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ANALYSIS OF ECOLOGICAL AND FISCAL PHASES OF INNUMERABLE CRUCIAL ENERGY SOURCES IN SUB-SAHARA APPLICATIONS

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ABSTRACT

This examination researches the financial reasonability and advantages of utilizing coal contrasted with wood fuel or condensed oil gas in Botswana by investigating the measure of carbon dioxide and other nursery gasses radiated by every vitality source created when consuming the vitality source and how much vitality every vitality source is required to heat up a limit of water. The fundamental point is to accumulate, dissect exact information in order to empower pertinent partners to settle on educated choices on the utilization of indigenous coal, where monetarily feasible. The examination is mostly done at a Junior Community Secondary School in Gabane town of Botswana, where tests were tentatively done on washed and unwashed coal, wood and condensed oil gas. It has been broke down that unwashed coal has the most elevated strength to environmental fermentation, trailed by washed coal, at that point LPG and in conclusion wood. Washed coal has the most astounding strength (10.83 x 10-3 te/y) to a dangerous atmospheric deviation. In light of the examination, it is embraced that the economy of Botswana can be helped by its own indigenous assets, rather than bringing in LPG at higher cost.

Keywords: wood fuel, washed coal, unwashed coal, LPG, GWP.

I. INTRODUCTION

It is evident that the choice for application of energy source is not based on anything substantial but what is just near or convenient, but is convenience best? The choice and recommendation of an energy source by stakeholders, economic planners and technical advisors should be well informed so that they make reasonable and economic decisions as to why they recommend the use of a specific energy source over the other and not just make a choice haphazardly.

This research looks at Botswana coal (washed and unwashed) and compare it to wood and liquefied petroleum gas. Electricity will not be considered in our research because the electricity produced in Botswana is generated using coal, so therefore it is a secondary source of energy. The study also looks at the emissions produced by the energy source; compare their carbon dioxide and other greenhouse gases emissions to the atmosphere. On the 8th of August 2003, Botswana agreed to curb emissions in accordance with the Kyoto Protocol, and the Kyoto Protocol is aimed at gradually reducing elements that contribute to global warming [1]. Therefore Botswana is striving to minimise amount of greenhouses gases emitted into the atmosphere and this research work would aid in achieving this goal. Economic planners, environmentalists, technical advisors and the Government of Botswana would benefit from this study as this would help them make informed decisions in as far as economic and environmental choices in selection of energy sources to use are concerned. The Global recession of

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2008/2009 left many countries including Botswana with a budget deficit so to reduce the impact, selection of the most economical energy source is vital.

II. LITERATURE REVIEW

Fossil fuels accounts for the vast quantity of world energy consumed to date. Coal, oil and natural gas are the three different forms of fossil fuels. They are formed by the process of decomposition of organic matter under surface pressure over millions of years. Combustion of fossil fuels produces large amounts of carbon dioxide, sulphur oxides and nitrogen oxides in the atmosphere. The negative effects of fossil fuels on global environment, eco-systems and public health are well documented; its use must be balanced between the development needs of a country and the welfare of its people [2]. Botswana has the second largest coal reserve in the world after the United States of America. It is estimated to have 220 billion tons of coal; this is according to statistics showcased at an international coal investor conference held in Gaborone in 2008. Nevertheless the resource is greatly under-exploited. Stating in terms of figures; less than one million tons of coal is mined every year. Which means less than one third (1/3) of our coal resources is utilized in a year. A study was conducted in 1984 with the assistance of Federal Republic of Germany Technical Cooperation Agency in view of the abundant coal in Botswana. The purpose of the study was investigating ways in which the use of coal could be broadened and in 1987 one of the recommendations, the Expanded Coal Utilization Project was commissioned. The different energy sources we will be dealing with different aspects-

