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The Namibian Electrical Energy Mix and Its Implications for Air Quality and Climate Variability

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Abstract

The urgent need for sustainable energy choices, local sustainable value creation, and reduction of import dependencies and non-sustainable resource use in Namibia cannot be over emphasised. This study was conducted with the ultimate goal to provide the basis for accurate energy fuel mix and climate change monitoring, and reporting and planning for addressing a global problem at local/domestic level. The energy consumption and production data for the country were used with International Panel on Climate Change (IPCC) and International Energy Agency (IEA) conversions, and carbon footprint calculation tools to determine the GHG emissions and air pollutants per type of energy fuel; and the carbon footprint associated with each energy fuel option for the country. The study showed that: 1) there is no single energy fuel which is not associated with GHG emissions and/or other environmental implications; 2) increase in population and energy consumption and production yields increase in GHGs and other major pollutants (SO_x, NO_x, Particulate Matter); and 3) the choice of fuel mix determines the success of GHG emissions reduction. A future energy mix dominated by renewable energy technologies; and a balanced view of the actual benefits of the Namibian energy supply choices was also recommended.

Keywords

Electrical Energy Mix, Greenhouse Gases, Air Pollutants, Namibia

1. Introduction

Emission of greenhouse gases (GHGs) and their implications to climate change have sparked global interest in

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understanding the relative contribution of the electrical energy generation industry. The world emits approximately 27 gigatonnes of CO_2e from multiple sources, with electrical production emitting 10 gigatonnes, or approximately 37% of global emissions. Electricity demand is expected to increase by 43% over the next 20 years [1]. This substantial increase will require the construction of many new power generating facilities and offers the opportunity to construct these new facilities in a way to limit GHG emissions [2].

Greenhouse gas (GHG) and air pollutant emissions share the same sources namely transport, industry, commercial and residential areas [3]. All these sources depend on production, distribution and utilisation of energy for their daily activities. Depending on the type of energy used (e.g. wood, coal, oil, electricity, etc.) and the fuel and technology (coal, hydro, wind, etc.) used for electricity generation, the producers and consumers can contribute to direct GHGs (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6)) and/or indirect GHGs (non-methane volatile organic compounds (NMVOC), carbon monoxide (CO), nitrogen oxide (NO_x), and sulphur dioxide (SO_2)).

Namibia is ranked among countries with high urban to rural population ratio in Southern Africa. Moreover, the Namibia Statistics Agency [4] projected a decrease in rural population with increase in urban population from 1,068,625 and 1,212,091 in 2015, to 2,256,123 and 1,145,764 in 2040 for urban and rural populations respectively. Manuel (2013) [5] reported that 87 percent of Namibians in the rural areas use wood or wood charcoal as the main energy for cooking, heating and lighting. This is very high compared to only 16 percent of the urban residents who use 20% of wood-related sources for lighting and heating. According to Meier (2002) [6], the growing energy use in urban areas has been shown to result in a quantifiable and significant increase in the urban atmosphere temperature (urban heat island effect). This effect intensifies the impact of global warming and facilitates the formation of ground level ozone, thus increasing the need for careful fuel choice consideration in planning and policy development. The results of this study are thus relevant to accurate energy fuel mix and climate change monitoring, reporting and planning for addressing a global problem at local/domestic level.

2. Materials and Methods

The methods used for this study include secondary research on the population statistics, energy demand/consumption and production in Namibia, calculation of GHGs and air pollutant emissions based on the data from the Namibian national planning agencies and electricity supply and control boards. The GHGs and air pollutant emissions as a function of electricity production were determined following using purposive data acquisition outside organisational boundaries, and content analysis methods in Kgabi *et al*. (2014) [7]; and the primary energy use by means of the Cumulative Energy Demand method implemented in Ecoinvent by Alsema *et al.* (2006) [8].

3. Results

3.1. Energy Consumption/Demand

The most dominant sector of energy in Namibia is the liquid fuel which includes petrol and diesel and accounts for about 63 percent of total energy net consumption, followed by electricity with 17 percent net consumption, then coal with 5 percent, the remaining 15 percent is from other types of energy [5]. The findings presented in this study are focused on electrical energy.

3.1.1. Electrical Energy Demand

Projections of the electrical energy demand for the country are shown in **Figure 1** as reported by [9]. The electrical energy demand increases with population and industrialisation. The increase in demand also creates the need for increased electricity production and GHG and air pollutant emissions.

