Journal of Power and Energy Engineering, 2014, 2, 25-30
Published Online August 2014 in SciRes. http://www.scirp.org/journal/jpee
http://dx.doi.org/10.4236/jpee.2014.28003

Effects of Energy Production and Consumption on Air Pollution and Global Warming

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Received 12 June 2014; revised 20 July 2014; accepted 6 August 2014

Abstract

In this study, different fuel combinations that can be adopted to reduce the level of air pollution and GHG emissions associated with the energy generation are assessed; and the air pollution and global warming effects of the Jamaican electricity generation fuel mix are determined. Based on the energy production and consumption patterns, and global warming potentials, the authors conclude that: an increase in energy consumption and production yields an increase in GHGs and other major pollutants; choice of the fuel mix determines the success of GHG emissions reductions; and there is no single fuel that is not associated with GHG or other air pollution or environmental degradation implications.

Keywords

Energy Generation, Energy Utilization, Air Quality Implications, GHG Emissions, Jamaica

1. Introduction

The harvesting, processing, distribution, and use of fuels and other sources of energy have major environmental implications including land-use changes due to fuel cycles such as coal, biomass, and hydropower, which affect both the natural and human environment. Energy systems carry a risk of routine and accidental release of pollutants [1]. Greenhouse gas (GHG) and air pollutant emissions share the same sources—transport, industry, commercial and residential areas [2]. All these sources depend on production, distribution and utilization of energy for their daily activities.

The gases included in GHG inventories are the direct GHGs: namely, carbon dioxide (CO_2), methane (CH_4),

How to cite this paper: Kgabi, N., Grant, C. and Antoine, J. (2014) Effects of Energy Production and Consumption on Air Pollution and Global Warming. *Journal of Power and Energy Engineering*, **2**, 25-30.
http://dx.doi.org/10.4236/jpee.2014.28003

nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6), and the indirect GHGs: non-methane volatile organic compounds (NMVOC), carbon monoxide (CO), nitrogen oxide (NOx), and sulphur dioxide (SO_2) [2].

Jamaica has no known primary petroleum or coal reserves and imports all of its petroleum and coal requirements. Domestic energy needs are met by burning petroleum products and coal and renewable fuel biomass (*i.e.*, biogases, fuel wood, and charcoal) and using other renewable resources (e.g., solar, wind and hydro). In 2008, approximately 86 percent of the energy mix was imported petroleum, with the remainder coming from renewables and coal [3]. Electricity is generated primarily by oil-fired steam, engine driven, and gas turbine units. Smaller amounts of electricity are generated by hydroelectric and wind power. Use of solar energy is negligible, and the option for nuclear energy has not been exploited.

The increase in GHG emissions, with the country just a few years from the global warming tipping point is evident. Carbon dioxide emissions increased from 9531 Gg in 2000 to 13,956 Gg in 2005, methane emissions from 31.1 Gg in 2000 to 41.9 Gg in 2005. Nitrous oxide emissions also increased although in smaller quantities. Emissions from the electricity generation source category between 2000 and 2005 ranged from 2977 Gg to 3365 Gg for CO_2, 0.116 Gg to 0.132 Gg for methane, and 0.023 Gg to 0.026 Gg for N_2O [4].

The objective of this study was to assess different fuel combinations that can be adopted to reduce the level of air pollution and GHG emissions associated with the energy. The study bears significance to almost all countries that, due to the pressure of high energy demand, tend to settle for any available energy source without considering the environmental effects.

2. Methods

Desktop study methods were used to source data for this secondary research. Information relating to energy generation and utilization in Jamaica was accessed outside organizational boundaries, mainly from online sources, research journals, professional bodies/organisations and government published data and reports. The data acquisition approach was purposive and mostly "cherry-picking", *i.e.*, based on keyword searches, footnote chases, citation searches or forward chains, journal runs, and to some extent author searches.

Content analysis methods for drawing conclusions included noting patterns, themes and trends, making comparisons, building logical chain of evidence and making conceptual/theoretical coherence. The content analysis yielded some descriptive data giving a detailed picture of the energy generation, air pollution and climate change in Jamaica.

3. Results and Discussion

Electricity generation, transmission, and distribution are associated with GHG emissions like carbon dioxide (CO_2), and smaller amounts of methane (CH_4) and nitrous oxide (N_2O). These gases are released during the combustion of fossil fuels, such as coal, oil, and natural gas, to produce electricity. Less than 1% of greenhouse gas emissions from the electricity sector come from sulfur hexafluoride (SF_6), an insulating chemical used in electricity transmission and distribution equipment [5].

