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THE USE OF NUCLEAR ENERGY: CLIMATE CHANGE AND ENERGY SECURITY

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Abstract. *The supply and energy security are strategic points in government decisions to ensure energy supply and promote economic growth, requiring continuous investments in new energy sources and improving existing. However, with the worsening of global warming caused by Greenhouse Gas emissions (GHG) with Carbon Dioxide (CO_2), the main polluter, leads to search for new CO_2 mitigation projects on the environment through energy generation sources with levels minimum greenhouse gas emissions, less dependence on weather conditions, and to present plenty of fuel and security of energy supply. In this scenario, nuclear energy is alternative source to minimize the environmental impact due to the emission of greenhouse gases caused by burning fossil fuels, and enable the firm energy production in the electricity sector, in large capacity plants. This work present a brief overview of nuclear power plants worldwide, efficiencies, capacity factor, fuel availability, and costs associated with: maintenance, operation and fuel. Even as perform a quantitative analysis of CO_2 emission that would no longer be emitted into the atmosphere, when using a thermonuclear instead of burning fossil fuels in conventional thermal power.*

Keywords: *greenhouse gas emissions, nuclear power, energy security*

1. INTRODUCTION

Currently coal is the main source of electricity generation in the world around 40% of production. It is also mainly responsible for CO_2 emissions in the air, mitigation projects and investments in technology (Clean Coal Technologies) are being developed to mitigate this framework (WNA, 2015a).

More than 60% of the electricity production comes from coal and natural gas, making these two sources the main electricity generators in the world. (IEA, 2014)

Fig. 1.1 is presented with a range emission levels of equivalent carbon dioxide by Gigawatt per hour (CO_2e/GWh) according to the type of source power generation. Among the sources of electricity generation non-renewable, power plants and lignite coal are those with the highest rates of emission of CO_2e/GWh in its life cycle, as the natural gas plants occupy the fourth position of the largest stations. The nuclear plants are those with the lowest levels of emissions with average values 30 times smaller than the coal plants (WNA 2011).

Climate changes due to the increase in greenhouse gas concentrations is warning society of the need to reduce greenhouse gas emissions and the use of source of clean power generation and are not vulnerable to increase in extreme effects of climate change.

Low emission of greenhouse gases, the abundant uranium reserves, low operating costs, maintenance and fuel, together with high capacity factors, puts nuclear plants as a source of promising power generation to replace plants thermal coal and natural gas in the world.

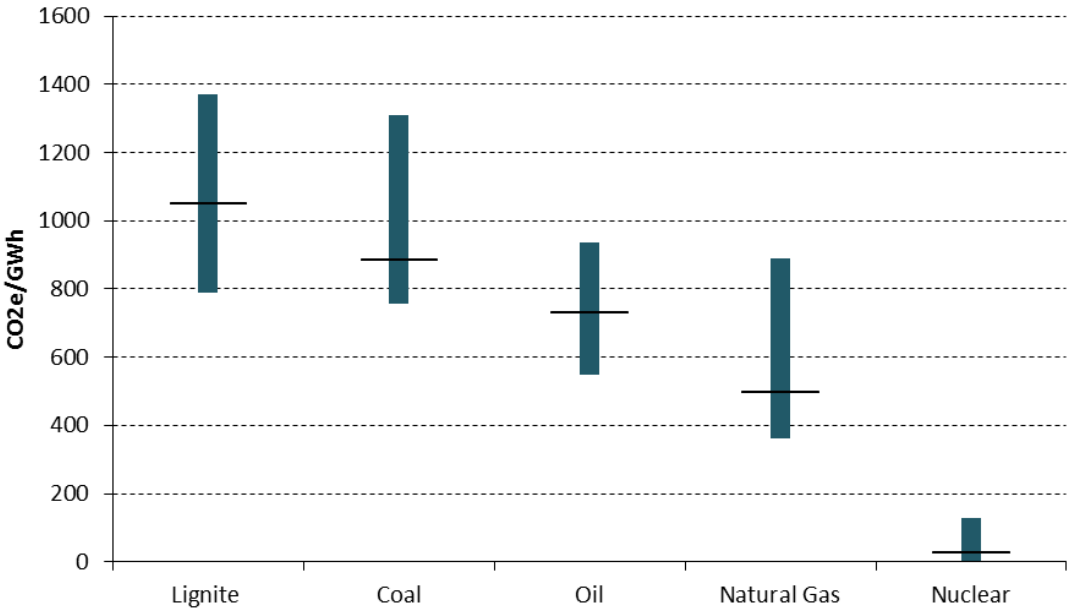

Figure 1.1 - Emissions of CO_2e/GWh in thermal life cycle with various types of fuels.
Source: processed data from WNA (2011)

