Role of Hydropower in Offsetting Electricity Consumer Behavior Contribution to GHG Emissions

M. Elmuntasir I. Ahmed[1], and Zeinab Osman Ali[2]

[1]Ass. Professor University of Khartoum, Faculty of Eng. and Architecture, Civil Eng. Dept., P.O.Box 321, Khartoum, Sudan, meibrahim@uofk.edu
[2] Former MScE Student, University of Khartoum, Faculty of Eng. and Architecture, Civil Eng. Dept., zoba72@yahoo.com

Abstract

The main objective of this study is to illustrate the electricity consumer behavior which accelerates the greenhouse gas emissions growth by increasing energy consumption, and to estimate the role of hydropower in offsetting the GHG emissions as a result of electricity consumer behavior in Sudan. The study used a questionnaire survey of 500 consumers from 445349 NEC electricity subscribers (as of 2007). The questionnaire was administered by telephone and face to face interviews among the random sample of 500 householders with different social categories; the questionnaire was then subjected to data analysis. The greenhouse gases emission from thermal power generation plants was evaluated based on different types of fuels and CO2 was selected to represent GHGs. The residential sector was selected as an indicator since the electrical consumption of this sector represent more than 47% of the total electricity consumption, further more the consumer behavior of this sector represents, to some extent, other sectors. It has been extracted from the results that the growth rate of GHG which emitted from thermal power plant would increase in 2014 by a factor of 4.5 relative to that of 2000. More than 25% of the energy consumption and CO2 emissions contributed by the residential sector are the result of energy "lost" due to the users' behavior and the use of old technology. The acceptance of the society to have a role in the reduction of electrical consumption is very low due to their poor awareness of the consequence of their behavior and the benefit they are going to gain, if they respond positively. Clean hydropower played a role in reducing these 'behavioral GHG emissions' and it was found that consumer behavior contributed 53 (Gg. CO2) in 2007 while it could have contributed 66 (Gg. CO2) if there was no hydropower generation in the Sudan. In 2010 and 2014 it is expected that consumer behavior contribute 105 and 97 (Gg. CO2) if demand is met by hydropower development plus regional cooperation in power trade, versus 175 and 207 (Gg. CO2) if demand was met via thermal generation expansion.

Key words: Environmental Management, Climate Change Mitigation, Climate Change adaptation, Hydropower, Electricity consumer behavior, Capacity Building, Greenhouse Gas emissions.

1. INTRODUCTION

Climate change is becoming increasingly one of the most important global challenges of this century. Despite the increasingly worldwide recognition of the problem of climate change and the urging importance to combat global warming, the International Energy Agency (IEA) predicts world primary energy demand to expand by 45% between 2006 and 2030 (IEA, 2004).

To solve this tension, several energy solutions have been suggested over the last decades, going from more efficient fossil-fuelled power generation, energy-saving building design, nuclear power, over water, wind and solar energy, to the use of bio-fuels (biomass), carbon capture and storage (CCS) technologies, a hydrogen economy or even fusion (Levine, 2007). The key question is which of the above approaches will turn out to offer the most effective and efficient solution to handle the challenge of the increased demand for energy within the context of the climate change.

UNFCCC as well as the Kyoto protocol on Climate Change (CC) provided for measures to be taken in combat of CC such as adaptation and mitigation. Specifically in the adaptation measures reference was made to integrated management of natural resources and the best use of water resources and water conservation. On the mitigation side energy use efficiency and availing better technology as well as use of renewable and clean energy alternatives was referenced (IPCC, 2001).

It has been estimated that about 18 million Tones of nitrogen oxides are added in the atmosphere every year. Out of this quantity about 46% are produced from transportation vehicles, 25% from electrical generation plants, 17% from industries, 9% from residences and remaining 3% from commercial operation. In other way 64% are derived from combustion of fuel oil and gasoline, 26% from coal burning and remaining 10% use of natural gas (IPCC 2001).