The demand for electricity also increases with increase in population, particularly urban population. The projected urban and rural population data sourced from [4] is shown in **Table 1**.

3.1.2. Electrical Energy Consumption

The overall consumption for the country is shown in **Figure 2**. The high percentage of losses has negative impacts both on electricity supply costs and accounting for GHGs emissions associated with distribution. The 18% consumption by Skorpion Zinc Mine is cause for concern considering the current energy crisis in the country.

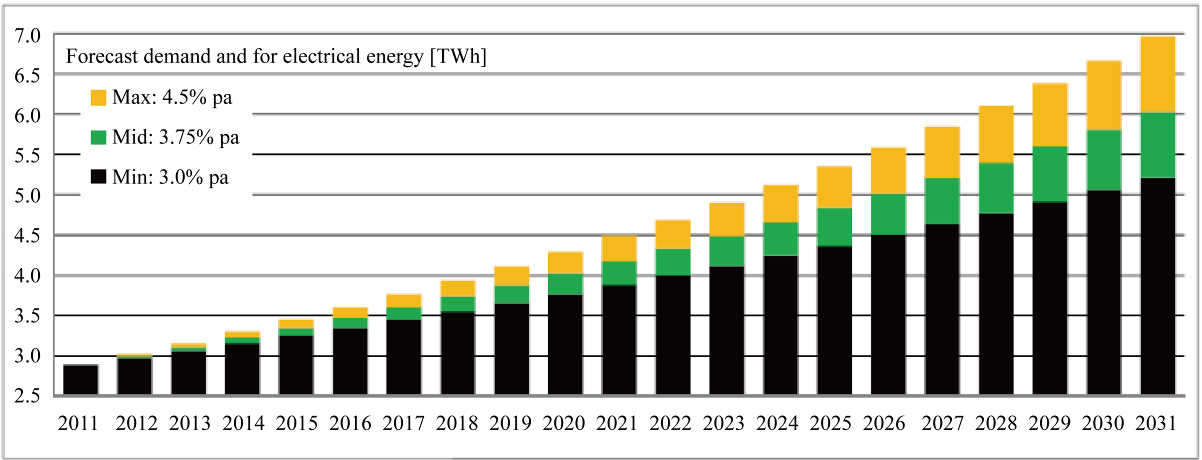

Figure 1. Namibian electrical energy demand.

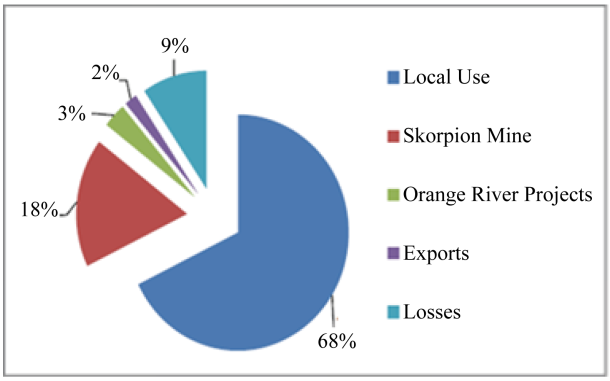

Figure 2. Country-wide electrical energy consumption pattern (adapted from [9]).

Table 1. Projected urban and rural population.

YEAR	URBAN	RURAL	COUNTRY TOTALS (NAMIBIA)
2015	1,068,625	1,212,091	2,280,716
2020	1,295,820	1,208,678	2,504,498
2025	1,531,917	1,201,421	2,733,338
2030	1,770,807	1,189,735	2,960,542
2035	2,011,793	1,173,212	3,185,005
2040	2,256,123	1,145,764	3,401,887

The consumption by an electro-winning smelter is an equivalent of Windhoek City, which is home to more than 350,000 residents and various industries.

According to Kgabi *et al.* (2014) [7], 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.

Electricity consumption by urban areas in Namibia was estimated by Kgabi *et al.* (2013) [10] as 71% based on energy fuel mix of selected towns including Karibib with the following consumption of 66.89% electricity, 17.93% wood and coal, 13.8% gas, and 1.38% paraffin; Lüderitz-Electricity (76%), Gas (19%), Wood and coal (4%), Paraffin (1%); and Ondangwa with Electricity (70.59%), Gas (14.71%), Wood and Coal (10.29%), Paraffin (4.41%). It is worth noting that the choice of fuel mix has direct implications for the type and quantity of GHGs and air pollutants.

