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The impact of cogeneration power and desalting plants (CPDP) on the environment in Kuwait

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ABSTRACT

Fossil fuels (petroleum oil, natural gas) are the only type of fuel used for electric power generation to desalt seawater in Kuwait, Gulf Cooperation Countries (GCC), and all Arab countries. The main constituents of fossil fuel are carbon (C) and hydrogen (H_2) besides small portions of impurities such as sulphur (S), nitrogen (N_2), oxygen (O_2), water moisture and particulate matters (ashes). When the fossil fuel is combusted (i.e. reacted with the oxygen in the air to generate heat), the produced gases include mainly carbon dioxide (CO_2), water vapour, carbon monoxide (CO), sulphur dioxide (SO_2) and nitrogen oxide (NO). The CO, SO_2 and NO gases pollute the air and are harmful to human health and the environment. CO_2 is the main component of the greenhouse gases (GHG) which cause global warming. The emission of CO_2, CO and NO gases from power plants to the environment creates great international concern. The basics of the environmental issues related to fossil fuel combustion and its released gases are outlined in this paper. The emitted gases due to fuel combustion to produce electric power and distilled water in Kuwait and some Arab and other countries are calculated. The mitigation of GHG is also discussed.

Keywords: Air polluted gases; Carbon dioxides; Cogeneration power desalting plants; Fossil fuel; Fuel consumption; Global warming; Greenhouse gases; Nitrogen oxides; Sulphurous oxides

1. Introduction

Electrical energy plays an essential part in our life. Its need is continuously on the rise everywhere. The main primary energy source which is converted to electrical energy is the chemical energy of fossil fuel (natural gas, oil, and coal). Only a part of this energy is converted to electrical energy and the balance is rejected to the environment. All power plants in the Arab countries use only natural gas and oil for electric power generation, while coal is also used in many power plants worldwide. The use of fossil fuel to generate electrical energy causes substantial damage to the environment, climate and thus the economy.

Other cleaner primary energy sources which should be considered include nuclear energy, renewable energy (wind energy, solar energy, fuel cell, water of high potential, i.e. level, tidal energy, ocean energy, geothermal energy, etc.).

The main components of fossil fuel are carbon and hydrogen and traces of impurities such as sulphur, nitrogen, oxygen, water moisture, and ashes. Analysis of typical residual oil usually used in power plants gives (in mass percentage): 86% C, 9% H_2, 2.4% S, 1.2% N_2, 0.8% O_2, 0.1% ashes, and 0.3% moisture. Typical natural gas consists (in mass percentage) of 74% C, 24% H_2, 1.7% N_2, and 0.3% O_2.

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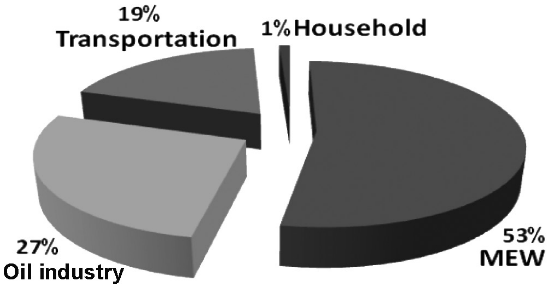

Fig. 1. The 2008 energy consumption in different sectors in Kuwait [1].

In 2008, the fuel energy consumed by the power plants in Kuwait (given in terms of 1000 equivalent (E) barrels (bbl) of oil per day E-bbl/d are: 66.24 natural gas, 24.19 crude oil, 18.83 gas/diesel oil, and 152.34 heavy oil [1]. These represent 53% of the total fuel energy consumed in Kuwait (Fig. 1).

One equivalent barrel of oil is an energy unit equal to 6.1 GJ. Therefore, the fuel energy used in Kuwait to generate electric power and desalinate seawater in 2008 was 95.5 million (M) equivalent barrels per year (M E-bbl/y), or 582.5 MGJ/y; while the total fuel energy consumption is 1099 MGJ/y (or 180.2 M E-bbl /y).

Fuel combustion is an exothermic chemical process where both C and H_2 and some of constituents such as S are oxidized by the O_2 existing in the air to produce hot gases. These hot gases supply the heat required to generate steam, which expands in the steam turbines of steam power plants. Also these hot gases, when at high pressure, expand in gas turbine power plants.

The combustion products are carbon dioxide CO_2, carbon monoxide CO, water vapour, sulphur dioxide SO_2, nitrogen oxides NO_x, and particulate matters. These gases are emitted to the atmosphere, after being relatively cooled. Other gases are also emitted due to combustion such as methane and hydrocarbon gases (volatile organic compounds VOC).

Air pollutants such as SO_2, CO, NO_x and particulate matters have a bad effect on human health and on the environment. The CO_2 is the main constituent of the greenhouse gases (GHG) which causes global warming. In 2007, the reported CO_2 production in Kuwait was 74.79 million tons. It is unfortunate that the only data available on the gases polluting air are dated back to 1996 as given in Fig. 2 [2].

