Economic and Environmental Issues Associated with Deployment of Nuclear Energy Generation

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Abstract- This paper presents completely comparison between generation cost analysis of nuclear power plants compared with two types of power plants that are natural gas and coal fired power plants. Also, the comparison of environmental impact between the nuclear power plants and both natural gas and coal will be regarded in this paper. Safety issues for the previously mentioned power plants are also studied in this paper. This paper aims to deliver a new type of power generation instead of these fossil fuel power generation. That's because in last few years, the world started facing some difficulties in its energy sector. The situation has been caused by the growing demand for energy and the need for sustainable development reducing greenhouse gas emissions. The main challenge is the overdependence on coal and lignite-fuel power plants as well as single-source oil, gas and coal (despite its own resources). So, it is found that nuclear fission energy generation is the best choice for selecting a large scale clean type of energy generation. This scope of this paper study is the first constructed nuclear power plant located in El-Dhabaa City, Egypt. Egyptian government convinced to establish this nuclear power plant and started to replace its dependent on the traditional fossil fuel generation to nuclear energy and signed an Intergovernmental agreement (IGA) on 19 November 2015 with Russian Rosatom Corporation. This nuclear power plant has a capacity of 4800-MW, consists of four 1200-MW similar pressurized water nuclear reactors PWR and it is planned for nuclear share in the Egyptian energy mix to be 10% by 2030. The financial pros and cons of nuclear power are measured against its chief fossil-fuel competitors coal and natural gas. After these comparative studies, the results of these studies show that the nuclear power plants would be more cost than that from either coal or natural gas, but have the lowest cost of energy generation for longtime.

Keywords: ***economics of energy generation, levelized cost of electricity, discount rate, gas-fired plant, coal-fired plant, nuclear plant, renewable energy, nuclear fission.***

I. INTRODUCTION

Humanity must face the unexpected indefinitely consumption of energy which depends on the fossil fuel energy generation like natural gas, oil and coal. Increasing of the energy demand in all the world motivates the researchers who work in energy generation field to looking another solution to can absorb this demand. So, the fossil fuel energy generation technique must be replaced to another type of energy generation. After many researches, it is found that the nuclear fission energy produce a large scale, reliable, economic, safe and clean energy with no greenhouse gases emissions. Hence, the world started to change its dependent on fossil fuel generation to nuclear fission generation. France is considered the best example of the countries which behaves to nuclear fission generation, also some of middle east countries like Egypt, Jordan and UAE started to enter the nuclear energy world [1].

In a first step of the global energy transformation, the emphasis must be on converting the main part of the world's energy generation from fossil fuels to nuclear fission energy. This can be achieved within a few stages, as that has been done in France from the year 1970 to 1980. When the energy transformation would reduce the carbon dioxide emissions, as well preventing other greenhouse gases like methane [2]. Industrial countries should take this transition in their considerations. Methane is considered a major greenhouse gas, and replacing coal-fired power plant with gas-fired power plant is not ideal method to reduce the rate of emission of greenhouse-gas even for low leakage rates of the pollutants emissions into the atmosphere [3]. The energy resources known as renewables such as solar and wind will be applied to supply the needed of sustainable energy reliably and low pollutants to the environment but there are extremely expensive to purchase. So, the nuclear energy is considered the best selection for generating clean base energy, figure (1) shows the percent of nuclear energy produced in all over the word and other types of energy generation [4].

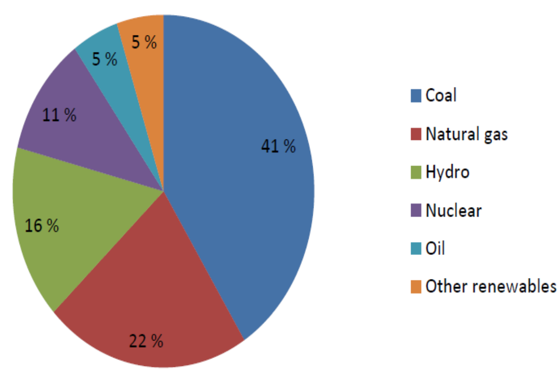
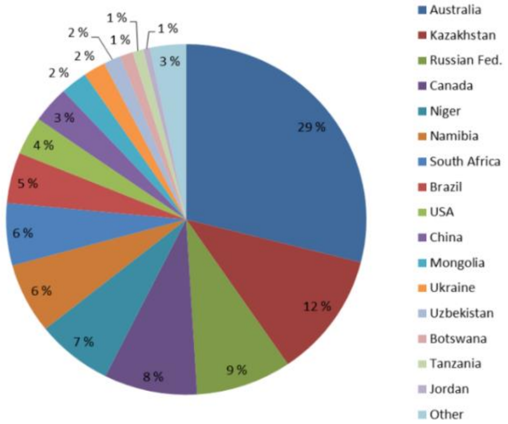


FIGURE 1. Percent of each energy generation type in all over the world.