Due to the expected rapid growth in Sudan economy the produced electricity is not sufficient. Huge expansion in the residential sector and residential sector energy needs is accompanying this economic growth. More hydro and thermal power plants will be constructed as planned by the National Electricity Corporation (NEC), as stated in their development medium term plan up to 2014 (1250MW will be added by hydro and 2000 MW added by thermal) (NEC, 2004). Thermal production of electrical power will increase the emission of gasses, as well as hydropower development (although clean but contribute to GHG emissions by deforestation, operation machinery emissions, and may be evaporation) and the role of each need to be estimated to enable decision making and explore financing options particularly regarding engaging the Clean Development Mechanism (CDM) process.

As will be discussed later the residential sector is one of the main consumers of electricity with 47% among all consumers. The energy use of a residential building also depends on the behavior and decisions of occupants and owners. Classic studies at Princeton University showed energy use variations of more than a factor of two between houses that were identical but had different occupants (Socolow, 1978). Levermore (1989) found a variation of 40% gas consumption and 54% electricity consumption in nine identical children's homes in a small area of London. When those in charge of the homes knew that their consumption was being monitored, the electricity consumption fell. Behavior of the occupants of non-residential buildings also has a substantial impact on energy use, especially when the lighting, heating and ventilation are controlled manually (Ueno et al., 2005).

The negative consumers' behavior toward the use of the electricity leads to increase in the level of GHG emissions. The residential sector was selected as an indicator since the electrical consumption of this sector represent more than 47% of the total power consumption, further more the consumer behavior of this sector represents to some extent, other sectors) (NEC, 2004). The residential sector, also, have opportunities of saving specially from the behavior point of view as documented by many previous studies) (NEC, 2004).

Therefore, the main objective of this Study is to illustrate the electricity consumer behavior which accelerates the greenhouse gas emissions growth by increasing energy consumption, to evaluate the contribution of hydropower in offsetting the behavioral contribution due to GHG emissions, to evaluate possible energy savings by modification in behavior, and to formulate recommendations to control the GHG emission. The paper also looks into which sustainable solutions provide a sound business case as well as provide other opportunities.

The specific aim of this study is to investigate the effect of power plants emission on the environment due to electricity demand in the Sudan, and how to control that, by changing consumer behavior as well as exploring renewable sources of electricity such as hydropower, and therefore we aimed at:

- Estimate the GHG emission from thermal power plants
- Evaluate the waste of energy by consumer usage, and the effect of using old technology
- Estimate offsets by hydropower to GHG emissions due to negative consumer behavior

2. BACKGROUND ON ENERGY IN SUDAN

The National Electricity Corporation (NEC) is responsible for generation, transmission and distribution of electricity in Sudan. Currently, the source of power in NEC depends on the hydro-generation (seasonal) and thermal generation. The two sources are complementary. The electrification ratio of the Sudan (percentage of the population with electricity supply) is very low, estimated at about 15% of the country. 70% of the available electric energy is consumed in urban centers namely Khartoum, the capital. However, the government of Sudan has set an ambitious program to electrify 75%-80% of the country by the year 2020 to promote agriculture, industry and social development to improve living standard of people. The power sector in Sudan has been constrained for number of years by unavailability of domestic and external financing required for adequate expansion of generation, transmission and distribution capacities.

The foreseen energy sources for power generation are hydro-electric resources, petroleum products, Red sea gas and geothermal resources. NEC medium term plan (2005 -2010) estimated load forecast range between 724 MW to 2800 MW .The generation expected to be installed in the same period range between 1200 MW to 3900 MW. The load forecast in 2014 is expected to be 4929 MW .The strategy within 15 years time to install12000 MW generation and at the same time to extend the national grid at the suitable voltage levels 500,220,110 KV to cover strategic areas.