3.1. Electricity Consumption

Consumption of electricity has direct GHG emission implications for the company/organization generating the electricity, and indirect implications for the consumer. **Table 1** shows the annual increase in GHG emissions with increase in electricity consumption. The main electric utility related gases are: GHGs—CO_2, CH_4, N_2O, SF_6; and Air Pollutants—CO, SO_2, NOx, NMVOCs.

Electricity sales data was obtained from World Bank, Benchmarking data of the electricity distribution sector in Latin America and the Caribbean Region 1995-2005; and the emission factors: CO_2—0.819 tons CO_2/MWh; CH_4—0.03716 kg CO_2/MWh; N_2O—0.00743 ton CO_2/MWh were used for calculation of the GHGs.

3.2. Electricity Generation

The annual fuel use for electricity generation between 2000 and 2005 ranged from 5,159,687 to 4,811,726 million barrels of heavy fuel oil and from 725,158 to 1,794,870 million barrels of diesel oil. Global warming potential of the fuel use are summarized in **Table 2**.

Table 1. Annual electricity sales and GHG emissions (data source for electricity sold [6]; source for emission factors used in the calculations [7]).

	Electricity Sold (MW h)	Methane ($tonCO_2e$)	Nitrous Oxide ($tonCO_2e$)	Carbon Dioxide ($tonCO_2e$)	Total GHG Emissions
2001	2,793,375	103.8	20754.8	2,287,774	2,308,633
2002	2,896,547	107.6	21521.3	2,372,271	2,393,900
2003	2,998,345	111.4	22277.7	2,455,644	2,478,033
2004	2,975,509	110.6	22,108	2,436,942	2,459,161
2005	3,055,154	113.5	22699.8	2,502,171	2,524,984
Average	2,943,786	109.38	21872.32	2410960.4	2,432,942
SD	101,539	3.769	754.431	83160.688	83918.9

Table 2. GHG emissions from combustion of fuel during electricity generation (data source for electricity sold [6]; source for emission factors used in the calculations [7]).

		Consumption (million barrels)	CO_2 ($\times 10^6$ tons CO_2e)	CH_4 ($\times 10^6$ ton CO_2e)	N_2O ($\times 10^6$ tons CO_2e)	Total GHG ($\times 10^6$ tons CO_2e)
2000	Fuel Oil	5,159,687	2513	2.16	6.96	2522
	Diesel Oil	725,158	306,322	104	2202	308,627
2005	Fuel Oil	4,811,726	874	0.75	2.42	877
	Diesel Oil	1,794,870	758,190	257	5450	763,897

The emission factors used above were obtained from DEFRA [7] as follows: Diesel = 2.6569, 0.0009, 0.0191, 2.6769 kg CO_2e/L; and Fuel Oil = 0.26729, 0.00023, 0.000074, 0.26826 kg CO_2 e/kWh; for CO_2, CH_4, N_2O, and CO_2e respectively. Other conversions used include 1 barrel = 158.99 liters; and 1 kWh = 0.00009 tonne oil equivalent.

Choice of the right fuel mix for electricity generation determines the amount of air pollutants and GHGs released into the atmosphere. The current electricity fuel mix of Jamaica is fuel oil (71%), diesel oil (24%) and 5% renewable. **Figure 1** shows the fuel mix used in 2007 based on the installed capacity by energy sources (MWh) data obtained from the United States Energy Information Administration (EIA) [8].

3.3. The Energy Fuel Mix

Jamaica's National Energy Policy 2009-2030: contribution of fuel mix to electricity generation mix is summarized in **Figure 2**.

The 3.3 percent increase in annual electricity generation (GWh) over the period (1998-2009), moving from 2950 GWh in 1998 to 4214 GWh in 2009; was used as baseline to estimate possible implications of the National Energy Policy on GHG emissions as shown in **Figure 3**.

Contribution by each fuel type is shown in **Figure 4**, emphasizing the importance of a correct fuel mix in reduction of GHG emissions.

Conversions used include: Natural Gas—CO_2 = 0.18483, CH_4 = 0.00027, N_2O = 0.00011, CO_2e = 0.18521 kg COe/unit; Coal-CO_2 = 0.32360, CH_4 = 0.00006, N_2O = 0.00282, CO_2e = 0.32648 kg COe/unit; and LPG-CO_2 = 0.21419, CH_4 = 0.00010, N_2O = 0.00025, CO_2e = 0.21455 kg COe/unit.