2. Air polluting gases

The SO_2 gas is created when sulphurous materials, particularly in oil and coal fuels, are combust. It is considered a major air pollutant. Exposure to high SO_2 concentration leads to lung and respiratory diseases which happened in Kuwait immediately after the liberation due to the burning of the oil fields. It has an acidifying effect on earth and water and therefore causes material damage. Its concentrations in Kuwait outdoor air are routinely measured and it is currently low to present a health risk. Certain plants can be damaged by high concentration of SO_2. The SO_2 emission from power plants can form gaseous sulphates and sulphate particles that eventually fall as acidic rain. Kuwait's current oil production and ex-

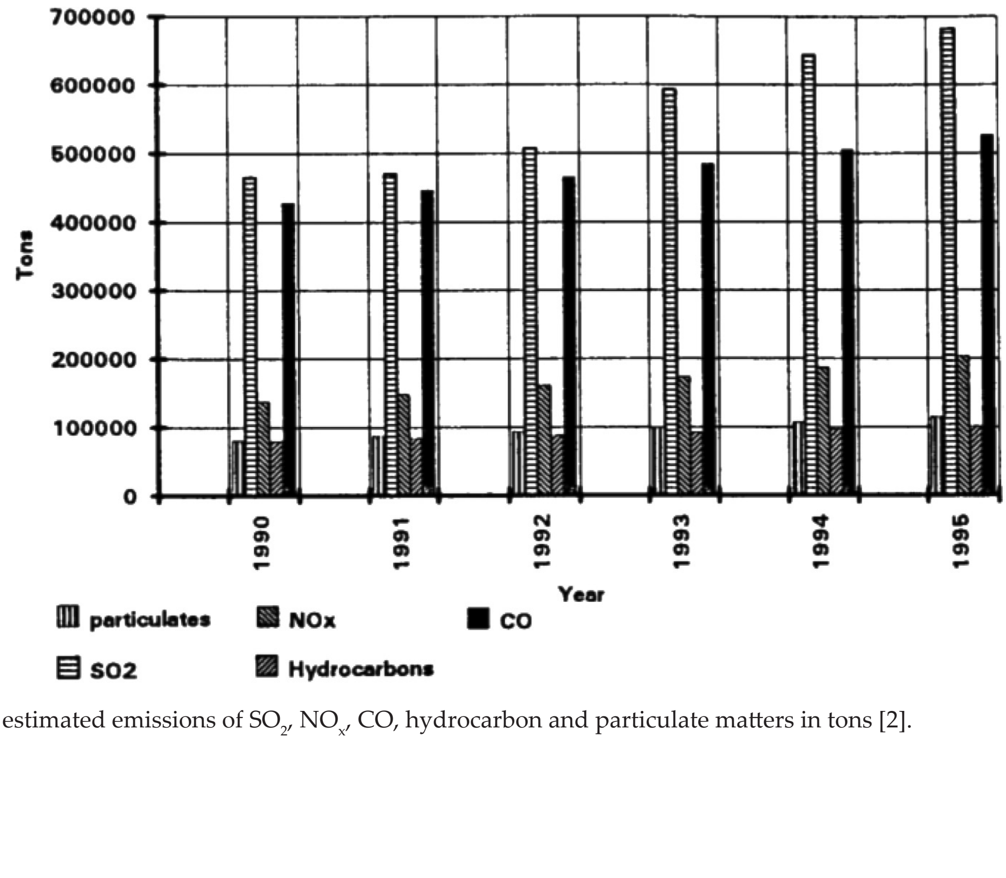

Fig. 2. Kuwait estimated emissions of SO_2, NO_x, CO, hydrocarbon and particulate matters in tons [2].

ports and refined crude are termed Kuwait Export Crude (KEC). KEC has 2.7% sulphur content. KEC is actually a blend of crude oils from several oil fields.

The SO_2 emissions from power stations account for 69% of its total emissions, whilst 13% comes from burning fuel in industry and construction. The World Bank estimated that the transport sectors' contribution to global SO_2 emissions is between 2–6%. With this in mind, the importance of capping the SO_2 emissions from power stations is indisputable [3]. The main method used to decrease the SO_2 emission is to de-sulphur the sour oil (of relatively high sulphur content) to sweet oil (low sulphur content).

The nitric oxide NO (formed by the nitrogen dissociated at high temperatures during the combustion and oxygen found in the air) emitted from power plants is transformed to nitrogen dioxides NO_2 in the air. Even at low concentration, the NO_2 pollutes the air, irritates the human respiratory system, and causes respiratory illness, especially in children. The NO_x (any chemical combination of N_2 and O_2) is also an acidic gas and can cause acidic rain.

The NO_x also reacts with air O_2 to form ozone O_3 at the troposphere (lower level of the atmosphere), i.e.

$$NO_2 + O_2 \rightarrow O_3 + NO$$

The O_3 at the troposphere is considered as an air pollutant as it badly affects human health, while, the O_3 layer in the stratosphere (high level of atmosphere, 10–40 km from the earth) acts as protective layer against ultraviolet (UV) radiation, which causes skin cancer and solar burns. Therefore, the O_3 at the stratosphere is considered as good O_3, which absorbs UV radiation. When the NO_2 moves to the stratosphere, it depletes the ozone layer.

The emissions of the above mentioned gases, from heavy oil fired power plants for example, can be easily calculated if the oil analysis is given. A simplified example is given here. To produce one kWh (3600 kJ) of electric energy in a power plant of 0.3 efficiency (work output/heat input), 12,000 kJ heat per kWh work (electric energy) is required. If the heat released per kg of fuel (heating value) is 42,000 kJ/kg fuel, then the production of one kWh requires the combustion of (12000/42000) = 0.29 kg of oil. If the fuel carbon content is 87%, then 0.29×0.87 = 0.2523 kg of carbon is to be burned. This produces CO_2 equal to (0.2523×44)/12 = 0.925 kg CO_2/kWh according to the following reaction:

$$C + O_2 \rightarrow CO_2.$$

The 44 appeared in the calculation is the molecular mass (M_w) of CO_2, while 12 is the M_w of C.

Recorded CO_2 production/kWh from different power plants is about 1 kg/kWh.

Similarly for low 2% sulphur content, the SO_2 production/kWh electric power is equal to:

(0.29×0.02×64)/32 = 0.0116 kg (or 11.6 g) SO_2/kWh

according to the reaction

$$S + O_2 \rightarrow SO_2.$$

Again 64 is the M_w of SO_2, and 32 is the M_w of S or O_2.

Also reported NO production per kWh is 2.01 g/kWh [4].