Table 2 shows the population and electrical consumption/utilisation of selected urban areas in Namibia, compiled from data obtained from the National Statistics Agency (2011) [11].

The country urban average shown in the last row is not a sum total of selected urban areas listed in the Table nor statistical average, it includes all urban areas in the country.

The data presented in **Table 2** also show that in general, the countrywide electricity consumption for the past six years have been at least double the production.

3.2. Electrical Energy Production—Fuel Mix

The Namibian electrical energy mix is characterised by varied sources from different countries. The contribution of different sources can be categorised into coal-fired (from Van Eck—Namibia, Zimbabwe Electricity Supply Authority (ZESA), and Electricity Supply Commission—South Africa (ESKOM), Diesel Oil (from Paratus and Anixas Power Stations—Namibia), Hydro (Ruacana—Namibia, Electricidade de Moçambique (EDM), Zambia Electricity Supply Corporation Limited (ZESCO), and some unspecified sources (Short-term Energy Market (STEM) offered through the Southern African Power Pool (SAPP)). An estimate of the Namibian electrical energy mix is presented in **Figure 3** based on the data extracted from [9].

Table 2. Electrical consumption/utilisation of selected urban areas in Namibia.

	Urban population	Annual growth rate	Average size of household	% HH using electricity for cooking	% HH using electricity for lighting
Arandis	5170	2.6	4.2	95.7	96.1
Aranos	3683	Data not available	4.2	25.7	38.7
Eenhana	5528	6.8	3.7	41.3	56
Gobabis	19,101	3.2	3.9	33.9	48.5
Grootfontein	10,415	−3.1	3.8	44.7	94.8
HelaoNafidi	19,375	Data not available	3.8	36.6	47.3
Henties Bay	4720	3.6	3.1	59.2	71.6
Karasburg	4401	0.8	4.4	41.7	70.5
Karibib	5132	3.2	3.7	55.9	60.5
KatimaMulilo	28,362	2.5	4.2	41.5	76.2
Keetmanshoop	19,447	2.1	4.2	58	86.6
Khorixas	6796	1.4	4.1	42.2	78.7
Luderitz	12,537	−0.6	3	46.9	78.1
Maltahohe	2379	Data not available	4.3	45.1	56.7
Mariental	12,478	2.4	4.4	65.4	87
Nkurenkuru	618	Data not available	4.7	75.6	89.4
Okahandja	22,639	4.8	4.4	62	73.1
Okahao	1833	Data not available	2.9	66.1	77.3
Okakarara	3927	1.8	3.7	39.7	48.2
Omaruru	6300	2.8	3.6	38.3	53.3
Omuthiya	3794	Data not available	4.2	20.4	24.3
NAMIBIA (Country Urban Average)	**895,691**	**3.9**	**3.8**	**59.7**	**71.1**

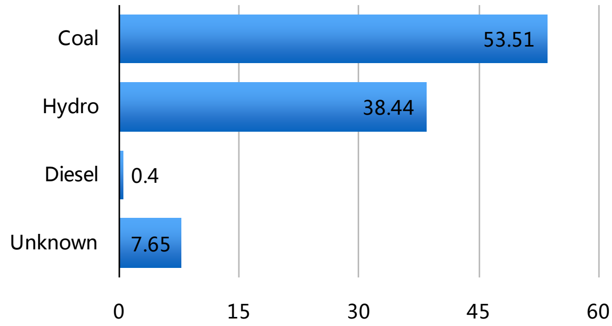

Figure 3. Estimate contribution of different fuel types to the electricity production in Namibia.

For accurate reporting and reduction of GHGs and other air pollutants, it is essential for the planners, decision makers and the scientific community to have an accurate and complete picture of the electricity generation sources utilised by the country and/or local energy suppliers. According to VO Consulting [9], the Namibian local electricity generation (from the four NamPower stations) accounted for 36.6% (1430 GWh) of the total energy/power supply in 2010/11. About 98.2% of the 1430 GWh (*i.e.* 1404 GWh) was generated from Ruacana (hydro), 1.4% (20.02 GWh) from Van Eck (coal), 0.3% (4.29 GWh) from Paratus (diesel oil) and 0.1% (1.43 GWh) from Anixas (diesel). Based on the information provided above, it can be concluded that the total electrical energy/power supply in 2010/11 was 3907 GWh.