Figure (2) presents the distribution percent of 5,902,500 tons of uranium ore resources in the whole world.



Other includes: Malawi, India, Czech Republic, Brazil, Romania, Pakistan and France.

FIGURE 2. The distribution percent of the uranium ore resources in the world.

The first generation of nuclear energy was applied in 1942 when the fission of nuclear reaction was controlled and self-sustainable. This fission of the reactor is known as atomic pile and it can provide a sustainable chain of the reaction in fissile uranium isotope U-235 that represents 0.7% of natural uranium; and the rest percent 99.3% is the fertile isotope U-238 [3]. From this reactor, the industry has been found that has caused to 435 operating nuclear reactors.

In addition, many research reactors in the world provide a clean energy and a lot of number of services and products for the use in many activities for the human applications, including medical therapy/diagnosis, agriculture and industries. In this paper, the process of nuclear fission to produce electric energy will discussed and studied. Nuclear energy produced from fission the uranium and plutonium fission, transmitted from U-238, is capable of conversion most of many missions which are caused by fossil fuels combustion. Thorium also have a fission energy application in the future. However, the environmental governments and organization have opposed the abundant applications of the nuclear energy, because they claim that the reactor fission energy is unsafe, uneconomic, unsustainable and might be used for nuclear weapons [4].

The most important issues that must be discussed, that if the nuclear energy is sustainable or not and if it is possible to convert the fossil-fuel power plant with renewables power plant or not, although many environmental organizations and governments advocated to start reduction the green-house gases emissions. To explain these issues, we must firstly to explain the meaning of the word 'sustainable'. The word 'sustainable' is often understood to be able to generate power with compromising to can supply the energy demand continuously.

In the situation of energy features, sustainable energy implies to the ability of providing energy for determined long periods without green-house gases emission due to the energy generation. This energy generation must be economically, environmentally friendly, viable, safe and reliable [5].

II. GENERATION COSTS ANALYSIS OF NUCLEAR POWER PLANTS COMPARING WITH NATURAL GAS FIERED POWER PLANTS, COAL FIRED POWER PLANTS AND RENEABLE ENERGY

When energy generation cost for a certain energy generation unit would be evaluated, then the levelized cost of electricity (LCOE) must be determined. The LCOE is defined as the charged price on each of electricity unit that would be sold from a power plant in order to recoup the its generation cost. To determine of the LCOE of the project, its cash flows must be estimated. A cash flow is the difference between the project purchase and its revenues during a certain period of time. In this paper, the cash flow determination depends on one year period with t which refers to the year end. In other meaning, the cash flow for one year period t, denoted by *CFt*, and it is the sum of the differences between project costs *(Ct)* and its revenues *(Rt)* between the end previous year *(t-1)* and the end of year t. Costs and revenues through the life time of the power plant are evaluated by using the financial and technical specifications. The summation of the discounted cash flows is defined as the project net present value *(NPV)*. If d is symbolized to the discount factor, then *NPV* can be evaluated by using equations (1) and (2) as follows:

$$\text{NPV} = dCF_1 + d^2CF_2 + d^3CF_3 + \cdots + d^TCF_T \quad (1)$$

$$= d(R_1 - C_1) + d^2(R_2 - C_2) + d^3(R_3 - C_3) + \cdots + d^T(R_T - C_T) \quad (2)$$

It is understood that both costs and revenues of the project depend on the electricity price P. Revenue depends on P in case of the revenue is equal to the price and electricity sales products. Cost depends on price also, because the taxes are included through the project taxes and its costs.

