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Power Generation Expansion Planning in Nigeria: A Goal Programming Approach

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Abstract
Sustainable electric power generation is imperative for the steady growth and development of any nation. Critical planning and optimal resource management provides assurances in attaining the goals of electricity generation expansion. In this paper, a multi-criteria generation expansion planning problem is explored. Two multi-objective generation expansion planning models that include two objectives are proposed, the first objective seeks to minimize generation expansion cost while the second seeks to minimize carbon dioxide emission. Using a multi-criteria decision making theory, these models provide results which indicate the most recommendable amount of each type of generation technology to install. A frame work to solve and generate alternative solutions is provided for each model and representative case study of the Nigerian power system is used to show the performance of the models. The proposed models are a single period and a multi period power generation expansion planning models which are MPGEP I and MPGEP II respectively. Pre-emptive and weighted goal programming methods were used to solve the models. The two methods gave similar result which were satisfactory. In MPGEP I, 6670, 1000, 0, 2500, 5000, and 4707 MW of Hydro, Wind, Nuclear, SC, CC and Coal power plant respectively were recommended for addition at an investment cost of US\$46.2 billion while keeping CO_2 *emission at 38600000 tonnes. While in MPGEP II, 6000, 1000, 0, 0 5000 and 7876 MW of Hydro, Wind, Nuclear, SC, CC and Coal power plant respectively were recommended for addition at an investment cost of US\$ 34.4 billion while keeping* CO_2 *emission at 146000000 tonnes. It is importance to state that the solution obtained in this study is an approximation of the real generation expansion planning problem. However, the solution looks reasonable given the considered data and scenario. Moreso, the computational effort to obtain the expansion plans is minimal. Thus, with more accurate input data, the results can be better.*

Keywords: *Generation expansion planning, Power plant, Multi-criteria analysis, Goal programming.*

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I. INTRODUCTION

Steady and affordable electricity supply for domestic and industrial activities stimulate rapid growth and development [1, 2]. For electricity to get to the end users, several processes are involve which include generation, transmission and distribution. Each of these processes must be carefully planned, coordinated, executed and managed for a reliable and stable electricity supply. With increasing economic and industrial activities, forecasters often do project an increase in electricity demand over a given time horizon. This projections often do help electricity capacity planners to plan for capacity increase to meet future demands. Increasing capacity has often been challenging for electricity planners due to the uncertainty associated with input data, such as forecast of demand for electricity, economic and technical characteristics of new evolving generating technologies, construction lead times and governmental regulations [3, 4, 5]. In an environment where stiffer regulations exist on CO_2 emissions, the choice for adopting conventional generation technologies (i.e., generation technologies that involve the burning of fossil fuel) for capacity increase becomes more difficult [6, 7]. Hence, generation capacity planners have to explore other energy sources like hydro, nuclear, wind, solar and geothermal for generating power which often do not come cheap compared to the conventional energy sources like coal and natural gas. Moreover, energy sources like hydro, solar and wind which are renewable are usually not stable and cannot be completely relied upon [8, 9]. For the case of nuclear energy, it is quite effective and reliable, yet a lot of concerns are raised due to it detrimental environmental and safety concerns. These challenges are often viewed by electricity planners as generation expansion problem and adequate knowledge and techniques in tackling it is required to arrive at the best decision.

Generation expansion planning problem is a problem of WHAT, WHEN and WHERE new generation units should be installed over a long-range planning horizon to meet the expected demand [3]. This is a strategic planning problem for any country and Nigeria is not an exception. The Nigerian economy is the largest in the sub-saharan Africa but it power sector is characterized with lot of limitations which has constrain it growth [1, 10].

Electricity in Nigeria is mainly generated from hydro and thermal (gas) power. The total installed electric capacity in 2015 is about 10124 MW of which about 80.84 % is mainly gas and about 19.2 % is hydro [11, 12]. Current daily power generation ranges between 3500 MW to 4517 MW with an available capacity of about 6522 MW which cannot be fully utilized due to the associated challenges in transmission and distribution [1]. It estimated that Nigeria will require about 20,000MW of electricity by 2030 [14], hence adequate capacity planning is required.

According to the Power sector Reform Roadmap initiated in 2010, generation capacity of 40000MW was targeted in 2020. It was also estimated that about US$3.5 billion will be required per annum for the next 10 years (2010-2020) to meet the target goal of 40000MW generation capacity. However, the 2010 Power road map mainly highlighted generation capacity expansion through hydro and gas power plant. Holistic energy mix and renewable energy technology seem to have been of less priority in it expansion plan. This is evident as most ongoing and newly completed power generation expansion project developed under the National Integrated Power Project (NIPP) are mainly gas and hydro power plant.