Studies for hydro- electric potential are estimated to be 5000 MW. To-date only about 300 MW is generated and an additional of 1250 MW is expected to enter the national grid by 2010 from Merowi dam. Interconnection of power lines (transmission lines) with neighboring countries is part of Sudan power plans – to export and import power with Egypt in the north, Ethiopia in the east and with East Africa through Uganda (Abu Gedairi , 2006).

The existing hydro power generation plants in the Sudan are located in Blue Nile, Atbara, and on the Main Nile, and are described in Table 1 below.

The existing thermal generation units in Sudan are diesel units, steam turbines, and gas turbines. The diesel units use both Gas Oil and heavy fuel oil, and the steam turbines use heavy fuel oil where the gas turbines use Gas Oil. Table 2 gives brief description of the thermal generation in Sudan and Table (3) summarize NEC medium plan for generation and transmission.

Table 1: Existing Hydropower generation plant in Sudan

PLANT	No. of Unit	Installed capacity (MW)	Effective capacity (MW)	Total (MW)	Expected retirement date
Rosseries Power Station	7	40	40	280	
Sennar Power Station	2	7.5	7.5	15	2012
Kashm Algerba Power Station	5	3.12 and 2.07	3.12 and 2.07	12	2013

Table 2: Existing thermal generating plants in Sudan

Plant	Description	Installed Capacity (MW)	Effective capacity (MW)	Fuel type
Khartoum North Steam Turbine	Turbine , Boiler & Generators	180	160	HFO 3500RW
Garri I Combined Cycle	Gas Turbine and steam Turbine	228.8	190.4	LPG / Gas oil
Garri II Simple Cycle	Gas Turbine	114	90	Gas oil
Burri III Diesel	Diesel Engine	63	34	HFO 3500RW
Khartoum North Gas Turbine	Gas Turbine	90	80	LPG
Killo x Gas Turbine	Gas Turbine	15	10	Gas oil
Burri Gas Turbine	Combustion turbine	26	20	LPG
Kuku Gas Turbine	Combustion turbine	18.5	23	Gas oil
Kassala		5.3	3	Diesel Oil

Table 3: NEC development medium term plan (2004-2009) (national grid) generation expansion plan.

years	Load Forecast		ADDITIONS		System Install. Capacity MW
	MW	GWh	Description	Timing	
2004	724	3487	-10x0.38MW (jebel Aulia)	Sep.2004	1200
			-10x0.38MW (jebel Aulia)	Oct.2004	
			-10x0.38MW (jebel Aulia)	Dec.2004	
2005	818	3960	-10x0.38MW (jebel Aulia)	Mar.2005	1211.4
			-10x0.38MW (jebel Aulia)	May.2005	
			-10x0.38MW (jebel Aulia)	July.2005	
			-100 MW CCGT Garri(2)	Dec.2005	
2006	1135	5537	-141MW -1st CCGT Garri(3)	Mar.2006	1322.4
			-22MW-1ST Unit kilo X	July.2006	
			-40MW-2nd Unit kilo X	Sep.2006	
			-40MW-3rd Unit kilo X	Nov.2006	
2007	1772	8694	-2x100MW Steam Kh.N(phase#3)	Nov.2006	
			-40MW-4th Unit kilo X	Jan.2007	1565.4
			-50 MW 1st Unit Garri(4)	Feb.2007	
			-40MW-5th Unit kilo X	Mar.2007	
			-141MW -1st CCGT Garri(3)	Mar.2007	
			-50 MW- FROM Hydro at sennar	Mar.2007	
			-40MW-6th Unit kilo X	May.2007	
			-50 MW 2nd Unit Garri(4)	May.2007	
			300 MW-Thermal Generation at el bagir	June.2007	
			-40MW-7th Unit kilo X	June.2007	
			2x125 MW Morewe	Dec.2007	
2008	2372	11637	2x125 MW Morewe	Mar.2008	2566.4
			2x125 MW Morewe	Jun.2008	
			2x125 MW Morewe	Sep.2008	
			-300 MW- Coal/generation port sudan	Sep.2008	
			-300 MW- Thermal Generation at kosti	Oct.2008	
2009	2800	13782	-2x125 MW Morewe	Jan.2009	3916.4
			-300 MW Thermal Generation at al fula	Dec.2009	