All power plants in Kuwait produce distilled water from seawater and are called cogeneration power distillation plants (CPDP). The production of distilled water in the CPDP contributes also to the given gases emission. The consumed equivalent mechanical (or electrical energy) to produce one meter cube (1 m^3) of distilled water is 20 kWh/m^3 [5]. This includes 16 kWh/m^3, counted for the heat added to the desalting unit, and 4 kWh/m^3 for the pumping energy. The average fuel energy consumption to produce 1 m^3 of distilled water is about 200 MJ heat energy (equivalent to almost the combustion of 5 kg of fuel having 40 MJ heating value, i.e. heat generated per kg of fuel).

Based on the given emissions/kWh, desalting 1 m^3 of seawater causes the emission of: 20 kg CO_2/m^3 distilled water, 232 g SO_2/m^3, and 40.2 NO g/m^3.

3. Greenhouse gases phenomena

3.1. The carbon dioxide emission and greenhouse gases

The recorded emissions of CO_2/kWh of generated electric energy from different types of power plant in some countries are given in Tables 1 and 2 [6]. The CO_2 emitted due to fuel combustion causes the greenhouse gas effect or global warming (GW). The GW is the increase in the average temperature of the earth's near-surface air and oceans since the mid-twentieth century and its projected continuation. The global surface temperature increased by 0.74±0.18°C (1.33 ± 0.32°F) during the last century [7]. The United Nations report Intergovernmental Panel on Climate Change (IPCC) concluded that anthropogenic

Table 1
Estimation of CO_2 emissions from different power plants in g/kWh [6] Geoscience Australia, no. 42, p. 26

Energy source	Operation	Remainder	Total
Coal 600 MWe	892	111	1003
Fuel oil	839	149	988
Gas turbine	844	68	912
Diesel	726	159	895
Hydro-pumped storage	127	5	132
Photovoltaic	0	97	97
Hydroelectric	0	5	5
Nuclear energy	0	5	5
Wind energy	0	3	3

Table 2
Estimation of CO_2 emissions from different power plants in g/kWh in some European countries [6]. ANSTO, Exhibit no. 74, presented by R. Cameron and I. Smith, p. 32, UIC, Submission no. 12, p. 15

Generation method	Finland	Sweden	Japan
Coal	894	980	975
Gas thermal	—	1170	608
Gas combined cycle	472	450	519
Solar photovoltaic	95	50	53
Wind	14	5.5	29
Nuclear	10–26	6	22
Hydro	—	3	11

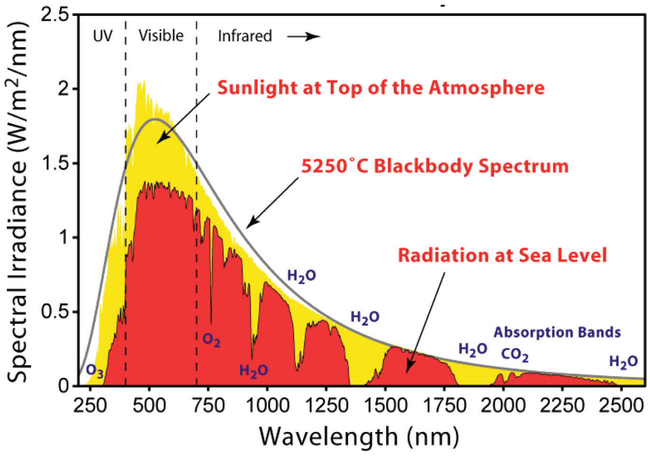

Fig. 3. Spectral emissive power in W/(m².mm) variation with wave length [10], http://en.wikipedia.org/wiki/File:Solar_Spectrum.png.

(i.e. due to human) activities of emitting GHG are responsible for most of the observed temperature increase since the middle of the twentieth century [8]. Natural phenomena such as solar variation and volcanoes probably had a small warming effect from pre-industrial times to 1950 and a small cooling effect afterwards [8,9].

The CO_2 is a main GHG constituent. While the air polluted gases such as SO_2, NO_x are chemically reactive and can be washed out of the atmosphere in a matter of days, the CO_2 is chemically stable and non-reactive gas that can remain in the atmosphere for hundreds of years. The GHG absorb most of the heat radiation (reflected or emitted) from the earth due its heating by solar radiation. Solar radiation consists of electromagnetic waves of a wide range of wave lengths (Fig. 3) [10]. More than 50% of its energy is concentrated in the visible range (0.4–0.7 mm) with a maximum spectral power emission at 0.5 mm. The radiation in the wave length range of 0.01–0.4 mm is called the ultraviolet UV (or short wave). A large portion of UV is absorbed (and thus prevented) from reaching earth by the O_3 layer. Radiation in the wave length range of 0.7–100 mm is called the infrared (or the long wave) range. The solar radiation is partially absorbed by (and heats) the earth. This heat is radiated from the earth but as infrared radiation. While the atmospheric main air gases (oxygen and nitrogen) are almost transparent to both short and long wave radiations, gases such as water vapour, CO_2, NO_x, and methane absorb most of the infrared radiation; and trap the absorbed heat. The CO_2 concentration in the atmosphere has been significantly increased in the last decades, and is considered as the main cause of global warming. Continuous measurements of atmospheric CO_2 showed that its level is rising steadily (from 315 in 1958 to 370 part per million in volume (ppmv) in 2001 and to 387 ppmv in 2008, almost 40% since the industrial revolution). The atmospheric CO_2 concentrations since very long time are given in Fig. 4a [6] and in the last few decades is in Fig. 4b [6] and in very recent years are given in Fig. 4c [11]. The percentage of the CO_2 in the GHG, without the water vapour is given in Fig. 5 [12].