So this work will be presented a brief summary of nuclear power plants along with the completion of the quantification of CO_2 that no longer emitted into the atmosphere during the process of generating energy when used the nuclear power plants in place of coal plants or natural gas.

2. NUCLEAR ENERGY

IAEA (2014a) present that by December 2013 there were 434 reactors in operation worldwide, which together ensure a generation of 371 733 MWe, which 273 (62.9%) of the activity in reactors are Pressurized Water Reactor type (PWR) , and 68.0% of the entire power available worldwide come from these types of reactors. In the same period they are set up 72 nuclear reactors under construction in the world, which together account for a total of 69,367 MWe, and of these 60 reactors are PWR, and account for 87% of all power being installed. Since the 92 reactors in the planning stages, 78 reactors are PWR.

The energy mix in some countries the use of nuclear energy is predominant for the purposes of electricity generation, with share exceeding 50%, as is the case in countries such as France (73.3%), Belgium (52.1%), Slovakia (51.7%) and Hungary (50.7%), wherein 100% of these countries operation are PWR reactors. Other countries with 100% of its nuclear generation with PWR reactors are: South Africa, Armenia, Brazil, Bulgaria, Slovenia, the Netherlands, Iran, Ukraine and Czech Republic (IAEA, 2014a).

2.1 Efficiency and Capacity factor

Generally nuclear power plants in operation worldwide (December 2013), have an average efficiency of 32%, but with major disparities between their efficiencies ranging from 17% to 39% depending on the reactor and cycle model that the plant operate. It's presented in Fig. 2.1 the real values of average efficiency, minimum and maximum for each type of nuclear reactor in operation in the world.

The operating plants that have lower efficiencies are the old plants projected between the 60s and 70s still the first generation of reactors, for LWGR plant Bilibino (1, 2, 3 and 4) located in Russia with reactor model EGP -6 with 17% efficiency. Among the plants with higher efficiencies are the GCR to plants Hartlepool (A-1 and A-2) and Heysham (A-1, A-2, B-1 and B-2) all located in the United Kingdom and efficiencies between 38.3% and 39.7% (IAEA, 2014a).

Already advanced nuclear reactors tend to present an average efficiency of 35.6%, with values ranging from 23% to 47%. Despite having a higher high efficiency of these reactors are still under development, and the 60 models classified as advanced reactors only 7 are under construction and 3 in operation (IAEA / ARIS, 2013). They are shown in Fig. 2.2 the estimates of average efficiency, minimum and maximum for each type of advanced reactor.

When comparing the efficiency of nuclear power plants with other sources of energy it is observed that nuclear power plants do not exhibit the best efficiency ratios. As can be seen in Fig. 2.3.