2.1 Environmental Impacts of Wood Energy Consumption

Wood fuel may be available as firewood, charcoal, chips, sheets, pellets, and sawdust. There are different wood species of wood in Botswana being mophane, mosetlha, moselesele, moloto, mosu, oak, etc. Different species of woods have different energy contents and this energy content depend on the moisture content of the wood rather than the species. As the wood dries the more the energy content increases. A common hardwood, red oak, has an energy content of 14.89 Mega Joules per kilogram (6,388 BTU per pound), and 10.423 Mega Joules recoverable if burned at 70% efficiency[3]

Another aspect is deforestation, which is due to excessive cutting down of trees could lead to increasingly irregular rainfall, biodiversity being lost, flooding and drought as well as migration of animal. It also leads to soil erosion. In Botswana this can lead to desertification. The effect of burning wood is close to neutral with regards to carbon because as trees grow they remove carbon from the atmosphere which is released into the atmosphere when the wood is burnt [4]. Burning wood fuels within the household creates indoor pollution as firewood and charcoal both produce smoke on burning. To minimize the particulate output from fire one should burn properly dried wood. The nitrogen substance of wood is around 0,75 %, differing fairly from one tree animal types to another. For instance, nitrogen-settling birch (alnus sp.) contains twice as much nitrogen as most coniferous trees. Wood has for all intents and purposes no sulphur by any stretch of the imagination, as its offer in wood is 0,05 % at the most astounding [5].

2.2 Economic Impacts of Wood Fuel

Firewood is perceived to be cheap to use because it is mostly available for free in rural areas. It also does not require any special tools for extraction; a simple axe can be used to harvest wood. Use of wood as energy source is economical because some of the by products are useful[5]. For example wood ash produced from burning

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wood can be used as fertilizer (mainly potash), used to build traditional mud huts and decorating the traditional mud huts. This is particularly referring to rural areas where firewood is available in abundance and closer to residents or consumers [6].

2.3 Environmental Impacts of Liquefied Petroleum Gas

The combustion of LPG produces pollutants including particulate matter, sulphur dioxide, nitrogen oxides, nitrous oxides, carbon monoxide, carbon dioxide and methane and non-methane total organic carbon. These pollutants can contribute to global warming. Some of the gases produced are dangerous to both flora and fauna and this could lead to disturbances in the ecosystem.

2.4. Economic Impacts of Liquefied Petroleum Gas

LPG is an energy rich fuel source with a higher calorific value per unit than other commonly used fuels including coal, natural gas, diesel, fuel oils and biomass derived alcohols [7]. LPG has high combustion efficiency than kerosene and other solid fuels. This is because it has a high octane rating which enables it to mix better with air and to burn more completely than other fuels and also generating less carbon. LPG is expensive to low income households, this expense is due to mainly transportation fares since it is imported and because it is dependent on the availability and prices of crude oil [8]. This is also because the government of Botswana does not control LPG prices. Transportation accidents because of the presence of propane and butane, poses a risk of sudden depressurization and explosions during storage and transport [9].

2.5 Environmental Impacts of Coal

Coal is a combustible sedimentary rock, which was formed from fossilized carbon. There are two forms of coal; washed coal and unwashed coal. Washed coal is coal from which impurities have been reduced by treatment, and unwashed coal no treatment has been done to the coal to remove impurities. Cleaning coal also reduces the amount of fly ash and air pollutants, reduce the need to import higher-quality coals; and improves health and safety and reduces environmental degradation [10]. Combustion of coal causes carbon dioxide and sulphur dioxide to be emitted into the atmosphere contributing to global warming. Combustion of coal in large quantities also produces soot. When soot is inhaled by humans it remains in the body for a long time as it is not removed quickly, and this may cause respiratory irritation [11].

2.6 Economic Benefits of Coal in Botswana

There is a large amount of coal in Botswana, therefore the cost of coal would be reasonable to an average Motswana, and there will be no extra charges of transportation or availability.

Combustion of coal produces fly ash. Fly ash can be used to make cement and soap, as well as building traditional mud huts. African Energy Resources has recently revealed that the Sese coal is good for industrial boilers. The research showed that the coal ignition and combustion are good with no adverse effects on the boiler when generating heat and steam[12].