The record temperature increase worldwide is shown in Fig. 6. The warming observed thus far 0.74±0.18°C since the late 19th century) due to GHG emission is modest and in itself is unlikely to lead to a substantial

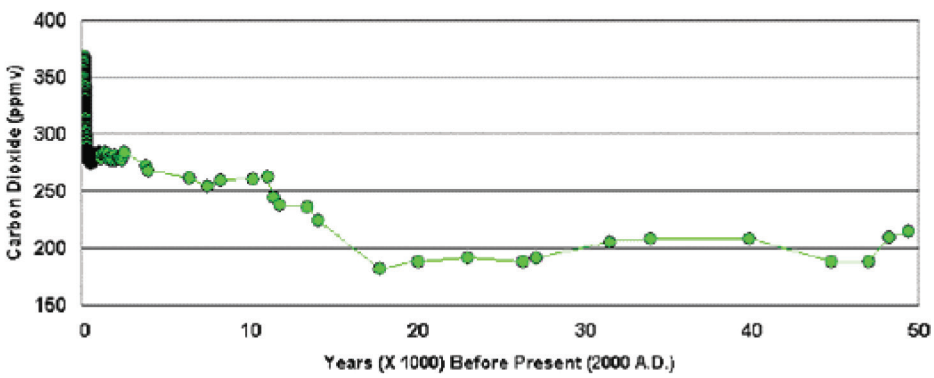

Fig. 4a. Atmosheric concentration of CO_2 over the last 50,000 years in ppmv [6]. ANSTO, Exhibit no. 74, presented by R. Cameron and I. Smith, p. 32, submission no 12 p. 15.

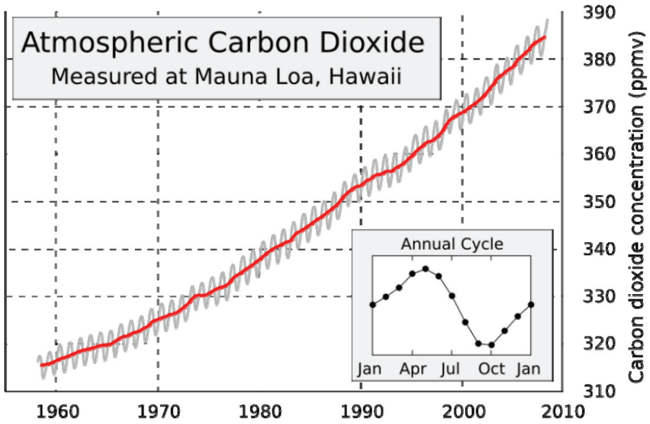

Fig. 4b. Atmospheric concentration of CO_2 over the last few decades in ppmv [7] cited from Mauna_Loa_Carbon_Dioxide-en.svg, in Global warming, from Wikipedia, http://en.wikipedia.org/wiki/Global_warming.

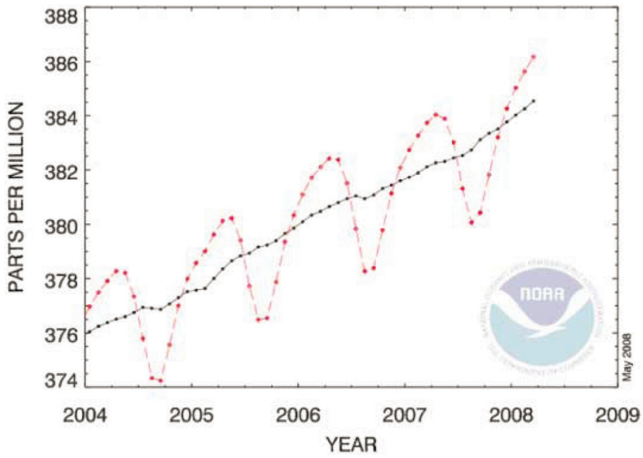

Fig. 4c. Atmosheric concentration of CO_2 over the last few years, in ppmv [11], http://www.thewe.cc/weplanet/news/air/co2_record_high_levels_in_the_atmosphere.htm.

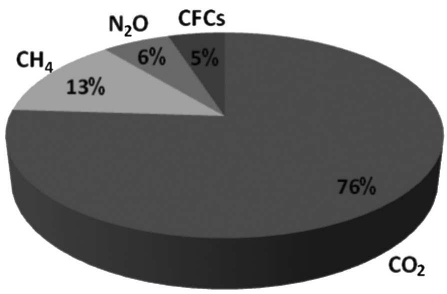

Fig. 5. Distribution of GHG in the gases envelope around the earth [12].

global impact. The real problem is the continuous increase of this phenomenon. The temperature record is not the only indication of a changing climate. There are many other indicators such as the substantial retreat of mountain glaciers in many locations around the world, decreased snow cover in the Northern hemisphere, decreased tropical precipitation, increased mid-to-high latitude precipitation, sea level rise, decreased extent of Arctic ice, and thinning of Arctic ice. The combined data prove beyond any reasonable doubt that global climate is changing. Concern regarding global warming centres on the future climate.

Most of the earth warming is believed due to the release of GHG such as CO_2 from fossil fuel combustion. Substantial increases in its emission have occurred during the past century, and there are expected emission increases in the future. The atmospheric concentration of CO_2 in the year 2100 will be substantially greater than that of today and the climate will continue to warm. The IPCC