From these equations, all costs and the amount of sold electricity during each period of the power plant life time are defined. If the sold electricity amount is received for each unit of electricity, then it would be specified. So, the project *NPV* can be evaluated. The standard rule states that if the project *NPV* is positive, then this project is worthwhile to be an investment. On another way, if the *NPV* is negative, the advice is not to purchase the project and can invest the project funds in elsewhere.

If the received price P for each unit of electricity sold, where the project *NPV* is positive. This leads to there is some lesser price P' for which *NPV* is still positive. In other meaning, the project is considered a viable if electricity sold price P is going the other price which is merely P'. But we observe that the true of P is true of P'.

So, there is a price P'', less than P', but the project would still be viable. Then, the *NPV* is still positive when the electricity price is P''. The *LCOE* can be considered the answer of the previous question. Finally, we note that the lower-bound on the electricity price that ensures viability can be estimated by using the *LCOE* which satisfies the *NPV* equals zero [6].

A. *Construction Cost*

The purchase cost of all types of power plants even nuclear power plants have essential relation with their construction cost. On the other side, the construction cos is different and variable according to the type of power plant. For example, there are significant variations in the construction cost of coal-fired, gas-fired and nuclear power plants.

Because of the low number of constructed nuclear power plants, the construction cost of nuclear power is related to the construction cost of gas and coal fired power plants. The shortage of recent construction leads to costs may increase when a new nuclear power plant is built. This principle can also apply where if there are lack in fossil fuel and renewable power plants.

The construction cost of power plants depends on part of construction which is done at the night. This part of construction cost increases the cost of construction because it needs more facilities and expenditures for the employees who work in all day hours such as more lighting and emergency services against any incident during the working time. The owner must cover these more expenditures because working in the night is according to his request.

B. *Fuel, Maintenance and Operation Costs*

When the plant construction has been finished, there are periodic costs which last during the plant operation and considered one of all costs of the project. These periodic costs are fuel costs, fixed costs, incremental capital and variable costs. Incremental capital costs and Fixed costs depend on the generation capacity of the plant, while variable costs and fuel costs depend on fraction of the utilized capacity of the plant.

When comparing the cost of gas and coal based power generation with the cost of nuclear power generation, it is found that the nuclear power generation has the lowest cost value of the fuel. On another hand, the cost of nuclear fuel is doubled, that leads to increase the total nuclear power generation cost approximately 10 percent. Otherwise, when natural gas and coal fuel costs are doubled, that leads to increase the total generation cost of natural gas and coal approximately 77 and 32 percent, respectively. The generation cost of natural gas-fired power plant is particularly related to the price of natural gas. Since the prices of natural gas are variable from time to another, the risk of fuel price is much higher for than that prices for either coal or nuclear.

The cost of nuclear energy generation is insensitive to the cost of nuclear fuel (uranium), the basic element of nuclear fuel. It is found that natural gas and coal prices have change to for carbon dioxide emissions. For next 30 to 40 years, nuclear energy would be approximately 40 percent expensive more than either coal or natural gas for the base power unit. The combination of fossil fuel prices and carbon dioxide emissions CO_2 makes the desire of power generation expansion which depends on fossil fuel decreases while the expansion of nuclear power generation is increased significantly more than that generation dependent on either natural gas or coal.

The prices of supplied coal and natural gas per million BTU (MMBTU) are approximately $2.00 and $5.00, respectively. Higher prices of coal and natural gas and/or charges required for reduction of carbon dioxide emissions CO_2 raise the power generation cost from these sources. So, the relative economics of nuclear power generation is improved. In addition, the inflation of natural gas prices will be greater than $7.50 per MMBTU through next 30 to 40 years, and this leads to the power generation cost dependent on natural gas will be more expensive than nuclear power generation even the charge of reduction of carbon dioxide emissions CO_2 is not regarded. The charge of reduction of carbon dioxide emissions CO_2 is estimated to be around $25/ton, while the waste rejection charge for nuclear power generation is estimated to be $6.50 per MMBTU generated energy.

C. *The Discount Rate*

The power plants generate both revenues and costs throughout their lifetime. Revenues depend on the sales electric energy during the operation phase of the plant, while costs must be evaluated throughout both construction and operations phases of the power plant. So, we observe that the difference between revenues and costs throughout a certain period of the plant lifetime is defined as the cash flow of the plant. During the construction phase, the cash flow will be negative because in this phase there are only costs and no revenues. But the cash flow would be positive during most periods of the plant operation phase but not necessarily.