Source: National Electricity Corporation (NEC, 2004)

A breakdown of greenhouse gas emissions from Khartoum residential energy usage by activity is shown in Figure (1) However; this breakdown is based on approximated data, so it should be treated with caution. There is great variability in equipment ownership, behavior, climate and resulting emissions from household to household. Nevertheless, this breakdown provides a useful overview of the significance of each activity's contribution to Khartoum greenhouse gas emissions, and it form the bases for questionnaire formulation and analysis.

Analysis of emission-generating activities carried out within households, estimation of the scope to carry out projected levels of such activities in ways that reduce greenhouse gas emissions, and assessment of the scope for change in behavior, provide essential inputs to the development of effective greenhouse responses.

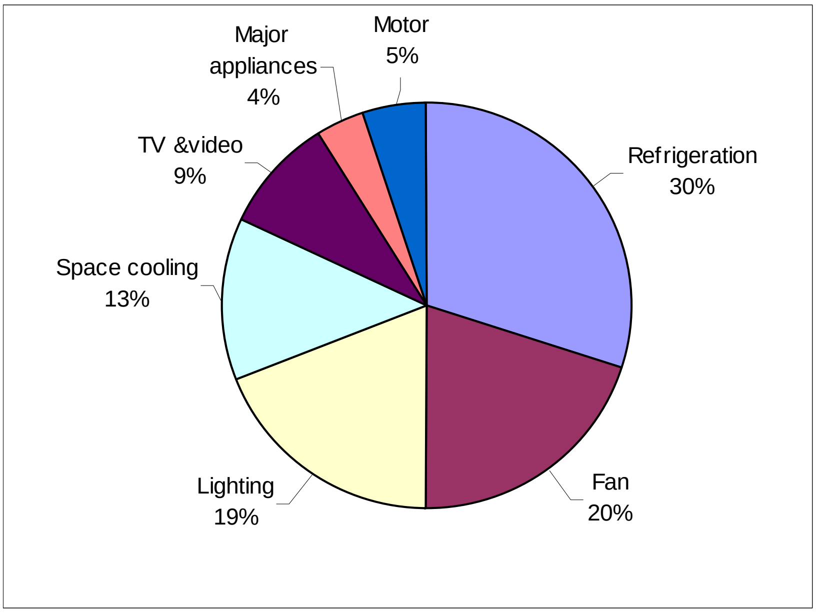

Figure 1: Greenhouse Gas Emissions from Khartoum Residential Sector Energy Use by Activity

3. METHODOLOGY

This research has adopted variety of methods to arrive at quantities of significance to estimate the role of hydropower in offsetting electricity consumer behavior contribution to GHG emissions demonstrated in the Sudan, a country with limited renewable energy sources, modest hydropower potential, increasing energy demand, and abundant oil reserve and ambitious thermal energy development plans. The methodology included a survey of energy sources, energy demand, and energy development projections in the Sudan, a questionnaire to estimate wasted energy in various sectors due to erratic consumer behavior, estimation of equivalent GHG emissions based on thermal power generation and expansion scenarios, estimation of emissions due to current hydropower generation and expansion scenarios, estimating reductions in emissions due to hydropower development based on these scenarios. Each of these methodologies is described separately below:

1. Collection of general data on electricity generation, consumption, and future projections, including information on the residential sector. The National Electricity Corporation (NEC), the only power company in Sudan, was contacted to furnish generation data, consumer data and profiles, demand and consumption patterns, sources of generation, proposed expansion plans and the future short term and long-term projections when available.