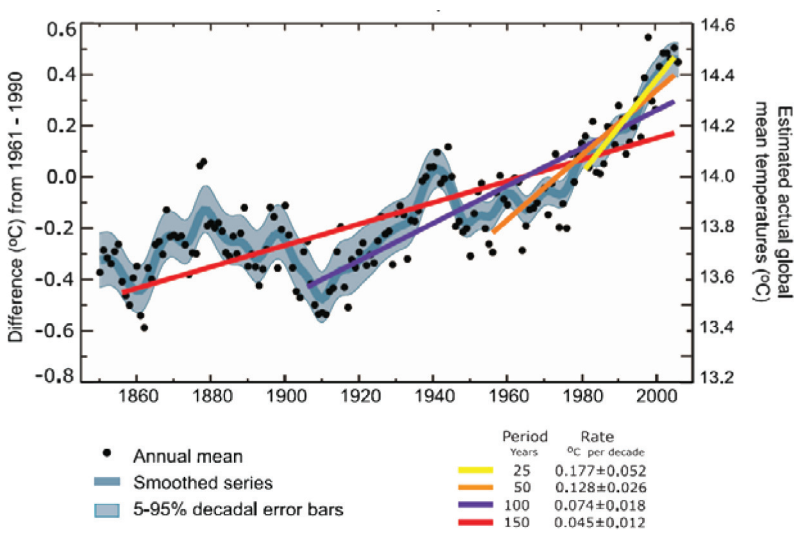

Fig. 6. Global mean surface temperature anomaly relative to 1961–1990 [8].

(Intergovernmental Panel on Climate Change [8]) has considered numerous emission scenarios and concluded that global temperature may rise between 1.4 and 5.8°C by 2100 (depending on emission scenario).

3.2. Earth temperature in the absence of GHG and due its existence

An attempt to explain the phenomenon of global warming is given in this section. The solar radiation arriving at the top of the atmosphere has a heat flux of 1370 W/m^2, (i.e. Watts per unit area perpendicular to the sun rays) and this is called the solar constant (Sc). The earth cross-sectional area CSA, πR^2, is perpendicular to the sun rays where R is the radius of earth. As the earth rotates, the solar radiation is distributed over the earth outer surface area ($4\pi R^2$ or 4 times the cross-sectional area of the earth). Hence, the 24 h average solar radiation at the top of the atmosphere has a power of 1370/4 = 342 W/m^2 of the earth outer surface. Scattering by air molecules and reflection from clouds and snow return an average of 107 W/m^2 back to space (called Albedo), and leaves the balance Sa = 235 W/m^2 to heat the earth.

If there are no radiation absorbing gases surrounding the earth, 235 W/m^2 would arrive to and be absorbed by the earth. The only mechanism for the earth to cool itself is to radiate the absorbed heat with infrared radiation into space. When the earth behaves as a black body radiating long-wave (infrared) radiation, its emissive power would be

$E = \sigma \times T^4$

where σ is the Stefan-Boltzmann constant (= 5.67×10^{-8} J/(s.m^2 K^4) and T is the temperature in Kelvin. When the received and the radiated energy are equalized

235 W/m^2 = 5.67×10^{-8} J/(s.m^2 K^4) ×T_e^4

the resulting average earth surface temperature is calculated as T_e = 254 K (or –19°C).

In reality the average earth surface temperature is around 288 K (15°C); and the 34°C temperature difference is attributed to trapping the infrared radiation (heat) in the atmosphere by GHG. This can be explained by inserting the GHG layer between the earth and space as shown in Fig. 7.

When the 107 W/m^2 is reflected from the total incoming solar radiation of 342 W/m^2, the remained 235 W/m^2 solar heat passes through this layer. If say 29% of its heat content is absorbed (i.e. 68.15 W/m^2), the balance that reaches the earth is 235 – 68.15 = 166.85 W/m^2.

It will radiate $E = \sigma \times T_e^4$ if its temperature is T_e. This radiated heat is absorbed by the GHG layer.

Now the total heat absorbed by the GHG from outer solar radiation plus that radiated from earth is:

$(\sigma \times T_e^4)$ + 68.15 W/m^2.

The GHG layer will radiate what was absorbed from its upper surface to the space, and from its lower surface back to the earth. So the radiation received back by the earth from the GHG layer is: $(\sigma \times T_e^4 + 68.15)/2$. Then, the total heat gained by the earth is:

166.85 (from Sa) + $(\sigma \times T_e^4 + 68.15)/2$ (from GHG layer).

This heat should be radiated back as $\sigma \times T_e^4$, or $166.85+(5.67\times10^{-8}\times T_e^4+68.15)/2 = 5.67\times10^{-8} T_e^4$. This gives T_e = 290 K, or 17°C, which is close to the assumed 15°C.

3.3. Global warming

Global warming refers to the GHG effect expected to result from an increase in GHG concentration in the

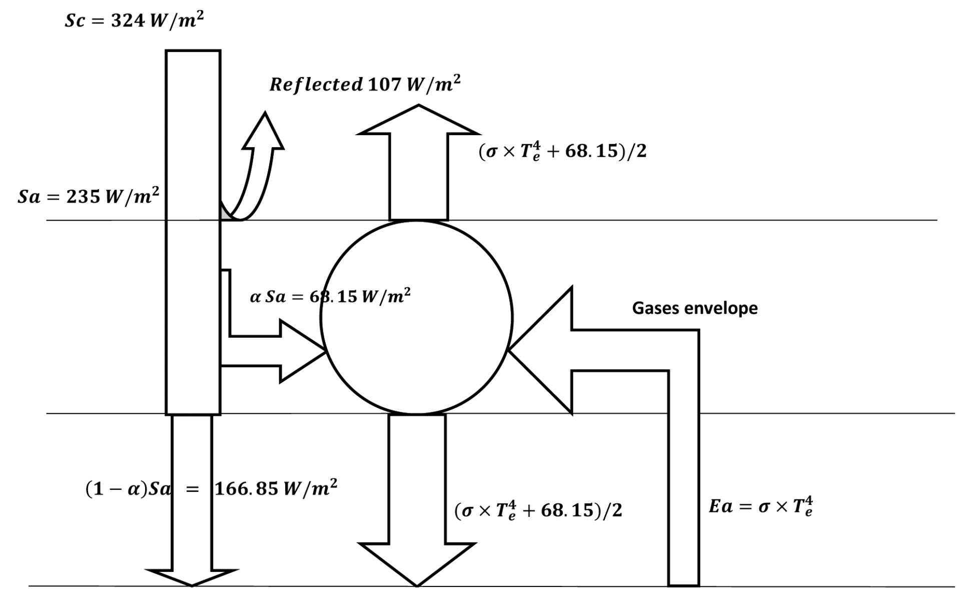

Fig. 7. Rough estimation of the ground earth if layer of gases completely absorbs the infrared radiation leaving the earth.