The assessment of the total value of the project cash flow needs to add different points in the future of that cash flow. Then, we collect these points and hence get the present value of the cash flow. Usually, the present value is considered the indication if the project will success or not. So that, the value of cash flow which can be received now is better than that can be received later. This statement can be explained as when the funds are now received that leads to ability to employ these funds in certain activities which can get a valuable financial return. Similarly, when the cash flow is negative or has negative slope straight line, that leads to decreasing the cost for the investor to farther point of the future. In this case, the future value in terms of its corresponding present value can be referred to discounting. So, the rate of transition from one period to the next discounting period is called the discount rate of the project and symbolized as r. Then, amount of discount which occurs through successive period of the future k.

When the investor makes a decision to establish a project, he must have many alternative investments to can get a right assessment for his own project and know if he is in a right way or not for his investments.

The rate of return of his alternative projects must be carefully determined with similar risk. Then, the lower-bound on the rate of return of the selected investment can be obtained and called *hurdle rate*. If the rate of return of the selected investment is at least equal to the hurdle rate if it operates at the same condition of the risk, then this investment is the best selection for the investor.

The weighted average of the rate of return *WACC* for the selected investment in both equity and debt must be added to the total value of the project.

Considering the stand for equity share *se*, the debt share *(1-se)*, the required rate of return on the equity re, the required pre-tax rate of return on debt *rd* and the tax rate t, then the *WACC* can be calculated as follows in equation (3), and table 1 summarizes the components and value of the *WACC* for each plant.

$$WACC = s_e \times r_e + (1 - s_e) \times r_d \times (1 - t) \quad (3)$$

TABLLE 1. Values of the WACC for nuclear, gas and coal fired power plants

Generation type	se	(1-se)	re	rd	t	WACC
Nuclear	50 %	50%	13.66 %	6.74%	40.7 %	7.86%
Gas	40 %	60%	10.7%	6.74%	40.7 %	6.8%
Coal	40 %	60%	10.7%	6.74%	40.7 %	6.8%

D. *The Levelized Cost for Combinations of Fuel Prices and Either Reduction Charge of Carbon Dioxides CO_2 Emissions or Waste Rejection Charges Due to Nuclear Energy Generation*

The levelized cost of electricity LOOE will be evaluated simultaneously for three types of base power generation through a range of fuel prices and reduction of CO_2 emissions charges or reduction of nuclear wastes charges. These three type of fuel are natural gas, coal and uranium, respectively. In tables II, III and IV, the columns correspond to fuel prices and the rows correspond to either the reduction charges of carbon dioxide CO_2 emissions or the waste rejection charges due to nuclear energy generation.

In table 2, the generation cost evaluation of the natural gas-fired plant is shown. The levelized cost of electricity LCOE for each combination of natural gas price between $2 and $22 per MMBTU and each reduction charge of CO_2 emissions between $0 and $120. For example, if natural gas costs $2/MMBTU and there are no CO_2 emissions, the LCOE is $34/MWh. But if natural gas costs $8/MMBTU and there is a $25/ton charge for reduction of CO_2 emissions, then LCOE is $101/MWh.

TABLE 2. Levelized cost of gas-fired power plants for various combination of natural gas prices (columns) and CO2 emissions elimination charges (rows).

	$2	$4	$6	$8	$10	$14	$18	$22
$0	34	53	72	91	110	148	186	224
$5	36	55	74	93	112	150	188	226
$10	38	57	76	95	114	152	190	228
$15	40	59	78	97	116	154	192	230
$20	42	61	80	99	118	156	194	232
$25	44	63	82	101	120	158	196	234
$30	46	65	84	103	122	160	198	236
$35	47	67	86	105	124	162	200	238
$40	49	68	87	106	125	163	201	239
$45	51	70	89	108	127	165	203	241
$50	53	72	91	110	129	167	205	243
$60	57	76	95	114	133	171	209	247
$80	65	84	103	122	141	179	217	255
$100	73	92	111	130	149	187	225	263
$120	80	99	118	137	156	194	232	270

In table 3, the generation cost evaluation of the coal fired power plant is shown. The levelized cost of electricity LCOE for each combination of coal prices between $1 and $7 per MMBTU and each reduction charge of CO_2 emissions between $0 and $120.