It was also reported that Eskom South Africa provides up to 53% of Namibian Electricity from Coal-Fired Power Plant(s). Thus, the Eskom contribution for 2010/11 is assumed to be 2070 GWh. Considering the fact that ZESA provided up to 150 MW from the coal-fired Hwange station from 2008-2014, EDM provided 2.5% of total Namibian supplies in 2009/2010, and ZESCO supplies firm capacity of 50 MW for 2010-2020; contribution of the three suppliers in 2010/11 is thus computed as follows: 0.0039% (0.15 GWh), 2.5% (97.68 GWh) and 0.0013% (0.05 GWh) for ZESA, EDM and ZESCO respectively. Thus the Namibian electrical energy mix for 2010/11 can be represented (in percentages) as shown in **Figure 4**.

The 7.65% described as unknown might be inclusive of renewables and unidentified sources. The Namibian electricity supply is highly reliant on imports from different countries Reliance on imports was reported by Manuel 2013 [5] as summarised in **Table 3**.

Both the production and imports are largely from non-renewable sources, thus increasing contribution to GHG emissions and air pollutants.

3.3. Renewable Energy Supply

Namibia has access to various renewable energy sources including biomass, hydro, solar and wind. The availability and potential energy output for selected sources is documented by von Oertzen (2009) [12] as 1100 TWh from biomass, assuming a 10 tons of bushy biomass per bush-infested square hectare from extensive areas in Namibia (of the order of 26 million hectares) covered by invader bush; 1.3 TWh from Ruacana hydro-electric power station; 0.08 TWh per annum per 50 MW of solar photovoltaic (PV) plants installed capacity from annual solar radiation average exceeding 6 kWh per square meter per day; and 0.12 TWh per annum from a typical 50 MW wind farm positioned on the southern coast. Despite the current energy crisis in the country, these readily available resources have not been utilised. If utilised, the renewable energy sources could augment the current electricity production/supply, and accelerate the reduction in GHGs and air pollutant emissions.

The total renewable energy supplied from 2000 to 2011 (MWh) is shown in **Table 4** based on data reported by Electricity Control Board of Namibia (2014) in [5].

3.4. GHG Emissions

The Commonwealth of Australia (2006) [13] reported that CO_2 emissions from electricity generation have grown by 170 percent since 1971, and in 2003 electricity generation accounted for 40 percent of global CO_2 emissions. Of this, coal-fired electricity plants accounted for some 70 percent, natural gas-fired plants for ap-

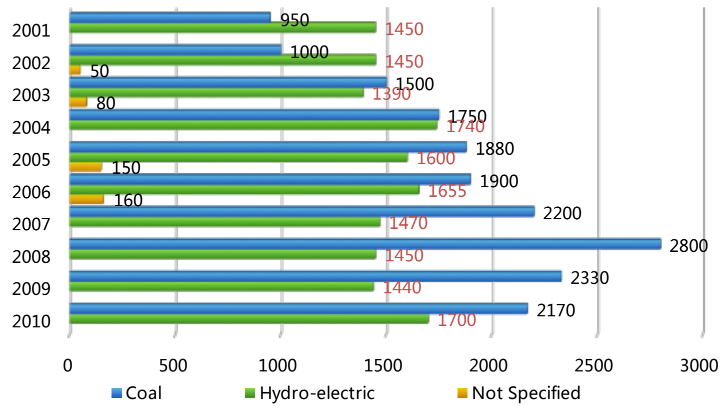

Figure 4. Electrical energy mix for the 2010/11 period.

Table 3. Annual electricity production and consumption in GWh.

Year	Production	Export	Import	Supply	Gap	Consumption
2000	1407	108	785	2084	−89	1318
2001	1211	69	1066	2208	871	2082
2002	1429	54	942	2317	44	1473
2003	1421	53	1045	2413	772	2193
2004	1380	23	1519	2876	1392	2772
2005	1662	31	1695	3326	1283	2945
2006	1612	36	1867	3443	1551	3136
2007	1590	40	1931	3480	1629	3219
2008	1595	47	2126	3673	1797	3392
2009	1520	144	2202	3578	1770	3290
2010	1347	294	2462	3515	2007	3354

Table 4. Annual renewable energy supply.