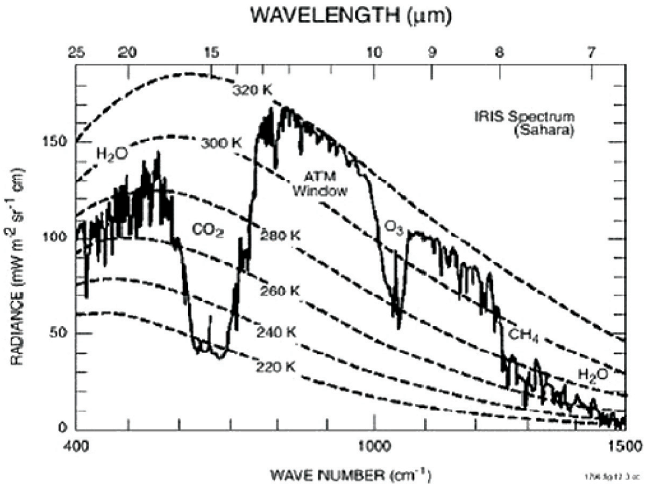

Fig. 8. Terrestrial infrared radiation spectrum recorded by an orbiting satellite over the Sahara desert [13]. (Reproduced with permission from Oxford University Press).

atmosphere as a result of these GHG emission. Absorption of infrared irradiation by greenhouse gases in the atmosphere has been well documented by satellite observations. Fig. 8 shows the infrared radiation observed by a satellite looking down on the Sahara Desert [13]. The dotted lines show emission spectra expected from blackbodies at various temperatures.

The atmosphere is transparent at wavelengths of 10–12 μm (800–1000 cm^{-1} wave number), infrared radiation at this wavelength reaching the satellite comes directly from the surface of sand grains in the Sahara which have a temperature of 320 K (47°C). The 10–12 μm region is known as the atmospheric window region. It can be seen from Fig. 8 that the infrared radiation on either side of the atmospheric window is characteristic of emission from a blackbody which is significantly cooler than 320 K. Thus, for example, the intensity of radiation at wavelengths around 15 μm is characteristic of that expected from a blackbody at approximately 220 K. The apparent discrepancy between the temperature inferred from the 10–12 μm and 15 μm radiation is explained by the fact that carbon dioxide absorbs strongly at 15 μm. Hence, at 15 μm the satellite does not observe emission from the earth's surface but instead observes emission from high in the atmosphere where the temperatures are much colder than at the surface and the emission much weaker. Water vapour, ozone, and methane are also strong absorbers of infrared radiation. The presence of these GHG in the atmosphere, as indicated in Fig. 8, prevents the direct escape of terrestrial infrared radiation into space. Increases in the atmospheric concentrations of GHG such as CO_2, water vapour, methane, and ozone will act to further hinder the escape of terrestrial infrared radiation and hence warm the earth's surface.

4. Fuel combustion contribution to GHG emission from Kuwait and some Arab countries

In this section, the GHG and polluted gases emitted due to fossil fuel combustion in Kuwait and some Arab countries are calculated. Fuel consumptions in terms of 1000 E-bbl/d from 2003 to 2007 are reported in the 2008 Organisation of Arab Petroleum Exporting Countries (OAPEC) published statistical data book [14]. The percentage annual increases between 2003–2007 as well as the expected consumptions in 2010 were calculated, and reported in Table 3.

The installed power plants capacity and generated electrical energy in Kuwait and some Arab countries from 2003 to 2007 are given in Tables 4 and 5, respectively [14]. In these countries, the installed power plants capacities in MW are shown in Fig. 9 for the year 2007; and the electric energy generated in GWh is given in Fig. 10 for the same year [14]. The data show that from 2003 to 2007, the generated electric energy increased from 34105 to 41277 GWh in Kuwait; and from 149767 to 181434 GWh in Saudi Arabia. This is 21% increase in 4 years or 5.5% annual increase for both countries and the generation is expected to be doubled in 13 years. So, the expected electric energy production in the year 2010 is 48469 GWh for Kuwait.

Besides generating electric power, all power plants in Kuwait also produce distilled seawater and are thus

Table 3
Energy consumption in terms of 1000 bbl.E/d for Kuwait and some Arab Countries between 2003 and 2007, and expected consumption in 2010 [15]

Country	2003	2004	2005	2006	2007	Annual%	2010
Kuwait	441.5	484.3	513.8	5547	588.7	7.45	730.32
Saudi Arabia	1857	2175.9	2320	2530	2650	9.2	3450.75
UAE	754.9	781.1	892.7	924.3	960	6.2	1149.86
Qatar	425.2	436.7	457	499.5	533.5	5.85	632.71
Bahrain	241.8	241.5	263.2	272.8	279.3	3.7	311.46
Oman	131.8	142.3	148.8	155.3	159.2	4.8	183.24
Egypt	1071	1145.3	1200	1210	1240.1	3.73	1384.11

Table 4
Installed power plants generating capacity in MW from 2003 to 2007 in some Arab countries [14]

Country	Year					2007 peak load	Installed/peak loads
	2003	2004	2005	2006	2007		
Kuwait	9763	9763	10763	10763	10848	9177	1.18
Saudi Arabia	28500	29300	32301	35885	36559	33503	1.09
UAE	12172	13550	15710	17280	18474	13438	1.37
Qatar	2655	2900	2829	3028	3164	3009	1.05
Bahrain	2629	2629	1849	2500	2500	1971	1.27
Oman	2550	2750	3166	3325	3858	3300	1.17
Egypt	17675	18569	19039	19766	20266	18511	1.09