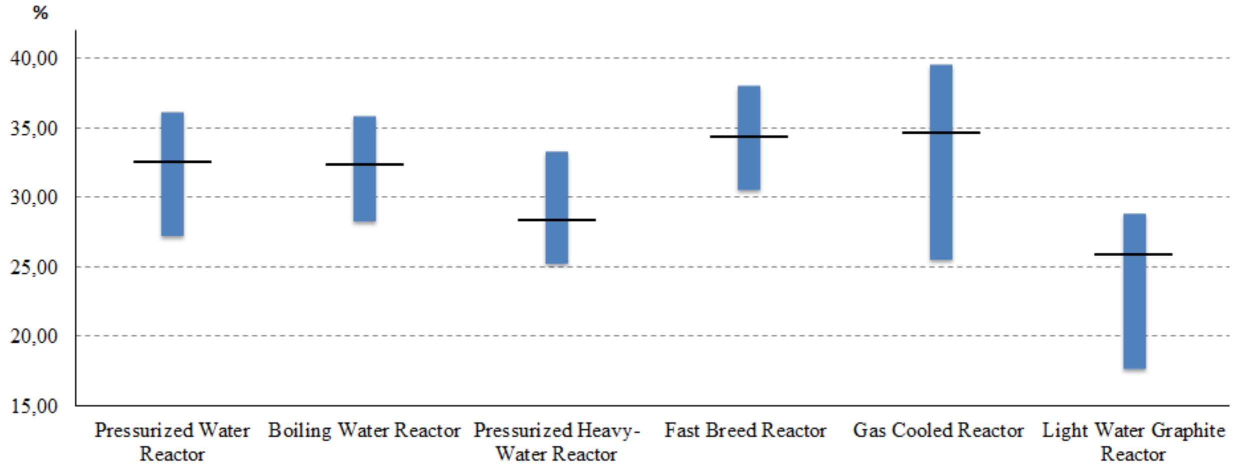

Figure 2.1 - Real efficiency of nuclear power plants in operation by type reactor (up to December 31, 2013)
Source: Processed data of IAEA (2014a)

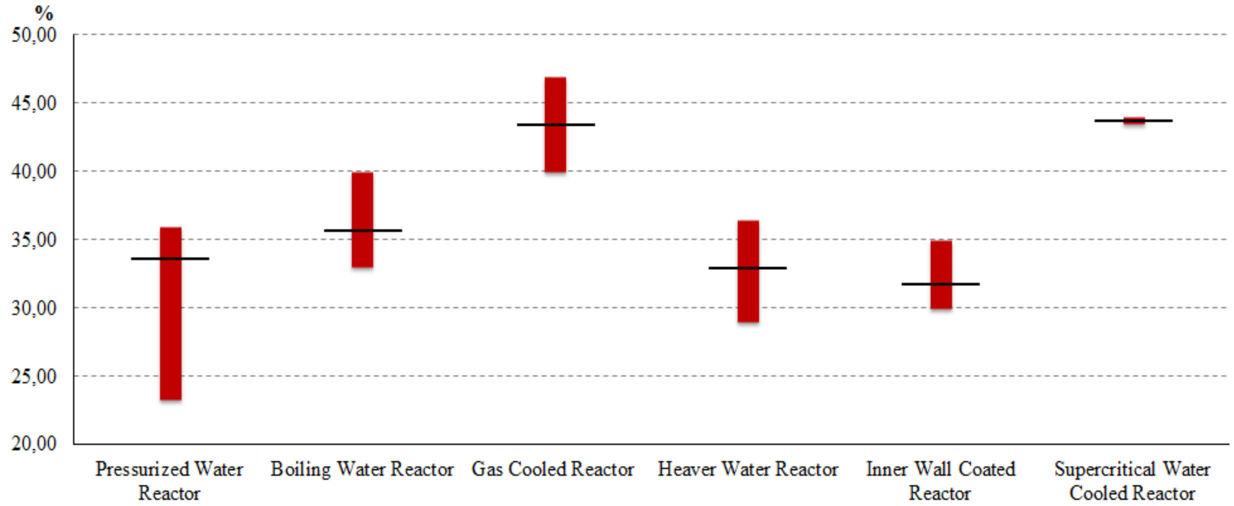

Figure 2.2 - Estimate the efficiency of nuclear power plants with advanced reactors
Source: Processed data of IAEA/ARIS (2013).