Period	Total Renewables	Hydro Power	Wood Charcoal	Solar CSP + PV	Wind Power
2000	7155	5026	2129		
2001	6489	4360	2129		
2002	7204	5123	2081		
2003	7266	5108	2157		
2004	7952	4921	3031		
2005	8984	5962	3022		
2006	8520	5443	3077	0.2	
2007	8943	5551	3392	0.4	
2008	9302	5023	4278	0.7	
2009	9352	5072	4278	0.9	0.6
2010	8952	4489	4461	1.4	0.6
2011	9260	5058	4200	1.4	0.6

proximately 20 percent and oil-fired plants for approximately 10 percent. It is thus imperative to report country-wide emissions from different sources.

3.4.1. GHGs from Electrical Energy Supply

The emissions in **Figure 5** below are reported in thousand (kilo) tonnes CO_2e based on the production/supply data given in **Figure 3**. Conversion factors of 888 ton CO_2e/GWh for coal and 6 ton CO_2e/GWh for Hydroelectric from the IEA were used for calculations. The unspecified sources were assumed to be coal.

Though the CO_2e is inclusive of all the GHGs depending on the source, it is imperative to delineate all the GHGs separately for each source/fuel type. For example, as a GHG, CH_4 has a warming potential in the atmospheric sink that is approximately 25 times greater than CO_2 per 100 years [14].

For the purpose of generating projections data and for demonstrating the effect of renewable energy sources in the electrical energy mix; the period 2010/11 (herein referred to as 2011) in **Figure 4** with consumption of 3907 GWh generated from 53.51% coal, 38.44% hydro, 0.4% diesel and 7.65% unidentified sources; was used as base year. The maximum percentage increase (4.5% per annum) in electrical energy demand reported by [12] in **Figure 1** was used to determine the projections. The 7.65% unidentified sources was first assumed to be coal, yielding the emissions in **Table 5**, then renewables (4% solar PV and 3.65% wind), yielding the GHGs in (**Table 6**).

A change from the current energy mix presented in **Table 5** (61.16% Coal (*i.e.* 53.51% coal + 7.65% unknown—assumed to be coal), 38.44% Hydro, 0.4% Diesel) to the mix in **Table 6** (53.51% Coal, 38.44% Hydro, 0.4% Diesel, 4% Solar, 3.65% Wind) the country could benefit from a 6.1% reduction in GHG emissions. However, to effectively reduce reliance on import of electricity and electricity generating fuels like coal and oil, it would be advisable to effect a rapid (5-year steps) change to the electrical energy mix by reducing the proportion of coal:hydro:diesel:solar:wind.

This study thus proposes the energy mix with component percentages summarised in **Figure 6**, to achieve an overall GHG reduction of 51% (**Figure 7**).

Introduction of renewables into the country energy mix has been proved to reduce the GHG emissions. For example, in 2013, the roughly 168 million megawatt-hours (MWh) generated by wind energy delivered 4.1% of US generation and avoided over 96 million metric tons of carbon dioxide (CO_2)—the equivalent of reducing power-sector CO_2 emissions by 4.4%, or taking over 16 million cars off the road [15].

Also, a study by the Electric Reliability Council of Texas (ERCOT) found that 9400 MW of added wind capacity on their system would avoid 17.6 million tons of CO_2 [15].

3.4.2. GHG Emissions from Renewables

Though the actual GHG emissions from the electricity generation process using renewables is usually assumed to be zero, the carbon neutrality of most renewables has been re-examined and summarised by the International Energy Agency [1] in **Table 7**. It should be noted however, that the GHGs associated with renewable energy sources are normally emitted during the construction and decommissioning processes, not the actual generation.

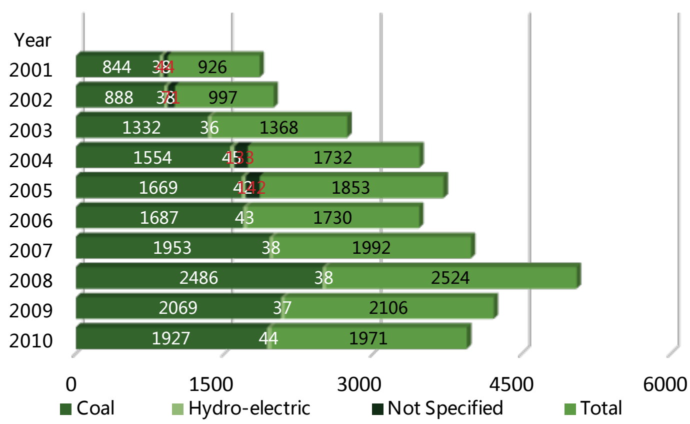

Figure 5. GHG emissions from the annual electrical energy consumption/fuel mix.