TABLE 3. Levelized cost of coal-fired power plants for various combination of coal prices (columns) and CO_2 emissions elimination charges (rows).

	$1	$1.5	$2	$3	$4	$5	$6	$7
$0	50	55	60	69	79	89	99	108
$5	54	59	64	74	84	93	103	113
$10	59	64	69	78	88	98	108	117
$15	63	68	73	83	93	102	112	122
$20	68	73	78	87	97	107	117	127
$25	72	77	82	92	102	112	121	131
$30	77	82	87	97	106	116	126	136
$35	82	86	91	101	111	121	130	140
$40	86	91	96	106	115	125	135	145
$45	91	95	100	110	120	130	139	149
$50	95	100	105	115	124	134	144	154
$60	104	109	114	124	133	143	153	163
$80	122	127	132	142	151	161	171	181
$100	140	145	150	160	169	179	189	199
$120	158	163	168	178	188	197	207	217

In table 4, the generation cost evaluation of nuclear power plant is shown. The levelized cost of electricity LCOE for each combination of uranium prices between $0.25 and $2.75 per MMBTU and the waste rejection charges due to nuclear energy generation between $0 and $120 [6].

TABLE 4. Levelized cost of nuclear power plants for various combination of uranium prices (columns) and waste reduction charges (rows).

	$0.25	$0.5	$1	$1.5	$2	$2.25	$2.5	$2.75
$0	83	86	92	97	103	106	109	112
$5	83	86	92	97	103	106	109	112
$10	83	86	92	97	103	106	109	112
$15	83	86	92	97	103	106	109	112
$20	83	86	92	97	103	106	109	112
$25	83	86	92	97	103	106	109	112
$30	83	86	92	97	103	106	109	112
$35	83	86	92	97	103	106	109	112
$40	83	86	92	97	103	106	109	112
$45	83	86	92	97	103	106	109	112
$50	83	86	92	97	103	106	109	112
$60	83	86	92	97	103	106	109	112
$80	83	86	92	97	103	106	109	112
$100	83	86	92	97	103	106	109	112
$120	83	86	92	97	103	106	109	112

E. *Generation Cost Evaluation for Renewable Energy*

Renewable energy is considered the best choice to generate electricity with no air pollutants and this leads to availability of replacement the fossil fuel energy generation, but it has high purchase cost and low range of capacity factor compared with fossil fuel energy generation. Table 5 shows capital cost and capacity factor for renewable energy compared with other fossil fuel energy

TABLE 5. Capital cost of energy generation for renewable and non-renewable.

Generation Type	Nominal Capacity (MW)	Capital Cost ($/KW)	Assumed Capacity Factors	Expected Capital Cost ($/KW)
Natural Gas: Combined Cycle	620	917	90%	1019
Coal	650	3.246	90%	3.607
Hydroelectric: Conventional	500	2.936	75%	3.915
Nuclear: dual unit	2234	5530	90%	6144
Biomass: combined cycle	20	8180	90%	9089
Wind: onshore	100	2213	25%	8852
Wind: offshore	400	6230	35%	17800
Solar: photovoltaic	150	3873	20%	19365
Solar: Thermal electric	100	5067	20%	25335

Capacity factor for each designed power plant must be taken in consideration because there are some barriers that prevent power plants to operate continuously like loss of fuel for fossil fuel power plants, disappearance of sunlight for solar energy generation system and low speed wind for wind energy system. The energy generation cost $/KW for renewable energy generation compared with nuclear energy generation and different types of fossil fuel energy generation with taken in consideration the capacity factor is evaluated and these results are summarized as the following in table. It is clear that nuclear generation cost is the cheapest one as well as has high range of capacity factor [7].

III. Environmental Considerations Associated With Energy Generation Comparing With Fossil Fuel Power Plants

In this section, a scientific comparison between nuclear energy generation and other types of energy generation is applied in the environmental side. So that, we observe that nuclear energy generation has the lowest environmental impacts and pollutants. Energy generation from the nuclear fission don't produce carbon dioxide CO_2 emissions nor any air pollutants. There are 435 operating nuclear power reactors in all over the world and prevent carbon dioxide emissions of more than 2 billion tons. By contrast, the coal-fired power plants in all the world emit annually around 30 billion tons of carbon dioxide CO_2 and cause passive effects on the public health and premature death because of the air pollutants and the dispersion of pollutants including mercury, which is harmful to the nervous system especially for the infants [8]. Also, nuclear power plants emit less radioactive materials than coal-fired power plants like uranium and other radioactive isotopes which are found in the coal soot and ash. The greatest environmental impact associated with the nuclear energy generation is due to the uranium mining. The uranium mining must be drastically reduced when the nuclear reactor commercially operating and that may be expected by certain decades [9].