Table 1. Existing generation capacity in Nigeria

Generation Technology	**Installed capacity** (MW)	**Available capacity** (MW)	**Peak generation** (MW)	**Average energy delivered** (MWH)
Hydro	1940	1900	-	-
Single cycle SC	5331	-	-	-
Combine cycle CC	2853	-	-	-
Total	**10124**	**6522**	**4517**	**29196**

Table 2. Government proposed/ongoing generation capacity addition in Nigeria

Generating Technology	Hydro	Wind	Nuclear	SC	CC	Coal	**Total**
Capacity (MW)	4480.25	10.00	4800.00	3015.00	-	-	**12305.25**

Thus, this study seeks to develop generation capacity expansion plan base on the available energy resources in Nigeria which include fossil fuel (i.e., natural gas and coal), hydro, nuclear, wind, and solar energy sources. However, for the purpose of this study, only hydro, nuclear, wind, coal, simple cycle and combined cycle power generation plants shall be considered. It is hoped that the plan will reflect the best cost effectiveness as well as meeting the CO_2 emission requirement.

1.1 Goal Programming to Solve Multi-objective Optimization Problems in Power Systems

Solving generation expansion problems (GEP) which are multi-objective problems require adequate understanding of the nature of the problem. Several optimization methods have been used in solving GEP which include traditional approaches such as linear, mixed-interger, non-linear, decomposition schemes, dynamic programming, metahueristics approaches such as simulated annealing, tabu search, evolutionary algorithms, particle swam optimization and a combination of both [15]. The choice for a solution method depends on the complexity and peculiarity of the problem as well as how robust and fast the solution method can be. However in this study, goal programming solution method shall be adopted.

Goal programming algorithms have been applied to solve multi-objective problems in power systems research. Among them, weighted goal programming and min-max goal programming are common and used frequently by researchers [16, 3]. In Kim et al. [17], Fuzzy Goal Programming (FGP) is adopted to handle the multi-objective distributed generator (DG) placement problem incorporating the voltage characteristics of each individual load component. The original objective functions and constraints are transformed into the multi-objective function with fuzzy sets by FGP. The solution of the transformed multi-objective function with fuzzy sets is searched by Genetic Algorithm (GA). In Jos Ramn S.C. [18] a goal programming model for the optimal mix and location of renewable energy plants in the north of Spain is proposed. Since different types of plants can be placed in each location, the goal is to locate one plant in each place, maximizing the number of plants that are matched with comparable locations, in a way that the total deviations from goals are minimized. The problem was solved using Lingo. A fuzzy mixed integer goal programming approach for cooking and heating energy planning in rural India is introduced in [19, 20]. The solutions provide energy resource allocations at micro level with minimized cost, minimized emission, maximized social acceptance and maximized use of local resources. Pal et al. [21] used a modified extended goal programming model with interval programming to model the Economic Emission Load Dispatch (EELD) problem. In the study, target goals are considered as interval-valued numbers. The solution is sought then using genetic algorithm.

1.2 Multi-objective Generation Expansion Planning

In multi-objective models, the concept of optimal solution in single objective problems gives place to the concept of non-dominated solutions i.e. feasible solutions for which no improvement in any objective function is possible without sacrificing at least, one of the other objective functions. The concept of non-dominated solution is also known as Pareto-optimum, non-inferior solution, and efficient solution Coello et al. [22, 23].

A multi-objective mathematical model is defined as:

$$\text{Min or Max } x \qquad \{f_1(x),\ f_2(x)\ldots f_n(x)\}$$

$$\text{subject to} \qquad g_k(x) \begin{matrix}\le\\=\\\ge\end{matrix} b_k \qquad \left\{ k = 1, 2\ldots, m \right\} \qquad (1)$$

where x is an N-dimensional vector of decision variables; $f_i(x)$, $i = 1, 2\ldots n$ are n objective functions; $g_k(x)$, k = 1, 2, 3…m, are m constraint functions; and $b_1,\ldots b_m$ are the specified constant parameters.

A decision x^* is said to be non-dominated solution to the system in equation (1) if and only if there does not exist another $\bar{x}$ such that strict inequality holding for at least one *i*.

$$f_i(\bar{x}) \le f_i(x^*), \qquad i = 1, 2\ldots n, \qquad (2)$$

Consequently, for any non-dominated point no one of the objective function $f_i(x)$ can be improved without causing degradation in any other $f_j(x)$, $i \neq j$.