2. Administration of a questionnaire survey on Khartoum residential sector to infer upon consumer behavior (the questions and modes of administration will be discussed in the results section). Questionnaire had been prepared and distributed among random sample of 500 householders with different social categories; this Questionnaire was then subjected to data analysis. The questionnaire used in this research is a data collecting instrument. It is a mean of eliciting the behavior, beliefs, and awareness. It is a written form in gathering information from respondent and distributed personally hand to hand and by telephone to get the main purpose of its use. The questionnaire is composed of the following elements:

    1. Part one consists of three sub-sections:
        - General information to indicate the level of householder.
        - Type of lighting used and the other equipments used in the house
        - Monthly electric bill and electricity consumption.
    2. Part two consists of five type of question to test the behaviour of householders.
    3. Part three consist of four types of question and answer to test the acceptance of the householder to mitigate the problem.
    4. Evaluation of residential consumer possible electricity savings by change in behavior

An evaluation of the wasted energy due to consumer behavior was inferred upon from the questionnaire and questions were asked as to whether this wasted energy can be reduced if the consumers were given set of incentives such as reduction in electricity bill, contribution to climate change mitigation.

3. Calculation of GHG emissions based on three hydropower scenarios: In the present evaluation of long-term impact we have used for fuels (petroleum data) the parametric data compiling from NEC Central Laboratory and Nile Petroleum Company represents the actual allocation of different petroleum products to the various consuming sectors. Electricity consumption data obtained from National Electricity Corporation. Statistic data was obtained from statistical data reported by the Central Bureau of Statistics. For the assessment of the greenhouse gases emissions we employed the Revised IPCC Guideline (2006) and (Emission Inventory Guide book 2006) by using their methodology and default value. By using general approach, for years up to 2007 actual fuel consumption was obtained. And for years 2008 , 2009 , 2010 and 2014 projection were made based upon energy consumption forecast by NEC medium term plan and previous fuel usage records *(NEC, 2004)* . After estimating actual consumption, the following steps are taken to calculate the emissions of Greenhouse Gases:

   - Convert fuel data to energy unit (TJ) according to annual indexes for each fuel and according to the NEC Central lab report for each fuel analysis *(NEC, 2007).*
   - Select pollutant emission factor for each fuel product type. Emissions of the resulting CO_2 depend fundamentally on fuel consumption and on some particularities concerning its use. Specified emission factors used for CO_2. (The equation used to determination the emission factor and calculation taken from *(IPCC.2006)*
   - Calculate the total emissions released from the use of each fuel, in Gg. gas. Whenever specific data concerning emission were not available we have used recommended parametric values. For fossil fuel combustion, uncertainties in CO_2 emission factors are relatively low (Ali, 2007). Uncertainties in Emission factors for SO_2 are medium. Emission factors for CO and especially NO_X are highly uncertain. High uncertainties in emission factors ascribed to use default value which lacks to relevant measurements and subsequent generalizations, uncertainties in measurements, and an insufficient understanding of the emission generating process. Uncertainties of activity data result from missing or inappropriate statistical information concerning activity data.

4. Calculation of role of hydropower in reduction of emissions was based on three scenarios. The first scenario is zero hydropower to illustrate what would be contributed if there was no hydropower, the second is the status quo with the actual hydropower production considered, and the third is the future expansion scenario. In each of the three scenarios the emissions due to consumer behavior was calculated to demonstrate the role of hydropower in reducing GHG emissions. The calculations here neglected the deforestation from hydropower facility construction, the emissions from hydropower facility operations, and enhancement of evaporation due to reservoir storage. These effects are considered negligible for the purpose of this study.

4. RESULTS AND DISCUSSION

This section presents the findings of the GHG emissions estimates from actual and projected fuel consumption, then presents the questionnaire analysis and inferences upon consumer behavior and lastly presents the findings of the analysis to estimate the role of hydropower in offsetting emissions resulting from consumer behavior.

4.1 Emissions

Emissions from thermal power generation plants were calculated according to the methodology outlined above from actual fuel consumption or from projected fuel consumption. Again, emissions as a result of deforestation for hydropower, or from hydropower appurtances required for operation are neglected since they are very small. The calculated emissions are shown in Table 4 below.