Table 5. Projected consumption and GHG emissions without wind and solar energy.

Year	Total Consumption (GWh)	Coal		Hydro		Diesel		Total GHG Emissions (kilo tons CO_2e)
		Consumption (GWh)	GHGs (kilo tons CO_2e)	Consumption (GWh)	GHGs (kilo tons CO_2e)	Consumption (GWh)	GHGs (kilo tons CO_2e)	
2011	3907	2390	2122	1502	39	15.6	11.4	2172
2012	4083	2497	2217	1569	40.8	16.3	11.9	2270
2013	4267	2610	2318	1640	42.6	17.1	12.5	2373
2014	4459	2727	2421	1714	44.6	17.8	13	2479
2015	4660	2850	2531	1791	46.6	18.6	13.6	2591
2016	4870	2978	2644	1872	48.7	19.5	14.3	2707
2017	5089	3112	2763	1956	50.8	20.3	14.9	2829
2018	5318	3252	2888	2044	53.1	21.3	15.6	2957
2019	5557	3399	3018	2136	55.5	22.2	16.3	3090
2020	5807	3550	3152	2232	58	23.2	17	3227
2021	6068	3711	3295	2332	60.6	24.3	17.8	3373

Table 6. Projected consumption and GHG emissions with wind and solar energy.

Year	Consumption (GWh)	Coal		Hydro		Diesel		Solar PV		Wind		Total GHG Emissions
		Consumption	GHGs	Consumption	GHGs	Consumption	GHGs	Consumption	GHGs	Consumption	GHGs	
2011	3907	2091	1857	1502	39	15.6	11.4	156	13.3	143	3.7	1924
2012	4083	2185	1940	1569	40.8	16.3	11.9	163	13.8	149	3.9	2010
2013	4267	2283	2027	1640	42.6	17.1	12.5	171	14.5	156	4.1	2100
2014	4459	2386	2119	1714	44.6	17.8	13.0	178	15.1	163	4.2	2196
2015	4660	2493	2214	1791	46.6	18.6	13.6	186	15.8	170	4.4	2294
2016	4870	2606	2314	1872	48.7	19.5	14.3	195	16.6	178	4.6	2398
2017	5089	2723	2418	1956	50.8	20.3	14.9	203	17.3	186	4.8	2506
2018	5318	2846	2527	2044	53.1	21.3	15.6	213	18.1	194	5.0	2619
2019	5557	2973	2640	2136	55.5	22.2	16.3	222	18.9	203	5.3	2736
2020	5807	3107	2759	2232	58.0	23.2	17.0	232	19.7	212	5.5	2859
2021	6068	3247	2883	2332	60.6	24.3	17.8	243	20.6	221	5.7	2988

The GHGs from the annual renewable energy supply (tonnes CO_2e) is summarised in **Figure 8**, following the mean emissions data presented in **Table 7**.

3.5. Air Pollutant Emissions

Fossil fuel combustion produces pollutants with environmental and health impacts, including sulphur oxides (SO_x), nitrogen oxides (NO_x) and particulate matter, and also contribute to climate change [13]. The main elec-