III. METHODOLOGY

The washed coal used in the experiments was collected from the coal distribution centre in Gaborone west industrial. The coal is supplied by rail line from Morupule mine and they distribute to companies in Gaborone. Due to the unavailability of unwashed coal in Gaborone, unwashed coal was purchased at Morupule mine. The wood fuel used in the study is Mophane wood and was bought from Engen filling station. The proximate analysis for washed and unwashed coal was conducted at Morupule Power station whereas the proximate analysis for wood was conducted at Morupule Mine. The combustion of all fuels was conducted at Gabane Community Junior Secondary School. Methodology consists of three steps- preliminary experiment, proximate experiment and finally combustion of fuel experiment. Preliminary Experiments were conducted on coal and wood fuels and due to the volatile behaviour of LPG, experiment using the bomb calorimeter to obtain the calorific value were not possible; therefore technical information on LPG was supplied by AFROX. The experiment was repeated 5 times to increase accuracy. The average calorific value was recorded. The combustion experiments were done on different days therefore there was varying weather conditions.

IV. RESULTS AND ANAYLISIS

The inherent moisture of the unwashed coal (4.16%) to be greater than that of washed coal (2.12%) because during the cleaning process, some of the moisture is removed as shown in table 1 and 2 respectively.

Table 1 results obtained from Proximate Analysis

Properties	**Wood**	**Unwashed coal**	**Washed coal**
Calorific value (MJ/Kg)	20.33	22.11	27.39
Inherent moisture (%)	6.91	4.16	2.12
Ash (%)	3.50	25.72	24.00
Volatile matter (%)	69.46	24.7	23..42
Sulphur (%)	0.08	1.82	0.43

Table 2 combustion analysis

Products of combustion	**Unwashed coal**	**Washed coal**	**Wood**	**LPG**
CO_2(Kg)	1.98	2.61	1.840	3.012
CO(Kg)	1.26	1.66	1.171	1.916
SO_2(Kg)	0.0364	0.0086	0.0016	0.0046

Therefore washed coal has lower values of volatile matter, sulphur content and ash content because of reduced impurities. Figure 1 (a), (b) and (c) shows the combustion of coal, LPG and wood respectively. From the bomb calorimeter experiment, the results show that washed coal (27.399 MJ/kg) has a higher calorific value compared to unwashed coal (22.119MJ/kg) and wood (20.325 MJ/kg).

(a) *(b)* *(c)*

Fig 1 (a) Combustion of coal (b) Combustion of LPG (c) Combustion of wood

Table 3 results of the washed coal fuel

Properties	**Value**
Mass (kg)	7.50
O_2 (%)	19.40
CO (ppm)	1313.67
EFF(%)	44.80
X air (%)	1357.67
CO_2 (%)	0.37
CO/CO_2 (%)	0.41
NO (ppm)	12.33
NO_2 (ppm)	0.00
NO_X (ppm)	12.33
C_XH_Y (ppm)	0.67
NETT ^{0}C	95.83
FLUE ^{0}C	135.17
AMBIENT ^{0}C	39.33

Table 3 above shows the results obtained from the experiment, using washed coal as a fuel. From the above results the oxygen level in the air supply was 19.4% which is an expected result because the air was supplied naturally and not forced, and air contains 20.1% of oxygen. The high value of 1313.67 ppm of carbon monoxide emitted indicates that there was incomplete combustion. Due to natural draught there was 1357% of excess air. There were 12.33 ppm amount of nitrogen monoxide and no nitrogen dioxide found, due to natural draught and low temperature in the combustion chamber nitrogen does not chemically combine with oxygen to form nitrogen oxides and hence remains inert as part of excess air and only contributes to the loss of heat through the chimney. The efficiency of combustion of washed coal is 44.8%.