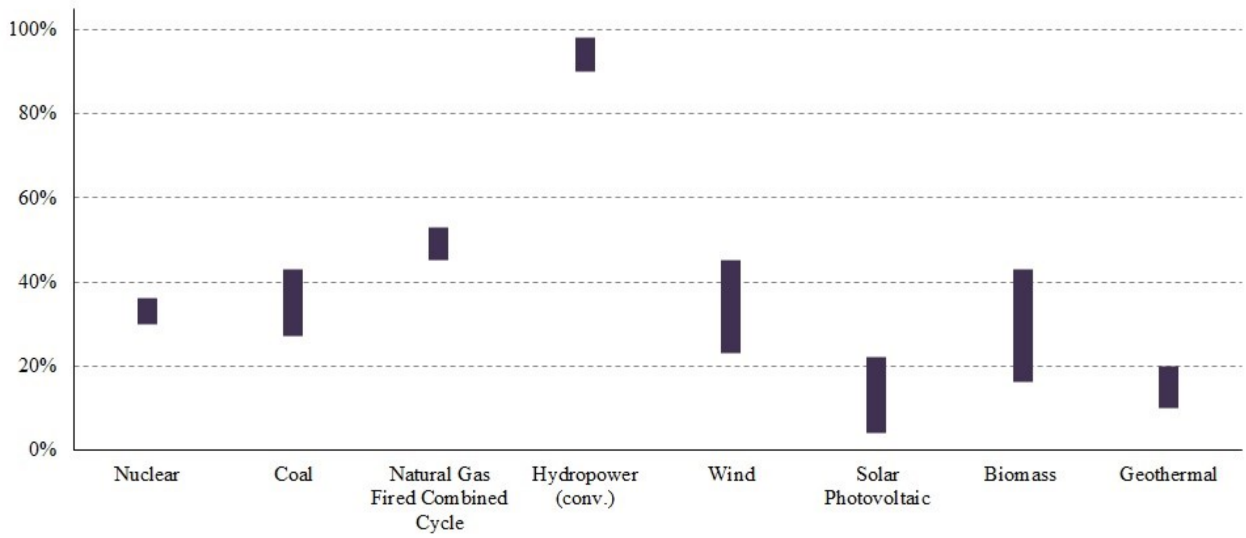

Figure 2.3 - Estimate maximum efficiency and minimum per power generation
Source: Processed data of Evans, Strezov, and Evans (2006).

It estimates that the energetic power of uranium contained in UO_2 pellets used in light water reactors, are approximately 3,092,300 MJ/kg. While a coal with calorific value of 27,000 kJ/kg present a power density of approximately 26.9 MJ/kg and natural gas 41.55 MJ/m^3. Considering an average efficiency of 32% for nuclear power plants, 40% coal and 55% natural gas in combined cycles are required 91.9 tons of coal or 43.3 thousand cubic meters of natural gas to generate the same amount of energy 1 kilogram of uranium (UO_2) (adapted from EPE, 2015).

But the availability of nuclear power plants factors are much higher than other energy sources, bringing security to the electricity supply system and ensuring a clean generation. According to EIA (2015), nuclear power plants have an average monthly capacity factor of 91.4%, while other sources such as coal, natural gas and hydraulic have average values respectively 60.4%, 48.2% and 38.5%. It is shown in Fig. 2.4 the maximum, minimum and average capacity factor by energy source obtained from monthly data from January 2013 to February 2015.