Table 4: CO_2 Emission Gg /year

Year	Heavy Fuel Oil (H.F.O)	Heavy Coker gas oil	Gasoline	Total Emission Gg.CO_2
2000	808.9333332	0	309.3495939	1118.282927
2001	1013.792005	0	405.1158114	1418.907816
2002	1091.606129	0	336.6134215	1428.21955
2003	1091.464819	0	684.0377404	1775.502559
2004	1101.458845	0	903.4921406	2004.950986
2005	1077.292701	0	1150.959661	2228.252362
2006	849.2956134	242.2503139	1144.701417	2236.247345
2007	678.1350534	410.0604459	1403.535348	2491.730848
2008	870.5688857	902.7298073	1819.277882	3592.576575
2009	866.0880221	1018.426554	1868.642723	3753.157298
2010	949.6981781	1030.574678	1963.660671	3943.933527
2014	1271.65278	1344.284041	2394.48066	5010.417481

4.2 Energy Consumption and User Behavior

Generally, the aim of sampling is not large sample rather a representative, credible and true one. The sample size determination depends on the population variance and the sample represents the whole population. Therefore, the feasibility of sampling emerges when the population is large and the elements are quite similar. For the study at hand, the numbers of electricity consumers in residential sector is large and the nature of behavior of these consumers is almost similar (Miaoulis and Michener, 1976).

Five hundred householders from Khartoum state were chosen as a sample for this study out of which 96% responded to the questionnaire. The classification of the sample was 34% first class residence, 36% second class residence, and 30% 3rd class residence.

The sample error can be obtained by applying standard formulas as in Equation 1:

$$\mathbf{n = N / (1 + N (e)^2)} \quad \mathbf{(1)}$$

Where n is a sample size, N is the population size, and e is the level of precision (Cochran (1977).

For the chosen sample size (500) and actual customers of (445349) the level of precision is 4% which seems high but as said previously the nature of behavior of consumers is almost similar, which makes the chosen sample error reasonable.

Electricity user behavior depends to a great extent on the awareness of the consumer with potential negative impacts of excessive usage such as contribution to global warming and climate change, unnecessary spending, reduced electricity coverage and related lost opportunities. The consumer behavior also depends on the availability of saving technologies such as sensors, electrical appliances with high power factor, and the awareness of consumers of these technologies as well as affordability of these technologies. To this effect a questionnaire was designed to infer upon the excessive unnecessary electricity consumption including lighting of unattended rooms, use of sensor technology and others.

The questionnaire analysis revealed the following categories on the monthly consumption of electricity as shown in Table 5.

Table 5: Categories of electricity consumption among electricity users sample

Equipments	Percent
>700 kwh (very high)	24
700-450 kwh (high)	30
400-200 kwh (medium)	34
<200 kwh (low)	12
Total	100

The questionnaire also gave data on how many rooms are left lit and the type of lighting, whether other appliances are left running and the type of these appliances and accordingly estimates were made on how much electricity is wasted due to the consumer behavior.

As seen in Table (6) Total emission from users behavior depend on activity about (65.98 Gg.CO2) per year. 14.7% out of total emission from elec. in residential. The lighting emits the major share of CO2, (16.1 Gg.CO2) per year, electronic appliances (15.72 Gg.CO2) refrigeration (15 Gg.CO2), fan (10 Gg.CO2), space cooling (5.8 Gg.CO2), and water pump (3.36 Gg.CO2).

That mean we can reduce this percent if we improve the users behavior by education, use of sensors, and other methods. Total emission can saved when new technology used around (125.2 Gg.CO2), 15% saved from refrigeration (20.16 Gg.CO2), 15% from lighting (12.77 Gg.CO2), 10% from fan (9 Gg.CO2), 10% from space cooling (5.8 Gg.CO2), 10% from electronic appliance (5.8 Gg.CO2), 20% from water pump when we used new one with high power factor (4.48 Gg.CO2) . Out of all we can save 15% by using power factor correction (67.19 Gg.CO2). But as we have mentioned previously only 40% from all households has ability to own new technology, and that mean we can save from new technology (50.08 Gg.CO2).