Table 4 results of the wood fuel

Properties	**Value**
Mass (kg)	6.36
O_2 (%)	18.87
CO (ppm)	1744.00
EFF(%)	50.27
X air (%)	1018.33
CO_2 (%)	0.77
CO/CO_2 (%)	0.33
NO (PPM)	19.33
NO_2 (PPM)	0.00
NO_X (PPM)	19.33
C_XH_Y (PPM)	36.33

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NETT ^{0}C	112.37
FLUE ^{0}C	161.47
AMBIENT ^{0}C	38.10

Table 4 shows the results obtained from the experiment using wood fuel. The above table shows that there was 18.87% of oxygen; this was due to using natural draught instead of forced draught. The carbon monoxide was 1774ppm, indicated incomplete combustion. There was an excess air of 1018.33% this is due to natural draft. The temperature of the flue gases was 161.47^{0}C at an ambient temperature of 38.10^{0}C. The efficiency of combustion of wood is 50.27%.

Table 5 results of the unwashed coal fuel

Properties	**Value**
Mass (kg)	7.50
O_2 (%)	19.1
CO (ppm)	1121.3
EFF(%)	58.5
X air (%)	1110
CO_2 (%)	0.7
CO/CO_2 (%)	0.27
NO (ppm)	22.33
NO_2 (ppm)	0
NO_X (ppm)	22.33
C_XH_Y (ppm)	29
NETT ^{0}C	86.37
FLUE ^{0}C	139.23
AMBIENT ^{0}C	40.1

The above table 5 shows the proximate analysis results of unwashed coal. From the results the oxygen level is 19.1% which is expected due to natural supply of air during burning (oxygen content in air is approximately 20.1%). The percentage carbon dioxide is 0.7% which was expected because the atmospheric CO_2 is 0.035% therefore the value increased because of combustion as CO_2 is one of the products of combustion. CO/ CO_2 R is 0.7 and the increase was expected because it is higher than that of fresh air which is 0. NO_2 is zero because the reaction needed 2 molecules of carbon dioxide which was insufficient. The value for NOx is 22.3 ppm and the value was expected because its summation of NO_2 and NO. Hydrocarbons value obtained was 29 ppm because coal has hydro carbons and also the value increased due to incomplete combustion and lack of thorough mixing.

Table 6 results of LPG fuel

Properties	Value
Mass (kg)	0.30
O_2 (%)	19.86
CO (ppm)	2.2
EFF(%)	52.5
X air (%)	1997
CO_2 (%)	0.7
CO/CO_2 (%)	0.00018
NO (PPM)	3.2
NO_2 (PPM)	0
NO_X (PPM)	3.2
C_XH_Y (PPM)	493.4
NETT ^{0}C	65.84
FLUE ^{0}C	99.64
AMBIENT ^{0}C	33.8

From the above table 6 it can be noticed that O_2 is 19.86% which slightly varies with the theoretical value of 20.1% and this may be because of the supplied air not being controlled. CO is found to be 2.2ppm which is greatly lower than the value of CO_2 which is 0.7% this is because during combustion close to 99.5% of carbon in LPG is converted to CO_2 and the remaining is converted to CO due to incomplete combustion. Efficiency is low at 52.5% may be because of incomplete combustion and also because of high percentage of excess air at 1997%. CO/ CO_2 R value is very low because of the little value of carbon monoxide. NO value was found to be 3.2ppm and is much lower than that of coal because there is very little nitrogen in LPG compared to coal. %. NO_2 is zero because the reaction needed 2 molecules of carbon dioxide which was insufficient. This is because of incomplete combustion, it is very difficult to bring each particle of oxygen in the air into contact with particles in the fuel that need to be oxidised. The value for NOx is 3.2 ppm and the value was expected because its summation of NO_2 and NO. Hydrocarbons value obtained is 493.4ppm which is greatly high due to LPG is made from hydro carbons.