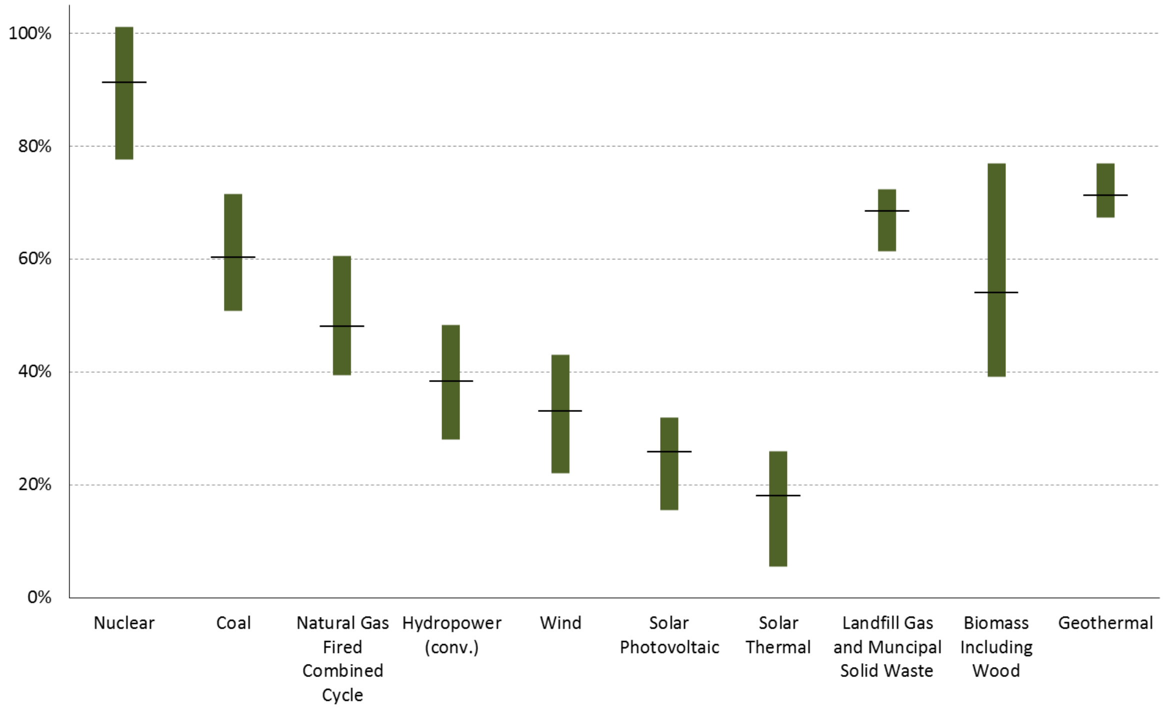

Figure 2.4 - Factor actual maximum capacity, minimum and average by energy source (Jan/2013 and Feb/2015)
Source: Processed data of EIA (2015)

2.2 Nuclear Fuel

Estimates that global supplies of uranium are approximately 5.9 million tons. The largest producer is Australia with 29% of world reserves, followed by Kazakhstan (12%), Russia (9%), Canada (8%). Brazil is in seventh place in the world rankings with 5% of world reserves (WNA, 2014).

The world's ability to conversion of triuranium octaoxide (U_3O_8) to uranium hexafluoride (UF_6) is 76,000 tons per year, as the demand for this product is between 60,000 to 65,000 tons per year. This conversion is carried out on a commercial scale by: Canada, China, France, Russia, United Kingdom and United States. Other countries such as Argentina, Brazil and Japan that have small conversion units (IAEA, 2014b).

In turn IAEA (2014b) shows that the uranium enrichment process is carried out to commercial levels of five major companies: China National Nuclear Corporation (CNNC), AREVA (France), Rosatom (Russian Federation), URENCO and USEC (both USA). Being that this process has a global capacity about 65 million Separative Work Units (SWU) per year, compared to the overall demand of approximately 49 million SWU per year.

2.3 Costs nuclear power plant

The cost of building a nuclear plant is quite uncertain, as there is significant uncertainty associated with construction times, like late works, public opposition and changing regulatory environment, so this factors lead to these plants be financed with high rates interest. Another important aspect are federal subsidies for the nuclear power industry in many countries are very low even more endearing the deployment of these plants (Schultz, 2012).

Schlissel and Biewald (2008) show that the nuclear power plant deployment costs are in the order of \$ 5,500 / kW to \$ 8,100 / kW, including escalation and financing costs. But nuclear plants have the lowest operating costs, maintenance and fuel for power plants. It is noteworthy that until the beginning of the century, the costs of nuclear and coal were equivalent, though the pressure of environmental agencies for generating energy more cleanly has led the coal plants to invest in measures aimed at reducing their indicies of pollution, especially greenhouse gas emissions of the greenhouse effect. This floating costs can be seen in Fig. 2.5.