Table 5
Electrical energy generated in GWh/y from 2003 to 2007 in some Arab countries [14]

Country	Year				
	2003	2004	2005	2006	2007
Kuwait	34105	35639	39550	41277	44244
Saudi Arabia	149767	156506	176134	181434	194969
UAE	49450	52417	60698	66768	76106
Qatar	11160	11718	13238	14033	15029
Bahrain	7715	8178	8698	9220	10020
Oman	10320	10836	11485	12059	13011
Egypt	88874	94840	1000927	108332	117824

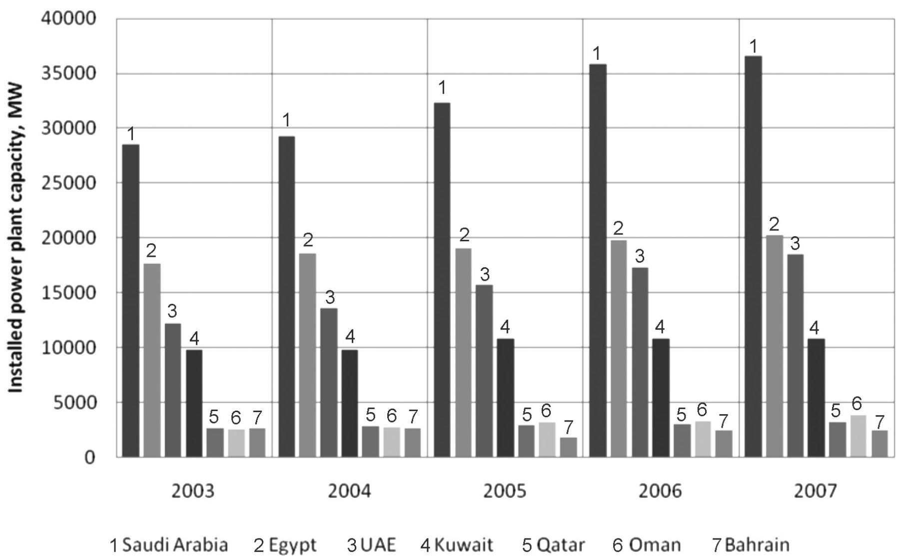

Fig. 9. Installed capacity of electrical power plants for some Arab countries [14].

called cogeneration power distillation plants (CPDP). The produced distilled water in Kuwait increased from 374.34 Mm^3 in 2000 to 496.32 Mm^3 in 2005, or about 5% annual increase [15]. Thus the expected distilled water output in 2010 as 633.43 Mm^3/y. The only desalting system used in Kuwait is the multistage flash (MSF) desalting system. As given before, the equivalent mechanical or electrical energy consumption per m^3 of kg distilled water for the MSF units operating in Kuwait is 20 kWh/m^3, then the equivalent electrical energy consumption due to desalt-

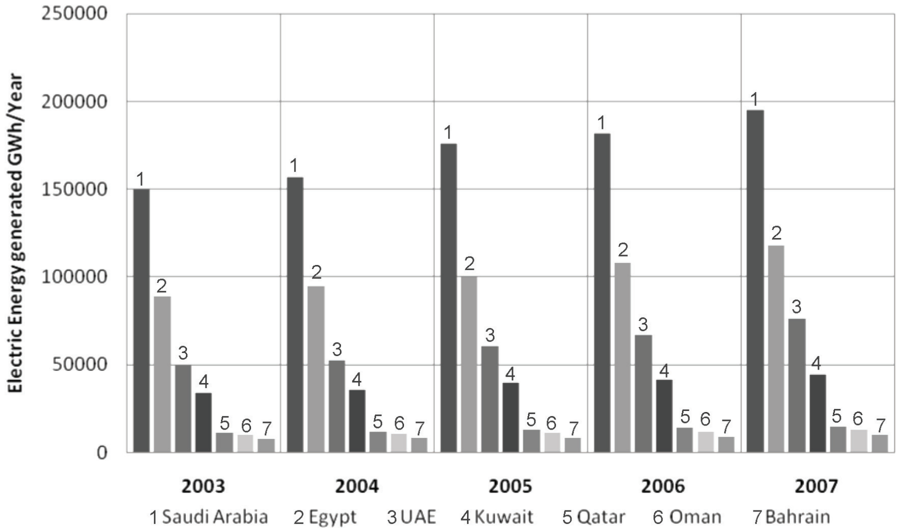

Fig. 10. Generated amounts of electrical energy in some Arab countries in GWh/y [14].

ing seawater in 2010 is 12,669 GWh (or a little more than 26% of the net generated electric energy). The fuel energy consumed for desalting seawater is about 20.7% of the total consumed fuel energy. Then, the total generated equivalent energy to account for both electric power and distilled water is 61,338 GWh.

Table 4 shows the peak load in 2007. Since the installed capacity should be at least 1.2 the peak load, then Kuwait, Saudi Arabia, Qatar, Oman, and Egypt need to increase their installed power plants capacity to face the continuously increasing peak load.

Table 6 gives the expected emissions of CO_2, SO_2, and NO for the above mentioned Arab countries in year 2010. The calculation of the amounts of the emitted gases is based on: each barrel bbl of oil is assumed to weight 0.136 ton/bbl and has heating value of 6.1 GJ/bbl. The carbon % (by mass) is assumed equal 86%. Calculation of the SO_2 gas emission was based on 340 g/GJ; and the NO gas emission was based on 129 g/GJ, typical values of fuel oil combustions [3]. Table 6 gives the calculated 2010 expected emissions of CO_2, SO_2, and NO for the above mentioned Arab countries.