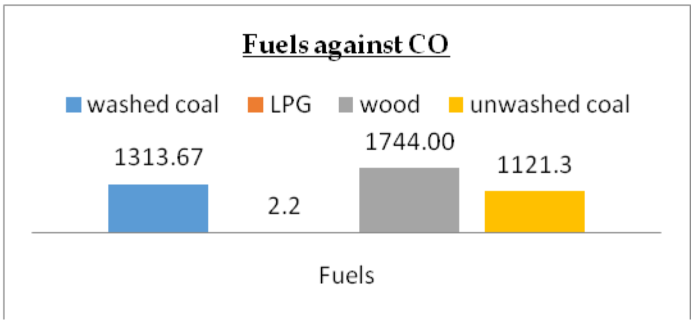

Fig 2 fuels against Carbon monoxide

Figure 2 shows the fuels against the carbon monoxide content. From the bar chart, wood has the highest amount of carbon dioxide with 1744ppm, followed by washed coal with 1313.67ppm, then unwashed coal with

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1121.3ppm, and lastly LPG with 2.2ppm. It is expected that there is a higher carbon monoxide content in washed coal than unwashed coal because it contains extra ash/ volatile matter than unwashed coal. The higher amount of carbon monoxide shows that there is incomplete combustion due to the difficulty of bringing oxygen particles into intimate contact with Carbon particles to be oxidized.

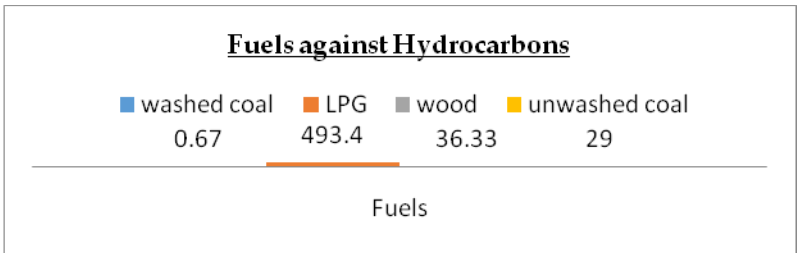

Fig 3 shows fuels against hydrocarbons

Figure 3 shows the fuels against hydrocarbon during combustion. LPG has the highest amount of hydrocarbon with 493.4ppm, followed by wood with 36.33ppm, then unwashed coal with 29ppm and lastly washed coal with 0.67ppm.As expected there is a high amount of hydrocarbons in LPG than the other fuels, this is because LPG is made from hydrocarbons (mainly propane and butane). The sapwood contained in wood has some hydrocarbon that will account for the hydrocarbon found in wood. The unwashed coal still has some impurities and this accounts for the hydrocarbons contained in it, whereas due to the beneficiation the hydrocarbons were reduced and that is why there is low hydrocarbons in washed coal.

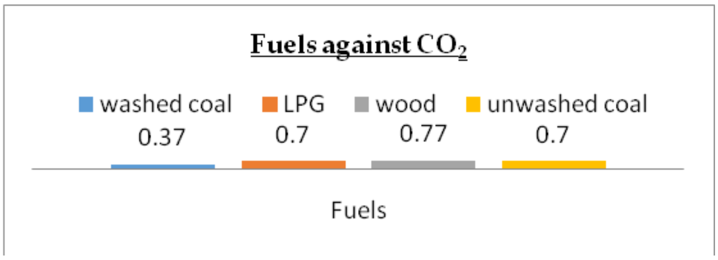

Fig 4 fuels against carbon-dioxide

Figure 4 shows fuels against carbon dioxide during combustion. Looking at the results above LPG, wood and unwashed coal emitted the same amount of carbon dioxide of 0.7 %. Washed coal emitted 0.37% of carbon dioxide. These results are due to the climatic conditions during the experiment. When conducting all experiments there was natural draft, but the weather conditions were not the same. During the experiment using washed coal and wood, it was a cloudy and windy day. When conducting the unwashed coal and LPG it was a sunny and windy day. Therefore discrepancies in results would be due to varying weather conditions that led to wood emitting the highest CO_2. The amount of CO_2 would also depend on the amount of carbon contained in the fuel.