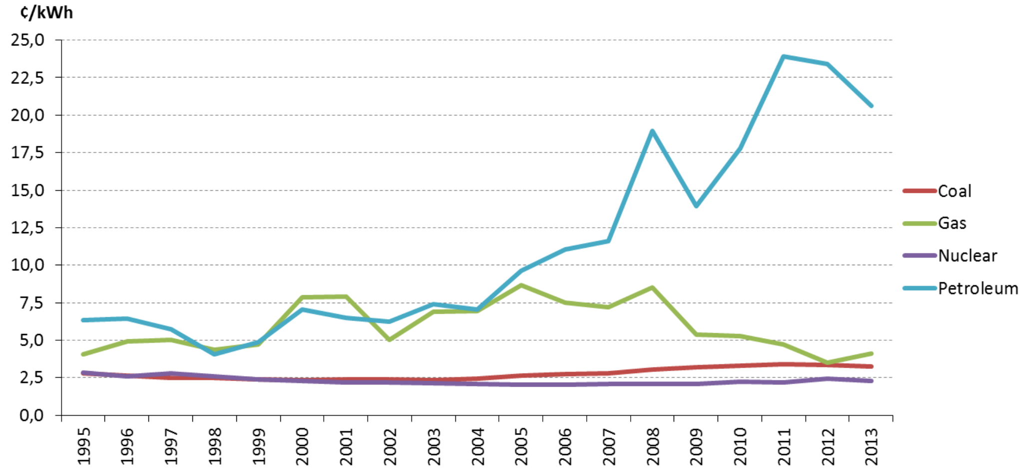

Figure 2.5 - Historical evolution of operating costs, maintenance and fuel by energy source.
Source: Processed data of NEI (2014)

3. METHODOLOGY

The quantification of CO2 emission was based on the chemical composition of the fuel being introduced in basis weight for the coal and on a volumetric basis for natural gas according to Tab. 3.1 and 3.2 respectively. The selection of countries took into account the high demand for electricity and / or abundance of fuel resources for consumption or export and / or feature presented by fuel for comparison purposes.

Table 3.1. Examples of representative Coal compositions for some countries

Country/Location	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Wet	Ash
USA/ Colowyo	67.54	4.46	13.74	1.40	0.35	7.96	4.55
RUSSIA/Siberia	64.03	5.04	15.20	1.30	0.52	6.08	7.82
SOUTH AFRICA/ Ermelo	67.58	4.29	12.69	0.94	0.26	5.66	8.58
CHINA/ Shanxi	62.23	3.94	9.08	1.14	0.62	2.23	20.76
INDIA/ Madhya Pradesh	53.64	3.54	5.59	1.16	1.16	7.28	28.50
AUSTRÁLIA/ Queensland	78.72	4.62	5.19	1.87	0.46	1.63	7.51
BRAZIL/ Rio Grande do Sul	45.86	3.03	8.57	0.76	3.07	11.60	27.11
COLOMBIA/ La Guajira	73.82	5.13	11.31	1.15	0.33	3.99	4.27
CHILE/ Magallanes Basin	52.21	3.91	12.17	1.14	0.48	16.74	13.35
PERU/ Alto Chicama	72.67	1.43	2.75	0.73	0.61	5.59	16.22

Source: USGS (2015)

Table 3.2. Examples of representative natural gas compositions for some countries

Country	CH_4	C_2H_6	C_3H_8	C_4+...	N_2	CO_2
RUSSIA	97.80	0.50	0.20	0.10	1.30	0.10
USA	81.80	5.60	3.40	2.20	6.90	0.10
CANADA	88.90	4.30	1.80	1.80	2.60	0.60
NORWAY	92.03	5.75	1.31	0.45	0.46	0.00
QATAR	90.90	6.43	1.66	0.74	0.27	0.00
BRAZIL	89.44	6.70	2.26	0.46	0.80	0.34
BOLIVIA	90.70	6.10	1.20	0.00	1.50	0.50

Source: Denys. F. and Vries. (2013); GasNet. (2015)

For thermoelectric mineral coal and natural gas were considered the following operating data:

- Average installed Power: 500MW;
- Thermal-efficiency of thermal coal and natural gas respectively: 40% and 55%;

- Ability to Fator of thermal coal and natural gas respectively: 60% and 48%;

The combustion process was modeled analyzed fuels at stoichiometric condition with a temperature of 298 K and 1 atm pressure.

The mass flow / required fuel volume is given by equation (1):

$$\dot{m} = \frac{\dot{Pot}}{PCI} \quad (1)$$

The Dulong equation (2) was used to estimate the PCI coal given in Tab. 3.3. Set the composition of the coal to 1% moisture which matches the drying process undergone by the coal before combustion process.

$$\mathrm{PCI} = 8140\ \mathrm{C} + 29000\left(\mathrm{H} - \frac{\mathrm{O}}{8}\right) + 2220\ \mathrm{S} - 600\ \mathrm{H_2O} \quad (2)$$

Table 3.3. Calorific value calculated for the representative Coal compositions for some countries