II. METHODOLOGY

A multi-criteria, single-period power generation expansion planning model (MPGEP I) and multi-criteria, multi-period power generation expansion planning model (MPGEP II) are proposed. Both MPGEP I and II are to determine the type and capacity of new generation units to achieve the best compromise between different objectives, and yet meet all the operating and economic restrictions that are placed on the system.

In these multi-objective models, minimization of the investment, operation & maintenance costs as well as the environmental impact in terms of CO_2 emission are considered. The proposed MPGEP I and II models are deterministic linear models. Mathematically, the model is describe as follows:

2.1 Mathematical Formulation of MPGEP I

The decision variables, constraints and objective functions are presented, as well as some constants used in the formulation.

2.1.1 Indexes

Θ	Set of generation unit
L	Set of fuel
q	An index representing type of generation unit for each $q \in \Theta$
k	An index representing type of fuel for each $k \in L$

2.1.2 Parameters of the model

D	Expected load (MW)
I_q	Investment cost ($/MW) of a generation unit of type q
G_q	Generation (operation and maintenance) cost ($/MW) of a generation unit of type q
GN_q	Maximum (MW) generation capacity of proposed generation units of type q
GE_q	Maximum (MW) generation capacity of existing generation units of type q
E_q	Tonnes of carbon dioxide (CO_2) emitted per MW generated by generation unit of type q
U_k	National availability (corresponding units) of fuel type k.
W_q	Fuel needed (units/MW) to operate a generation unit of type q
J_k	Index of units of fuel type k

2.1.3 Decision Variables

Two groups of decision variables in the model are:

ge_q	Generation (MW) from the existing units of type q
gn_q	Generation (MW) from proposed units of type q

2.1.4 Objective Functions

This model considers the minimization of the investment, operations & maintenance costs and environmental impacts in terms of CO_2 emission of the whole system.

- *Investment and Operational cost*: This objective function is defined as the sum of the investment cost for new units and the generation costs of the entire units. It is express as:

$$f_1 = \sum_{q\epsilon\Theta} I_q gn_q + \sum_{q\epsilon\Theta} G_q (ge_q + gn_q) \qquad (3)$$

- *Environmental Impact:* The aggregate Carbon dioxide (CO_2) emission from fossil-fuel plants is minimized.

$$f_2 = \sum_{q\epsilon\Theta} E_q (ge_q + gn_q) \qquad (4)$$

2.1.5 Constraints

In MPGEP I model, four types of constraints are imposed: load balance, generation capacity, amount of available local fuel and non-negativity constraint of the decision variables.

- Load balance equations: The power generated is equal to the power demand.

$$\sum_{q\epsilon\Theta} (ge_q + gn_q) = D \; ; \; q\epsilon\Theta \qquad (5)$$

- Generation capacity for each unit type q: Operating limits are imposed by the generation units.

$$ge_q \leq GE_q$$
$$gn_q \leq GN_q ; \qquad q \,\epsilon\, \Theta \qquad (6)$$

- Fuel demand for each fuel type k: Fuel used will be from local markets (U_k).

$$\sum_{q\,\epsilon\,\Theta} W_q (ge_q + gn_q) \leq U_{k;} \qquad k \,\epsilon\, L \qquad (7)$$

- Non-negativity: No negative values are permitted for the decision variables.

$$ge_q, gn_q \geq 0; q \,\epsilon\, \Theta \qquad (8)$$

Let

$f_l(x)$ = l^{th} objective function, l = 1, 2.
$x = (ge_q, gn_q)$ decision or solution vector
$x \in X$ = feasible solution space
The general MPGEP I model can be written as:
Min [$f_1(x)$, $f_2(x)$]
Subject to $x \in X$ (9)

2.2 Mathematical Formulation of MPGEP II

MPGEP II is a large-scale, linear mathematical programming problem with different conflicting objectives that must be considered simultaneously. The input data for MPGEP II includes the technology costs for new equipment, investment constraints, the generating capacity and investment/production costs of generating units, as well as the expected electric load and economic factors. Here, MPGEP II is described mathematically and parameters, constants, decision variables, constraints and objective functions used in the formulation are presented.