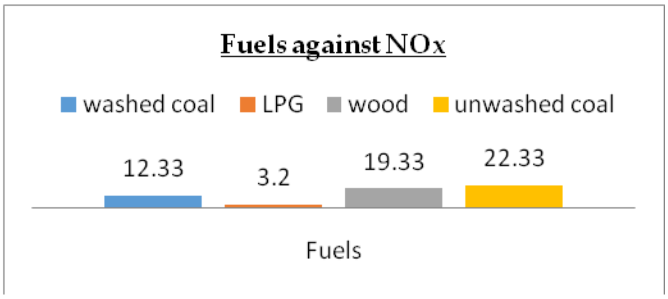

Fig 5 shows fuel against nitrogen oxides

Figure 5 shows fuels against nitrogen oxides during combustion. From the above results unwashed coal has the highest level of nitrogen monoxide of 22.33ppm, followed by wood of 19.33 ppm, then washed coal of 12.33ppm and lastly LPG of 3.2ppm. This is mainly affected by the temperature of combustion. The higher the temperature the more likely the nitrogen atoms will react with the oxygen because Nitrogen is an inert gas.

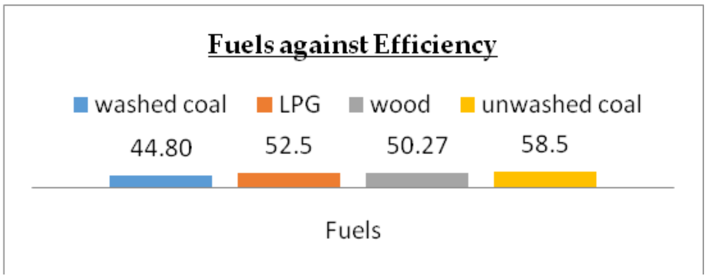

Fig 6 shows fuels against efficiency of combustion

Figure 6 shows fuels against efficiency of combustion. This efficiency shows the amount of combustible material that has been burnt. From the above results unwashed coal has the highest efficiency of 58.5%, followed by LPG of 52.5%, then wood of 50.27% and lastly washed coal of 44.8%. It is expected that LPG to have the highest efficiency because there is thorough mixing of air and fuel. Efficiency is also affected by the carbon in ash content. The results are not as expected due to experiments carried out on different weather conditions. Variation of supplied air may have impacts on results because the supplied air was not controlled.

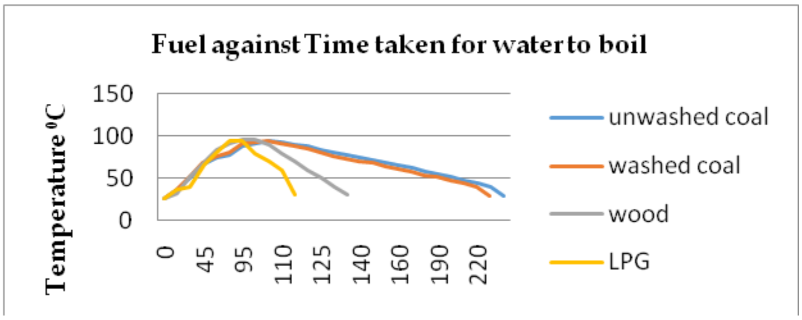

Fig 7 fuel against the time taken for water to boil

Figure 7 shows the fuel against the time taken for the water to boil. The graph indicates that it was quicker to use LPG than other fuels. After switching off the LPG the is no more energy supplied to the water, whereas with wood and coal even after there is no fire there is still some energy being released.

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Table 7 the cost of fuels

PARAMETER	WASHED COAL	UNWASHED COAL	LPG	WOOD
Mass (kg)	7.5	7.5	0.3	6.36
Calorific Value(MJ/kg)	27.39	22.11	49.6	20.33
Time (s)	6600	6900	5400	5700
Q_{Fuel} (MJ)	205.43	165.83	14.88	129.30
Useful energy (MJ)	5.85	5.85	5.93	5.93
Thermal efficiency (%)	2.8	3.5	39.9	4.63
Cost of fuel / kg (BWP)	3.22	0.40	18.80	3.00
Total cost of fuel	24.15	3	5.64	19.08
Power consumed (kWh)	31.12	24.03	2.75	22.68
Cost of fuel/ kWh	0.77	0.12	2.05	0.84

Table 7 above shows the cost of fuels. With reference to Botswana Power Corporation Domestic customer tariffs 2013 of 0.7571 kWh, we are able to compare the cost of fuels to electricity. Comparing LPG with electricity one is able to see that using LPG is more expensive than using electricity.