Country/Location	PCI Coal (kJ/kg)
USA/ Colowyo	28,326
RUSSIA/Siberia	27,025
SOUTH AFRICA/ Ermelo	27,592
CHINA/ Shanxi	24,949
INDIA/ Madhya Pradesh	23,056
AUSTRÁLIA/ Queensland	31,862
BRAZIL/ Rio Grande do Sul	20,430
COLOMBIA/ La Guajira	30,585
CHILE/ Magallanes Basin	27,368

Table 3.4. Calorific value representative consulted for Natural Gas compositions for some countries

Country	PCI Natural Gas (MJ/Nm^3)
USA	42.70
RUSSIA	39.60
BRAZIL	40.22
CANADA	43.40
NORWAY	42.69
QATAR	43.43
BOLIVIA	38.80

Source: Denys. F. and Vries. (2013); GasNet. (2015)

From the installed capacity of nuclear power plants and considering a 91% capacity factor for nuclear power, there was a comparison of how a thermoelectric coal or combined cycle gas / steam generates CO2 to operate in the same of thermonuclear power over a year.

4. RESULTS

Fig. 4.1 have to CO2 emissions by millions of tonnes a year (Mt/year) generated by thermal power with 500 MW capacity using coal and natural gas in the country of origin, except for China and India who considered natural gas from Qatar region.

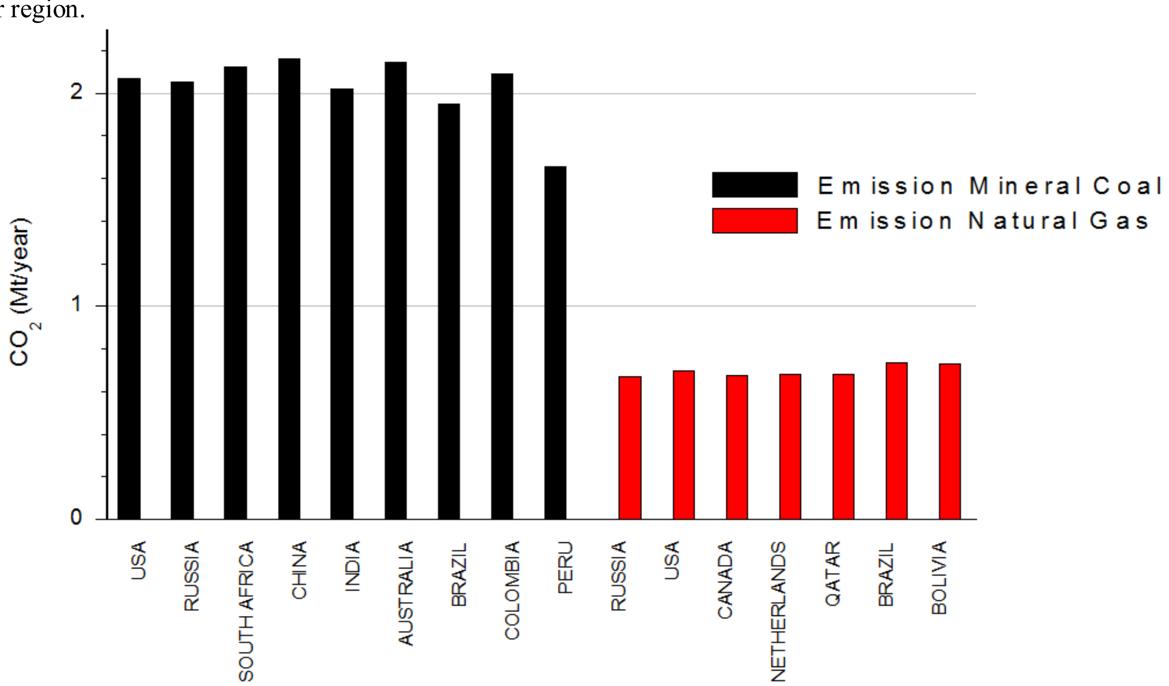

Figure 4.1 annual CO_2 emissions for thermoelectric mineral coal and natural gas located in various countries with 500 MW capacity

Tab. 4.1 presents some nuclear plants worldwide in operation or under construction in accordance with Nuclear Energy Institute (NEI), when operated break off emission CO_2 into the atmosphere compared to coal-fired or natural gas.