2.2.1 Indexes

Θ	Set of generation unit
L	Set of fuel
T	Set of time period in a planning horizon
q	An index representing type of generation unit for each $q \,\epsilon\, \Theta$
k	An index representing type of fuel for each $k \,\epsilon\, L$
t	An index representing different time period for each $t \in T$

2.2.2 Parameters of the model

T	set of periods in the planning horizon
r	discount factor (opportunity cost)
D_t	Expected load (MW) in period t
I_{qt}	Investment cost ($/MW) of a generation unit of type q in period t
G_{qt}	Generation (operation and maintenance) cost ($/MW) of a generation unit of type q in period t
GN_{qt}	Maximum (MW) generation capacity of proposed generation units of type q in period t
GE_q	Maximum (MW) generation capacity of existing generation units of type q
E_q	Tonnes of carbon dioxide emission (CO_2) per MW generated by a generation unit of type q
U_{kt}	National availability (corresponding units) of fuel type k in period t
W_q	fuel needed (units/MW) to operate a generation unit of type q
J_k	Index of units of fuel type k

2.2.3 Decision Variables

Three groups of decision variables in the model are:

gn_{qt}	Generation (MW) from new units of type q in period t
Q_{qt}	Added capacity of generation units of type q in period t
Y_{qt}	Cumulative capacity (MW) of unit type q in period t

2.2.4 Objective Functions

In this multi-objective model the minimization of the investment, operation cost, and environmental impact in terms of CO_2 emission of the whole system are considered.

- *Investment and operational cost.* This objective function is defined as the total present value sum of the investment cost for new units and the generation costs of new generation unit.

$$f_1 = \sum_{t\in T}(1+r)^{-t} \quad \left(\sum_{q\epsilon\Theta} I_{qt}Q_{qt} + \sum_{q\epsilon\Theta} G_{qt}\, gn_{qt}\right) \qquad (10)$$

- *Environmental impact*: Only the aggregate Carbon dioxide emission (CO_2) from fossil fuel plants is minimized. Thus

$$f_2 = \sum_{t\in T}\sum_{q\epsilon\Theta} E_q\, gn_{qt} \qquad (11)$$

2.2.5 Constraints

In MPGEP II, six (6) types of constraints are imposed; load balance, generation capacity, investment capacity, amount of available local fuel, cumulative generation capacity, and non-negativity of the decision variable. Such constraints are described below in details.

- Load balance equations in period t: The power generated in period t is equal to the power demand in period t.

$$\sum_{q\epsilon\Theta} gn_{qt} = D_t\ ;\ q\epsilon\Theta,\ t\epsilon T \qquad (12)$$

- Generation capacity for each unit type q during period t: Operating limits are imposed by the generation units.

$$gn_{qt} \le Q_{qt} + Y_{q(t-1)}\ ;\ q \in \Theta,\ t \in T \qquad (13)$$

- Maximum investment for each unit type q during period t: Because of natural reasons (space, resources, etc.), there is a maximum of investments in generation units.

$$\sum_{t\epsilon T} Q_{qt}{}^{t} \le \sum_{t\epsilon T} GN_{qt}\ ;\ q \in \Theta,\ t \in T \qquad (14)$$

- Fuel demand for each fuel type k: Fuel used will be from local markets (U_{kt}).

$$\sum_{t\epsilon T}\sum_{q\epsilon J_k} W_q gn_{qt} \le U_{kt}; \qquad k \in L,\ t \in T \qquad (15)$$

- Cumulative generation capacity for each unit type q during period t: The new generation capacity is accumulated through the horizon.

$$Y_{qt} = Y_{q(t-1)} + Q_{qt}\ ;\ q \in \Theta,\ t\epsilon T \qquad (16)$$

- Non-negativity: No negative values are permitted for the decision variables.

$$Y_{qt},\ Q_{qt},\ gn_{qt} \geq 0;\ q \in \Theta,\ k \in f,\ t \in T \qquad (17)$$

- Initial values

$$Y_{q0} = GE_q;\ \ q \in \Theta \qquad (18)$$

Since MPGEP I and II model are linear, it will be solved with the same methodology.

2.3 Framework to solve MPGEP I and II

The solution to the problem consists of four alternatives namely A, B, C and D. Alternative A is the ideal solution of the first objective while alternative B is the ideal solution of the second objective. Alternative C and D are solutions of equal weighted and lexicographic goal programming respectively. The goals are specified quantitatively using standard operating procedures. The goal of the cost objective function was determined from the average standard budget allocation of funds for the power sector in Nigeria over a nine (9) year period beginning from 2006-2014 [24]. The CO_2 emission goal was determined from the world standard CO_2 emission benchmark. According to [25, 26], Nigeria contributes about 0.3% of the world's 35,270 million tonnes of CO_2 emitted annually. It was determined that with increased generation capacity from different generation technology to meet the nation's electricity demand in 2030, overall CO_2 emission from new and existing units should be less or equal to 38.6 million tones, a value representing about 44 percent increase from the overall CO_2 emitted in 2013. The target values are imputed into the goal programming models. This solution provides a satisfactory decision vector for the decision maker.