The 2004 published world data on the CO_2 emission for different countries per capita are given in Fig. 11 [16]. It ranks Kuwait to have the highest after Qatar.

5. Mitigation of greenhouse gases

There are different options to mitigate the GHG emission. These include significant improvement in energy production and use efficiencies, substitution of fossil fuel with renewable energy or almost non-emitted GHG systems, and the use of CO_2 capture and storage systems.

Table 6
The 2010 expected emissions of CO_2, SO_2, and NO for some of the Arab countries

Country	2007 Fuel consumed 1000 bbl/d	% annual increase	2010						
			Fuel consumed			Energy consumed	Emitted CO_2	Emitted SO_2	Emitted NO
			1000 bbl/d	Million bbl/y	Million ton/y	1000 million GJ/y	Million ton/y	1000 ton/y	1000 ton/y
Kuwait	588.7	7.45	730.32	266.75	36.28	1520.47	114.4	516.96	196.1
Saudi Arabia	2650	9.2	3450.75	1260.39	171.41	7184.21	540.52	2442.63	926.8
UAE	960	6.2	1149.86	419.99	57.12	2393.92	180.11	813.93	308.8
Qatar	533.5	5.85	632.71	231.1	31.43	1317.26	99.11	447.87	169.9
Bahrain	279.3	3.7	311.46	113.76	15.47	648.44	48.79	220.47	83.65
Oman	159.2	4.8	183.24	66.93	9.1	381.5	28.7	129.71	49.21
Egypt	1240.1	3.73	1384.11	505.55	68.75	2881.61	216.8	979.75	371.7

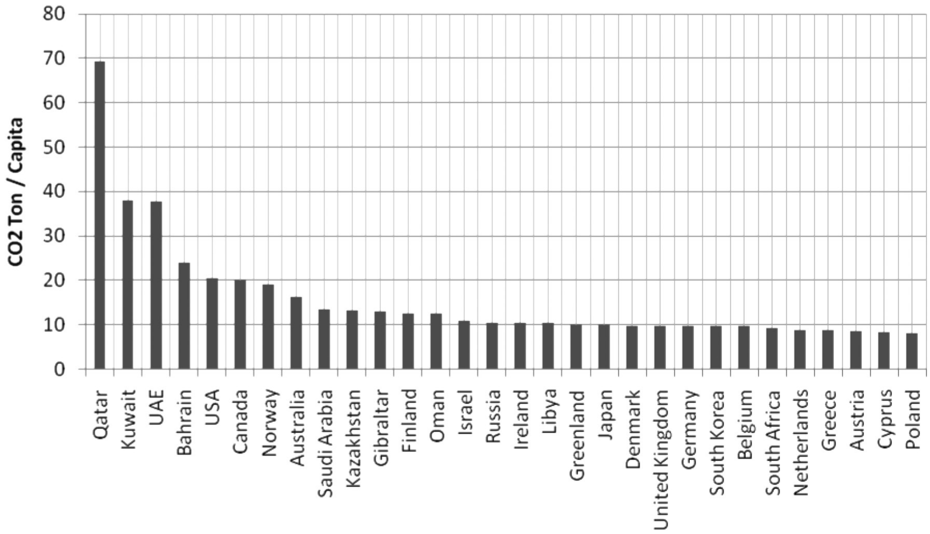

Fig. 11. Year 2004 CO_2 emission in t/y.capita [16].

The discussion in this section is limited to the specific conditions in Kuwait.

The most effective way to reduce the GHG (mainly CO_2) emission is to curb the excessive increase in the electric power and water consumption in Kuwait.

Electric energy consumption per capita in Kuwait is almost 1500 kWh/capita, among the highest in the world. This is due to the use of air-conditioning (A/C) units everywhere which use most of the electrical energy. This can be significantly reduced by adopting a strict code for building insulation. The potable water consumption per capita is almost 600 l/capita/d. Again this is among the highest in the world, so water demand management should be applied.

Another option is to mix electric power generation with the introduction of renewable energy generating systems (wind, photovoltaic, tidal power, etc.) which are almost CO_2 non-emitting, and nuclear energy. The nuclear energy is the only viable large capacity and economically alternative system for the conventional use of fuel. The main power plants operating in Kuwait have 2400 MW electric capacity each. It was suggested [17] to build a nuclear power plant NPP of 3000 MW capacity, e.g. 5 units × 600 MWe light water pressurized water reactor (LW PWR). If this NPP is operated with 90% capacity factor, it would produce 23,652 GWh per year. Since conventional power plants emit almost 1 kg of CO_2/kWh, the suggested NPP will avoid the release of 23.65 M tons of CO_2/y.

The government of Kuwait installed more than 2000 MWe simple gas turbines of almost 33% efficiency. Steam turbines should be added to these simple gas turbine cycles to form a combined gas/steam cycle of at least 46% efficiency.

The only seawater desalting method operating in Kuwait is the multistage flash distillation MSF plant known for its high energy consumption (~20 kWh/m^3 equivalent mechanical power energy). This system consumes huge amounts of energy compared with the use of the seawater reverse osmosis (SWRO) desalting system known for its low energy consumption of 4–5 kWh/m^3. The production of 633.43 million m^3/y distilled water (expected in 2010) by MSF requires the consumption of 126.7×10^6 GJ (based on 200 MJ/m^3) or 20.8 Mbbl/y of oil. The use of SWRO would reduce this amount to 5.2 Mbbl/y, or saving 15.6 Mbbl/y.

6. Conclusions

The environmental problems associated with the combustion of fossil fuel especially in power plants are very serious since the emitted gases pollute the air and produce greenhouse gases causing GW. The first and most effective solution is to be more efficient in generation and use of both electric energy and distilled water.

- The use of nuclear energy should be considered seriously.
- More energy efficient desalination plants, such as reverse osmosis plants, should be considered.

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