If implemented, the combined effect of the initiatives discussed above will substantially reduce overall emission of carbon dioxide in Khartoum. As can be seen in Table (6) the total carbon dioxide emission reduction by activity about 25.9% of the total emission from residential sector (which is 116.06 Gg. CO2).

Table 6: Greenhouse gas emissions reduction by activity

Activity	Greenhouse gas reduced by improving the users behavior (Gg. CO_2)	Greenhouse gas reduced by following new technology (Gg. CO_2)
Refrigeration	15	8.064
Fan	10	3.6
Lighting	16.1	5.108
Space cooling	5.8	2.32
Electronic appliances	15.72	2.32
Motor	3.36	1.792
Power factor correction	-	26.876
TOTAL	65.98	50.08

4.3 Role of Hydropower is Offsetting Electricity Consumer Behavior

It was demonstrated via the use of questionnaire that electricity consumers' behavior contributes significantly towards GHG emissions as shown in Table 4-14. This GHG contribution, of course, can be reduced by many measures such as education and awareness raising, use of new sensor technology and improving the power factor of many devices. It can also be offset by the use of clean energy sources that does not contribute to emission of GHGs, and in this case we are specifically referring to hydropower since it is a source of significant energy and have been used and developed in the past and for years to come.

As has been outlined in the methodology (section 3, bullet 4), the role of hydropower in offsetting the consumer behavior contribution to GHG emissions has been evaluated using three scenarios which are:

1. Status quo (2007) without hydropower (replace amount of hydropower generated with thermal)
2. Status quo (2007)
3. Future expansion if all hydro to meet future demand gap (2010 and 2014).

4.3.1 Status Quo Without Hydropower

The detail of emissions, energy production and amount of emissions that has been offsetby hydropower generation is given in Table 7 below.

Table 7: Annual emissions, energy production and amount of emissions that has been offset by hydropower generation

Year	Total Emission Gg.CO_2	Total generation (MW)	Hydropower generation (MW)	Carbon Offsetts by Hydropower (Gg. CO_2)
2000	1118.282927			
2001	1418.907816			
2002	1428.21955			
2003	1775.502559			
2004	2004.950986	1200	329.8	551.0274
2005	2228.252362	1211.4	329.8	606.635
2006	2236.247345	1322.4	329.8	557.709
2007	2491.730848	1565.4	379.8	604.548
2008	3592.576575	2566.4	379.8	531.6633
2009	3753.157298	3916.4	379.8	363.9692
2010	3943.933527	4164	1629.8	1543.665
2014	5010.417481	4929	2629.8	2673.239

The status quo has been demonstrated in Table 6 together with opportunities for saving electricity and reducing GHG emissions. These amounts represent the GHG emissions due to consumer behavior assuming all the power from thermal generation since emissions were calculated based on electricity consumption. In the case where hydropower replaces some of the thermal power generation, these amounts will reduce because of the clean source of electricity. In the case of 2007, the emissions were due to consumer behavior estimated from the questionnaire where 66 (Gg. CO2).

4.3.2 Status Quo

In reality hydropower in 2007 contributed more than 20% of the generation, and although consumer behavior has wasted electricity, however emissions due to this wastage are greatly reduced because of the clean hydropower source. The amount of emissions due to forest clearance for hydropower are assumed negligible, and the calculated actual emissions due to the consumer behavior were found to be

53 (Gg. CO2), representing 19.7% less emissions and therefore, hydropower and other clean energy sources can offset part of the consumer behavior contribution to GHG emitted from thermal power generation in the Sudan.