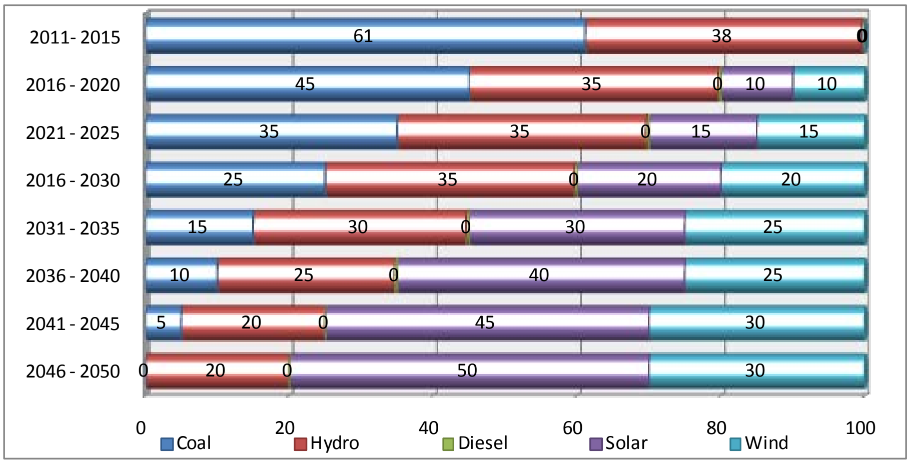

Figure 6. Proposed electrical energy mix.

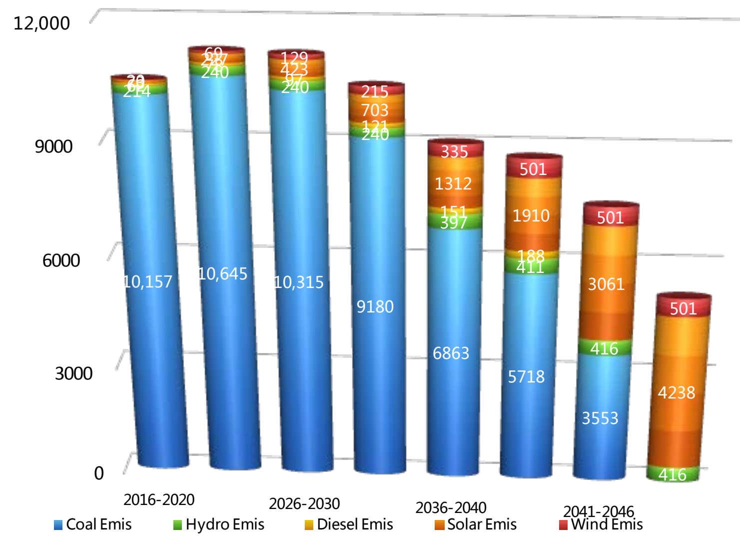

Figure 7. Projected emissions reductions if the proposed changes are effected.

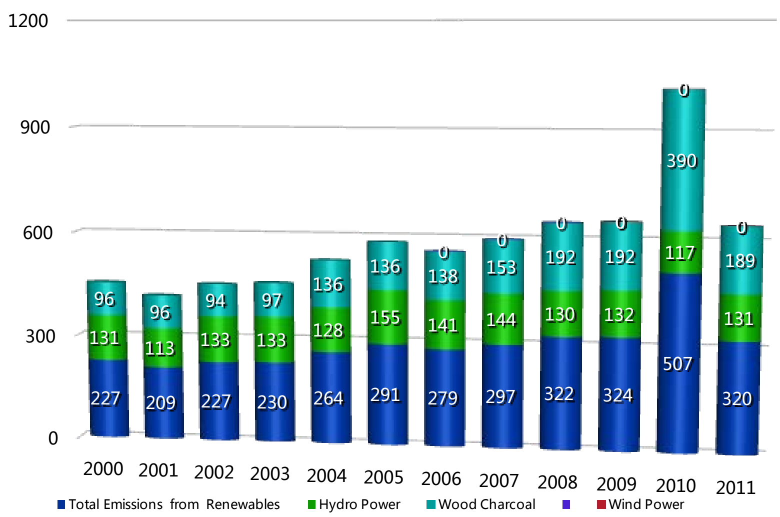

Figure 8. Annual GHG emissions contribution from renewables.

tric utility-related gases are GHGs—CO_2, CH_4, N_2O, SF_6; and Air Pollutants—CO, SO_2, NO_x, NMVOCs [7].

The main air pollutants (SOx, NOx and PM) shown in **Figure 9** for a typical coal-fired power station were quantified in tonnes per annum following Eskom (2008) [16] *i.e.* SO_x emissions = electricity consumption × 8.69; and NO_x emissions = electricity consumption × 4.39; PM emissions = electricity consumption × 0.23.

An increase in air pollutant emissions with increase in electrical energy consumption (leading to high generation/production) from 2390 to 3711 GWh within a ten-year period is evident for the 2011 to 2021 period. The continued increase should be expected if the fuel mix is not altered by increasing the readily available renewables *i.e.* solar and wind power.