Recycling of the used fuel is very important stage that drastically reduce the radioactive hazards, Moreover the waste volume must be isolated from the environment. For example, the repository of this type of waste can be after 300 year approximately comparable to that of natural uranium distributed around the world because of the radioactivity effect. Furthermore, the modern techniques for the waste isolation equal or exceed the level of isolation provided by the nature for radioactive ores. Publicized issues of the waste radioactivity will be reduced to the historical scale which takes a few hundred years instead of the geological scale which takes hundreds of thousands of years. This waste is disposed for any environmentally inert form such as vitrified solids or ceramic or which prevent leaching of any material into the environment for thousands of years after dissipation of their radioactivity.

On another hand, mercury and heavy metals which are considered the main elements of the waste of the coal-fired power plant will remain toxic in perpetuity and can be kept away from the environment [10].

Nuclear power plants need continuously cooling water, i.e., the light water reactors LWRs need larger amount of cooling water than fossil fuel power plants because LWRs operating at very low temperature. However, nuclear power plants which contain liquid-metal-cooled fast reactor LMFRs have operating temperature equal to fossil fuel power plants. So, they need the same requirements of the cooling water of fossil fuel power plants. Cooling water for all power plants, both fossil fuel and nuclear power plants, is not consumed but it is only used for cooling and then return after chemical treatments to its origin state to the river, lake or sea.

In regions which have no resource of water, a technique of cooling tower is used. In cooling tower technique, recycling of water which depends on evaporation of water and then return it to its nature as clean water is used. Table 6 shows the requirements of cooling water for 1000-MW energy generation for both once through cooling and cooling towers. Some of power plants which use cooling tower technique utilize the waste water of the city, which is cleaned firstly and then returned to pure water, in the water supply for the cooling tower system. The technique of cooling tower depends significantly on the atmospheric temperature. Therefore; the efficiency of the cooling towers system would be increased in Winter more than Summer [11].

TABLE 6. Cooling water requirements of 1000 MW (million liters/day)

Type of Cooling	LWR (typical coal plant) with 32% thermal efficiency	LMFR (fossil-fuel fired plant) with 42% thermal efficiency
Once-through cooling (temp. rise=12 °C)	3690	2330
Cooling towers	81.2	52.8

V. CONCLUSION

This paper has examined the economic prospects for nuclear energy generation and show that Egyptian governments convinced to establish the first nuclear power plant in its land although it has low price of natural gas to reduce air pollutants and to make diversity in the types of energy generation and reduce dependence on the fossil fuel energy generation.

The role of nuclear energy in the global future of energy systems is uncertain. Some government think the emission of greenhouse gases must be reduced and the fossil fuel energy generation must be converted to clean environment nuclear energy generation. Other governments are dismissive to nuclear energy because they think that nuclear energy may cause fatal accidents as well as it is not the best solution for preventing pollution as renewable energy. Regardless of these varied perceptions, Egypt and some Middle East countries have ambitious plan regarding nuclear energy. So, Egypt started to establish the first nuclear power plant in El-Dabaa City, north of Egypt in cooperation with Russian Rosatom State Nuclear Energy Corporation.

Dependence on fossil fuel large scale energy generation must be reduced over the coming decades, with the desire of completely transformation to nuclear energy generation before the end of the present century. Only nuclear energy generation is capable to providing the sustainable reliable large scale clean energy with good economically generation cost, and this is the main step for transformation the countries to be industrial societies.

Industrial countries in the world must guide other counties for their transformation from fossil fuel energy generation which produces greenhouse gases emissions to clean large-scale energy generation based on nuclear fission. France is the most famous industrial country which achieves large scale energy generation, 80% of generated energy in France depends on nuclear energy, as well as its contribution for drastically reduction of the global rate of greenhouse gases emissions with respect to both carbon dioxides CO_2 and methane in the atmosphere.

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