3.4. Electricity Distribution

Figure 5 shows annual percentages of losses that occur during distribution of electricity in Jamaica. The data used was obtained from the United States Energy Information Administration (EIA). Electrical transmissions and distribution systems contribute significantly to emissions of sulfur hexafluoride (SF_6), which is also a GHG. The losses during distribution also add to the emissions.

3.5. Air Quality Implications

Trace gases and aerosols impact climate through their effect on the radiative balance of the earth. Trace gases such as greenhouse gases absorb and emit infrared radiation which raises the temperature of the earth's surface causing the enhanced greenhouse effect. Aerosol particles have a direct effect by scattering and absorbing solar radiation and an indirect effect by acting as cloud condensation nuclei. Atmospheric aerosol particles range from dust and smoke to mists, smog and haze [10]. **Figure 6** gives the average air pollutant contribution by coal and petroleum products.

In addition to emission of GHGs, fuel combustion affects air quality. Combustion of 1 kg of coal results in emission of 19 g SO_2, 1.5 g NOx, 5 g VOCs, 4.1 g PM_{10}, 14.7 g TSP, 187.4 g CO and 0.0134 g benzene; while 1 kg of petroleum products emits 0.01 g SO_2, 1.4 g NOx, 0.5 g VOCs, 0.07 g PM_{10}, 0.07 g TSP, and 13.6 g CO into the atmosphere [11].

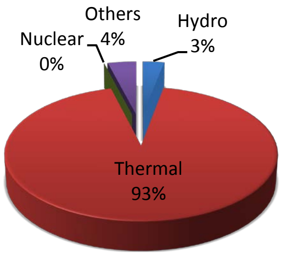


Figure 1. 2007 electricity generation fuel mix (data source: [8]).

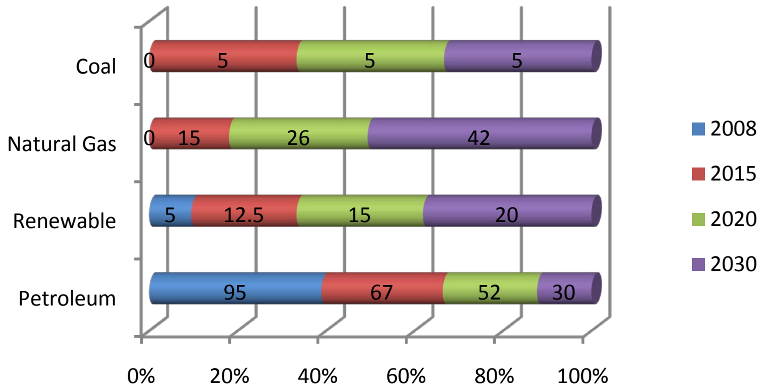


Figure 2. Electricity generation fuel mix proposed in the National Energy Policy (data source: [9]).

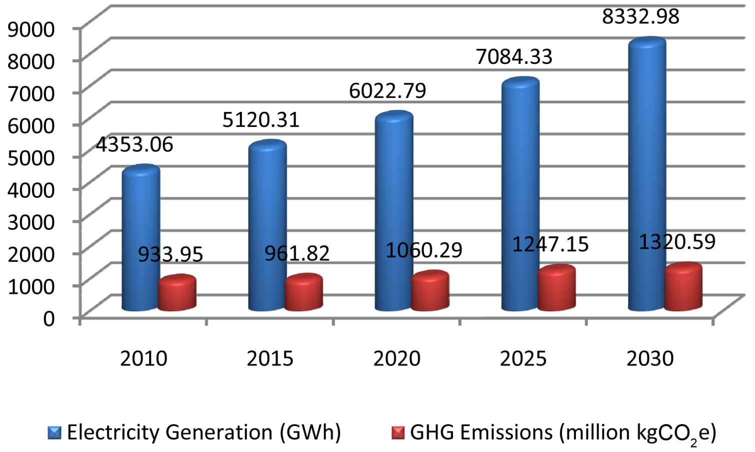


Figure 3. Estimate energy production and the potential GHG emissions (data source: [9]).