Table 4.1 Amount of CO_2 emitted annually by thermoelectric using coal or natural gas to operate in the same power of thermonuclear

Nuclear Power	Net Power (MW)	Country	CO_2 Coal (MWh/kg)	CO_2 Natural gas (MWh/kg)	CO_2 Coal (Mt/year)	CO_2 Natural Gas (Mt/year)
Angra 1 e 2	1884	Brazil	4.86	10.26	11.13	5.27
Angra 3 (1)	1245	Brazil	4.86	10.26	7.35	3.48
Ling Ao II	1080	China	4.37	11.08	7.09	2.80
Fuqing II (1)	1150	China	4.37	11.08	7.55	2.98
Vogtle 3	1117	USA	4.57	10.86	7.01	2.95
Rostov 2	950	Russia	4.60	11.30	5.92	2.41
Rostov 4 (1)	1011	Russia	4.60	11.30	6.30	2.57
Tarapur-3	490	India	4.69	11.08	3.00	1.27
Rajasthan 7 (1)	630	India	4.69	11.08	3.86	1.63

(1) Under construction

Due to international agreements on climate change like the Kyoto Protocol, countries must meet a maximum quota of emission greenhouse gases (GHG). To reduce CO_2 emissions, laws are created that restrict GHG emissions. So that. countries that fail to comply with GHG reduction targets, become carbon credit buyers. By convection, 1 tonne of carbon dioxide (CO_2) amounts to a carbon credit. This credit can be traded in the international market. Nuclear power plants can be built to reduce CO_2 emissions, allowing achieve GHG emission targets (EPA, 2015).

5. CONCLUSION

The use of the nuclear electricity generation allows for a substantial reduction in CO_2 emissions into the atmosphere compared with conventional thermoelectric operating with coal and natural gas. Thus nuclear power plants are presented as one of the energy sectors that contribute to the greenhouse gas reductions with a percentage share of approximately 19%. Despite advances in supercritical coal plants, IGCC and ultrasupercritiva such technologies tend to contribute only 7% of CO_2 reductions to the environment. While the contribution of natural gas plants are limited to 2% (WCA, 2012).

China has the highest energy demand in the world. Its electricity generation is predominantly thermoelectric where: 78.4% are coal, 1.72% to 2.2% natural gas and nuclear generation. The decarbonisation process of China's energy matrix undergoes massive investments in renewable energy like hydropower and Wind but who are vulnerable sources climate change and low capacity factors, especially wind plants. At the same time investments are occurring in nuclear power plants with 27 units under construction which will result in a total installed capacity 29 gigawatts, which will provide the country reducing their emissions and security of supply of electricity (IEA, 2014; SNPTC, 2013).

With the third largest global energy demand to levels India also features an array of electricity generation consists of thermoelectric (66%) being the most coal, 19% are hydroelectric plants and other or 15% of the matrix is a mix between nuclear power plants, wind, small hydroelectric plants, biomass and waste-to-electricity. It has strong investments in renewable sources especially wind, but investments are still presented as insufficient front of your energy deficit (CSO, 2013). Indian investments in nuclear power plants are turning mainly to development of nuclear fuels the basis of thorium in order to explore their abundant reserves of this mineral. There is a prospect that by 2020 India has 14200MWe installed and in 2050 that 20% of its supply of electricity is from nuclear sources (WNA, 2015b).

Brazil presented in 2013 a total power generation of 609.9 TWh. Since the total of this generation 79.3% is from renewable sources especially hydraulic generation that has a percentage of 70.6% of this total (including imports). Among the non-renewable sources to greater production is natural gas with 11.3%, followed by 4.4% of oil and derivatives, 2.4% nuclear source and 2.6% of coal and coke oven gas (EPE / BEN, 2014). Entrento the high dependence of renewables puts the array to a condition of vulnerability to extreme weather events, requiring non-renewable source to meet the energy demand in critical periods. With abundant reserves of uranium, and mastery of the entire nuclear cycle process has great potential to increase the share of nuclear energy in the matrix, allowing for electricity generation with greater security of energy supply and lower costs than mills to gas and fuel oil.

6. ACKNOWLEDGEMENTS

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