4.3.3 Future Expansion if All Hydro to Meet Future Demand Gap (2010 and 2014)

The calculations for the years 2010 and 2014 were based on the assumption that the percentage of possible electricity savings due to change in consumer behavior during the year of questionnaire (2007) to the total generation is valid for the years 2010 and 2014.

For the year 2010 it was assumed that electricity from Merowe dam is added to the system while for the year 2014 it is assumed that the gap was fully satisfied with development of hydropower or purchase of electricity from clean energy sources. This seems to be a reasonable assumption since transmission line between Ethiopia (almost 100% hydropower country) and Sudan is expected to enter into service in 2010 and many hydropower potential developments in the Sudan are being planned or implemented (such as Roseris dam heightening project).

It was found that possible emissions due to the consumer behavior were 175 and 207 (Gg. CO2) while the actual due to expansion in hydropower is estimated to be 105 and 97 (Gg. CO2). In essence developing hydropower will not only reduce GHG emissions from thermal generation sources but it also contribute to rectifying use issues such as behavioral issues.

5. CONCLUSION AND RECOMMENDATIONS

It was demonstrated via the use of a questionnaire of sample size 500 electricity consumers out of the 445349 consumers in 2007 that their behavior contributes significantly to the amounts of electricity consumed and that these amounts of electricity contributes significantly to GHG emissions (represented by CO2) if the generation was purely thermal. Given the limitations of this study discussed in the methodology section (section 3, bullet 4), clean hydropower played a role in reducing these behavioral emissions and it was found that:

1. Consumer behavior contributed 53 while it could have contributed 66(Gg. CO_2) if there was no hydropower generation in the Sudan.
2. In 2010 and 2014 it is expected that consumer behavior contribute 105 and 97 (Gg. CO2) if demand is met by hydropower development plus regional cooperation in power trade, versus 175 and 207 (Gg. CO2) if demand was met via thermal generation expansion.

6. REFERENCES

1. Abu Gedairi ,S.H., (2006), *"Power Factor Compensation in Power System".*
2. Ali, Z.O., (2007), *Electricity Consumer Behavior Effect on Greenhouse Gas Emission in Khartoum State,* MSCE Thesis, University of Khartoum.
3. Cochran WG. (1977), *Sampling Techniques*. 3rd Ed., Wiley, New York.
4. IEA GHG (2004), *'Improvements in power generation with post-combustion capture of CO2.'* Report PH4/33,Nov. 2004, IEA Greenhouse Gas R&D Programme, Cheltenham, UK.
5. IPCC, (2006), *Guidelines for National Greenhouse Gas Inventories,* Volume 2: Energy, Chapter 2: Stationary Combustion, Darío R. Gómez (Argentina) and John D. Watterson (UK),
6. IPCC, (2001). "*IPCC WGI Third Assessment Report - SPM*"
7. Levine, M., D. Ürge-Vorsatz, K. Blok, L. Geng, D. Harvey, S. Lang, G. Levermore, A. Mongameli Mehlwana, S. Mirasgedis, A. Novikova, J. Rilling, H. Yoshino (2007), *Residential and commercial buildings. In Climate Change 2007: Mitigation*, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

8. Levermore G.J., Chong W.B. (1989), *Performance lines and energy signatures,* Review and analysis Building Services Engineering Research and Technology, Vol. 10, No. 3, 105-114.
9. NEC Central Lab ,(2007)," *Fuel Specification Reports"*
10. NEC (National Electicity Corporation) (2004), *"NEC Development Plan"* (medium term 2005-2010)
11. Socolow, Robert H. (1978), *Saving energy in the home: Princeton's experiments at Twin Rivers*, Ballinger Pub. Co. Cambridge, Mass.
12. Ueno, T., Inada, R., Saeki, O and Tsuji, K. (2006), *"Effectiveness of Displaying Energy Consumption Data in Residential Houses,"* ECEEE 2005 Summer Study on Energy Efficiency in Buildings, Vol. 6, European Council for an Energy Efficient Economy, Brussels, p. 1289.