Table 8 potential of released gases to atmospheric acidification

SUBSTANCE (te/y)	UNWASHED COAL	WASHED COAL	LPG	WOOD
SO_2 E_B value(10^{-3})	0.0364	0.0086	0.0046	0.0016
NO_2 E_B value(10^{-3})	0.0343	0.0343	0.00224	0.00224
TOTAL (10^{-3})	0.0707	0.0429	0.00684	0.00384

Table 8 above shows that unwashed coal has the highest potency to atmospheric acidification, followed by washed coal, then LPG and lastly wood. Unwashed coal has the highest potency because of the higher emission of SO_2 and NO_2 which are one of the substances that contribute greatly to atmospheric acidification. The values of the emitted gases depend on the fixed content of Sulphur and Nitrogen in the fuel. The process of coal beneficiation reduces the amount of sulphur in the coal hence reducing the value of SO_2 in unwashed coal

Table 9 the global warming potential of gases

SUBSTANCE (te/y)	UNWASHED COAL	WASHED COAL	LPG	WOOD
Carbon dioxide EB value (10^{-3})	1.98	2.61	3.012	1.84
Carbon monoxide EB value (10^{-3})	3.78	4.98	5.748	3.513

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Nitrogen Oxides (NO_x) EB value (10^{-3})	3.24	3.240	0.212	0.212
TOTAL(10^{-3})	9.0	10.83	8.972	5.565

The table 9 depicts that washed coal has the highest potency to global warming, followed by unwashed coal, then LPG and lastly wood. For the potency of washed coal to be greater than unwashed coal is due to the higher carbon content in washed coal than unwashed coal, hence higher emission of CO_2 and CO which is one of the substances leading to global warming. LPG and wood have the lower potency due to the little content of Nitrogen in them hence lower values of NO_x which is one of the substances that lead to global warming.

V.CONCLUSIONS

From the research work performed and analysis it shows that LPG is the most expensive fuel compared to wood and both washed and unwashed coal. Unwashed coal is the most economic energy fuel but when considering the time taken for the coal to burn, controlling the intensity of the heat desired, wastage in coal because of the remaining unused fuel after burning and the time taken to heat or cook makes the fuel undesirable to many consumers. Most consumers use either LPG or electricity due to convenience and affordability as the world is diversifying and the standards of living are improving. LPG and electricity are convenient to domestic consumers because no time is wasted in waiting for the fuel to burn and the intensity of heat is easily controlled. There seems to be a demand for electricity and LPG and therefore comparing LPG and electricity from the results indicate that electricity is economical to use than LPG. When burning fuel consumers are after the maximum efficiency, they want as much as they can get out of burning the fuel because it is more economical. Though LPG may be expensive it has the highest thermal efficiency when compared to coal and wood.

Table 10 summary of cost comparison

Energy source	**Cost / year (BWP/annum)**
Unwashed coal	35040.00
Washed coal	224840.00
LPG	598600.00
Wood	245280.00
Electricity	221073.00

From the sustainability metrics analysis as in table 10 above, it shows that coal has the highest environmental burdens for emission to air, it has higher potency to atmospheric acidification and global warming. Wood seems to be the most environmentally friendly fuel because it has the lowest potency to both atmospheric and global warming as compared to other fuels, but it should not be used to replace coal wherever economically viable as it would affect people in rural areas. Rural area dwellers are highly dependent on this dwindling resource. It would mean the demand of wood increase and their supply would decrease due to depletion. Although coal emits more harmful gases than other fuels it cannot be ruled out because Botswana has it in abundance, unlike LPG which is imported. The Economy of Botswana can be boosted by its own indigenous resource, instead of importing LPG which is at a high cost to the Government as well as other consumers.

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Conflicts of Interest: “The authors declare no conflict of interest."

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