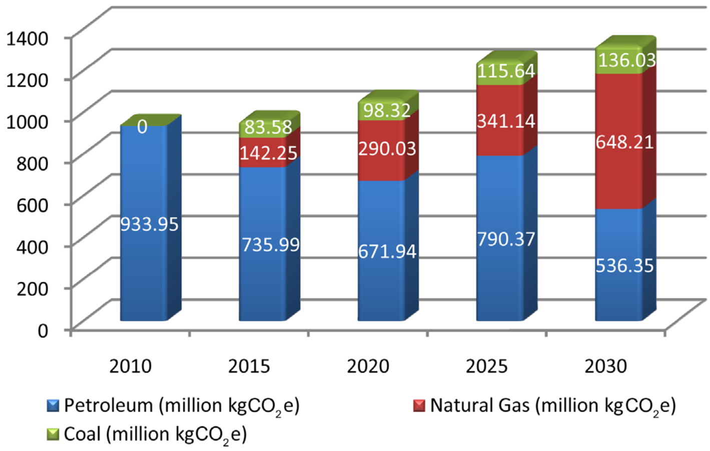


Figure 4. Contribution of the proposed fuels to GHG emissions (data source: [2], [7]).

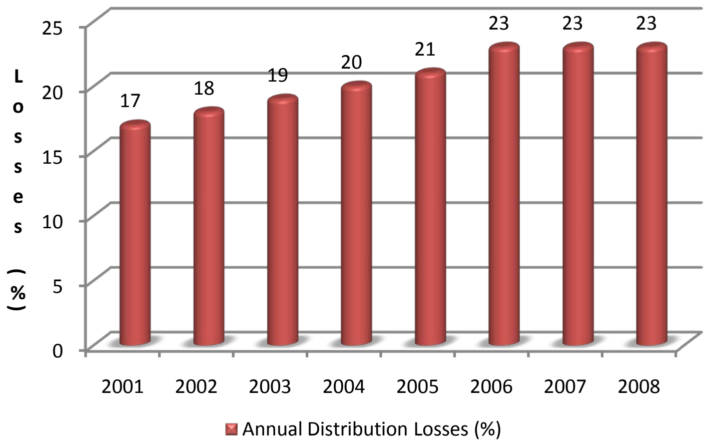
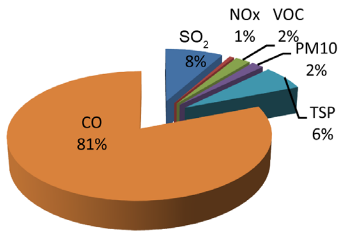
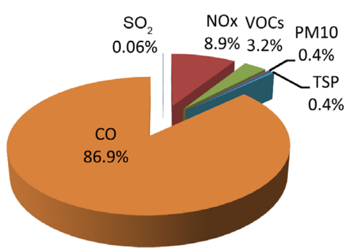


Figure 5. Electricity distribution losses (data source: [8]).



(a)



(b)

Figure 6. (a) Coal air pollutants; (b) Petroleum air pollutants (data source: [11]).

On combustion, fuel oil also produces primarily carbon dioxide and water vapour, but also smaller quantities of particulate matter and oxides of nitrogen and sulphur (OUR, 2012).

The potential environmental problem associated with coal is the formation of acidic effluents due to pyrite oxidation and the consequent mobilization of environmentally hazardous trace elements, which are mainly associated with the sulphide group of minerals in coal [12]. With combustion, these amounts of the SOx gases are emitted into the atmosphere.

4. Conclusions

The different fuel combinations (including coal, petroleum products, and natural gas) that can be adopted to reduce the level of air pollution and GHG emissions associated with the energy were assessed. This study has shown that: 1) choice of the fuel mix determines the success of GHG emissions reductions; and 2) there is no single fuel that is not associated with GHG or other air pollution or environmental degradation implications. The usual increase in GHG emissions with increase in energy consumption and production was observed.

Given the increasing energy demand and the environmental implications of the fuel mix options discussed, it may be necessary to also explore the nuclear energy option. Nuclear power plants do not require a lot of space when compared to equivalent wind or solar farms. The nuclear energy does not contribute to carbon emissions (no CO_2 is given out) thus does not cause global warming. Production and consumption of the nuclear energy do not produce smoke particles to pollute the atmosphere. The great advantage of nuclear power is its enormous energy density, several million times that of chemical fuels. Even without recycling, one kilogram of oil produces about 4 kWh; a kg of uranium fuel generates 400,000 kWh of electricity. This also reduces transport costs (although the fuel is radioactive and therefore each transport that does occur is expensive because of security implications). Furthermore, it produces a small volume of waste.

Acknowledgements

Support by the Academy of Sciences for the Developing World (TWAS), Polytechnic of Namibia, International Centre for Environmental and Nuclear Sciences (ICENS) and Faculty of Science and Technology, University of the West Indies (Mona Campus) is highly acknowledged.

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