Trace gases and aerosols impact climate through their effect on the radiative balance of the earth. The 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 ranging from dust and smoke to mists, smog and haze have a direct effect by scattering and absorbing solar radiation and an indirect effect by acting as cloud condensation nuclei [17].

Table 7. Renewable energy emissions.

Technology	Low	High	Mean
	Tonnes CO_2e/GWh		
Lignite	790	1372	1054
Coal	756	1310	888
Oil	547	935	733
Natural Gas	362	891	499
Solar PV	13	731	85
Biomass	10	101	45
Nuclear	2	130	29
Hydroelectric	2	237	26
Wind	6	124	26

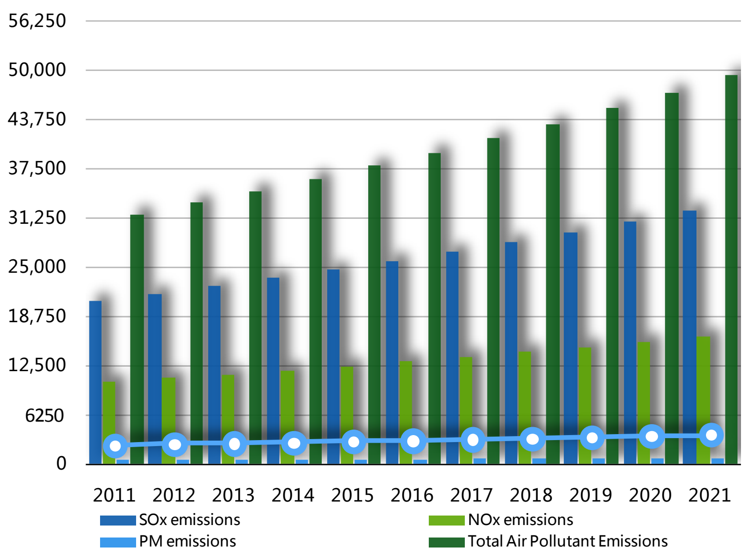

Figure 9. Main air pollutant emissions from the Namibian coal-fuelled energy production/consumption.

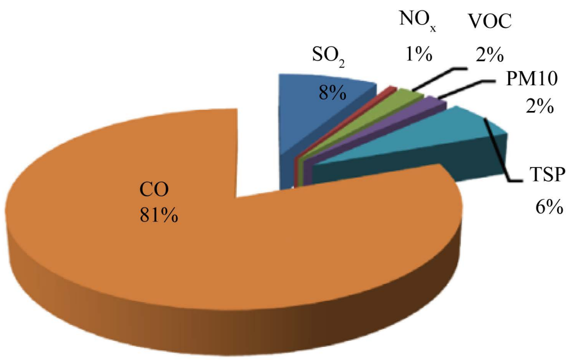

Figure 10. Pollutants from coal combustion during electricity generation [7].

It is thus imperative to determine the all the pollutants directly associated with fuel combustion during electricity generation/consumption. Air pollutant contribution from coal combustion during electricity generation is presented in **Figure 10**.

The combustion of 1 kg of coal results in emission of 19 g SO_2, 1.5 g NO_x, 5 g VOCs, 4.1 g PM10, 14.7 g TSP, 187.4 g CO and 0.0134 g benzene (Friedl, *et al*. 2014) [18]. It can therefore be concluded based on the information from [18] that air pollutants form 23.17% (231.71 g from the 1 kg coal) of the amount of coal used for electricity generation. All the pollutants represented in **Figure 10** have potential to act as GHG pre-cursors, thus contributing to enhance the greenhouse effect.

4. Conclusions

This study has demonstrated the effect of the current Namibian electrical energy mix on the enhanced greenhouse effect. The increase in energy consumption and production was also shown to increase in GHGs and other major pollutants. It is thus evident that the choice of fuel mix determines the success of GHGs and air pollutants reduction; and that there is no single fuel which is not associated with GHG or other environmental implications.

A future energy mix dominated by renewables (solar, wind and hydro) herein proposed has been shown to yield a substantial decrease (up to 51% reduction) in GHG emissions and associated air pollutants. The proposed energy mix is intended to promote sustainable energy choices for local sustainable value creation, and against import dependencies and non-sustainable resource use.

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