non-EU Eastern Europe (d).

6. Emission mitigation

Many technologies and practices are available to reduce methane emissions cost-effectively. Opportunities to reduce methane emissions generally fall into one of three categories:

i. Technology or equipment upgrades, such as low-emission regulator valves, that reduce or eliminate equipment venting or fugitive emissions
ii. Improvements in operational procedures and management practices to reduce venting
iii. Enhanced management practices, such as leak detection and measurement programs, that take advantage of improved measurement or emission reduction technology [22, 23, 24]

Table 6 provides detailed options to reduce methane emissions from natural gas and oil systems, which includes abatement options, description of options, applicable sub-sector and reduction efficiency. Methane emissions from natural gas and oil systems can be reduced by 4 to 100% based on abatement options [25, 26].

Table 6. Summary of Natural Gas Infrastructure Emissions Mitigation Options [26]

Abatement Option	***Description***	***Applicable Sub-Sector***	***Reduction Efficiency***
Install Vapor Recovery Units	During crude oil storage, light hydrocarbons vaporize out of solution and vent to the atmosphere. Vapor recovery units capture these vapors for fuel or sales.	Crude Oil Storage Tanks	95
Install Flare Systems	Flaring devices burn vented gas, thus converting methane to carbon dioxide. Applicable to onshore and offshore gas wells.	Natural Gas (NG) Production	95
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.	NG Production	4
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.	NG Production	70
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.	NG Production	54
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.	NG Processing and Transmission	54
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.	NG Production, Processing and Transmission	86
Replace High Bleed Pneumatics with Instrument Air Systems	Natural gas powered pneumatic devices can be replaced with compressed, dried air systems, eliminating methane emissions.	NG Production, Processing and Transmission	100

Table 6. Continued

Abatement Option	*Description*	*Applicable Sub-Sector*	*Reduction Efficiency*
Portable Evacuation Compressor for Pipeline Venting	This practice uses an in-line portable compressor to remove gas and lower pipeline pressure before venting.	NG Transmission	72
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.	NG Transmission	33
Directed Inspection & Maintenance (DI&M) at Compressor Stations	Conduct leak detection surveys of facilities to identify and repair leak sources that are cost effective.	NG Processing and Transmission	13
DI&M at Gate Stations and Surface Facilities	Conduct leak detection surveys of facilities and equipment to identify and repair leak sources.	NG Distribution	26
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.	NG Transmission	100

As seen from Table 6, there are many effective ways to reduce methane emissions in the oil and gas sector. However several issues are important for successful project development. Some of the key issues include:

i. Recognizing leak prevention and mitigation as a core business opportunity and directing available capital toward leak reduction projects.
ii. Making project investments economically viable in areas where there are artificially low natural gas prices.
iii. Providing robust information on and access to the many available emission reduction technologies and management practices.
iv. Identifying and addressing specific regulatory barriers that might inhibit project development.
v. Improving and expanding existing markets and creating new markets for methane gas [27].

7. Summary and conclusions

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. Methane, which is an important greenhouse gas, constitutes 16% of greenhouse gas emissions its concentration has doubled in atmosphere recently. 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.

The traditional fossil fuels are the dominant sources of primary energy in the world economy. They contributed about 90% of total primary energy supply in 2009. It is expected an increase in energy demand met predominantly by fossil fuels, with oil set to continue to maintain its major role complemented with an increasing role of natural gas mainly in electric power generation in the next two decades. Therefore, It would gain importance determine and mitigation of emissions in these sector. Although there are available options, new policies and technologies are required for further reduction in methane emission by these sectors.

Natural gas and oil systems are the second biggest sources of anthropogenic methane emissions constituted 62% of methane emissions from energy sector. These emissions increased recently as a result of non- EU FSU economic transition, the mild growth in production in parts of the OECD, and the accelerated growth in energy production and demand in all other regions.

Emissions in the study period increased in all regions except the non-EU FSU and the rank order of the regions did not change during the study period. Emissions share of each region in global emissions changed dramatically. Non-EU FSU and OECD90 & EU's total emissions accounted for the majority of emissions. These regions were followed by Middle East, Latin America, SE Asia, Africa, China/CPA and Non-EU Eastern Europe. It is obvious that there will be an increasing demand for natural gas and oil in near future. As mentioned in the study, mitigation of emissions from natural gas and oil systems seems to be possible and required to mitigate the impact on the environment. These emissions can be decreased by nearly 100% by upgrading technologies or equipment, improving management practices and operational procedures to reduce venting, enhancing management practices. Consequentially, methane recovery and use from natural gas and oil systems will have a large impact on future emission levels. Thus, not only would the economical benefits be obtained, but also enhancements in reducing the effects on global warming would be possible.

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