Steps to solving MPGEP I and II

1) Determine the ideal solution of the first objective by minimizing the cost function subject to the model constraint without considering the CO_2 function. This solution makes alternative A.
2) Determine the ideal solution of the second objective by minimizing the CO_2 emission function subject to the model constraint without considering the cost function. This solution makes alternative B.
3) Here, the model is solved using equal weighted goal programming technique. Set the target goals and equate these goals to their respective function. Set the functions as constraint and minimize the cost deviation variable subject to the model constraint. Obtain the value of the cost deviational variable and set it as a constraint. Minimize the CO_2 deviational variable subject to the model constraint. The final results represent the solution to the problem. This solution makes alternative C.
4) Here, the model is solved lexicographically. Set the target goals and equate these goals to their respective function. Set the functions as constraint. Set equal weight on the deviational variables and minimize the deviational variable function. This solution makes alternative D.

III. MODEL APPLICATION

The Nigerian power scenerio was used as a case study to illustrate this model. Existing generation technologies with various capacities were determined using available data as provided by [11]. Performance data of new and existing generation technology as shown in Table 3 was obtained from [27]. Investment cost of each generation unit and its associated fuel consumption rate is presented in Table 4 and 5 respectively. Table 6 provides an estimate of the construction schedule time of each generation unit while Table 7, 8 and 9 present the fuel availability data, planning periods, and the economic components of the investment respectively.

Table 3. Performance data of generation units

S/N	Type of generation Tech.	Capacity, GN_q (MW)	Factor Availability	Fuel Type	Average Fuel Consumption		CO_2 Emission, E_q (Ton/MWh)
					W_q	Units	
1	Hydro	8500	0.70	Water	0.0000	No	0.0000
2	Wind	1000	0.40	Wind	0.0000	No	0.0000
3	Nuclear	5000	0.95	Nuclear	0.0222	Kg/MWh	0.0000
4	SC	2500	0.88	Gas	10.1000	MCF/MWh	0.1811
5	CC	5000	0.89	Gas	5.0500	MCF/MWh	0.1811
6	Coal	8000	0.92	Coal	0.5200	Ton/MWh	0.3328

Table 4. Cost data of generation units

S/N	Type of generation Tech.	Investment cost, I_q ±25%	Generation cost, G_q = Fixed O & M + Variable O & M	
			Fixed O&M, F_q	Variable O&M, V_q
		($/MW)	($/MWyr)	($/MWh)
1	Hydro	3500000	15000	6.00
2	Wind	1980000	60000	0.00
3	Nuclear	6100000	127000	0.00
4	SC	651000	5260	29.90
5	CC	1230000	6310	3.67
6	Coal	2890000	23000	3.71

Table 5. Fuel consumption data of generation units

S/N	Generation Technology	Fuel consumed per MWh		Fuel consumed per MW in 15 years
		W_q	Units	
1	Hydro	0.0000	No	0.00
2	Wind	0.0000	No	0.00
3	Nuclear	0.0222	Kg/MWh	2917.08 Kg/MW
4	SC	10.1	MCF/MWh	1327140 MCF/MW
5	CC	5.05	MCF/MWh	663570 MCF/MW
6	Coal Plant	0.52	Ton/MWh	68328 Tons/MW

Table 6. Construction schedule time of generation units

S/N	Generation Technology	Capacity (MW)	Construction schedule (month)
1	Hydro	500	24
2	Wind	100	12
3	Nuclear	1125	60
4	SC	211	30
5	CC	580	41
6	Coal Plant	606	55

Table 7. Fuel availability data

	Generation Technology	Fuel Type	Fuel availability	Units
1	Hydro	-	Unlimited	-
2	Wind	-	Unlimited	-
3	Nuclear	Uranium	5.0E+7	Kg
4	SC	Natural Gas	2.8E+13	MCF
5	CC	Natural Gas	2.8E+13	MCF
6	Coal Plant	Coal	1.4E+9	Tons

Table 8. Planning periods

Periods	Year
0	2015
1	2018
2	2021
3	2024
4	2027
5	2030

Table 9. Economic component [12]

Parameters		Rate (%)
Investment cost inflation		5
Generation cost inflation	Fixed O&M cost inflation	5
	Variable O&M cost inflation	5

3.1 Test and result of MPGEP I

The model consists of twelve (12) decision variables and eighteen (18) constraints. Lingo optimization program was used to solve the model. The Lingo program was installed on Core i3 dell laptop computer running under windows 8 operating system. Three (3) seconds was recorded as the average computational time.

Pay-off table of electricity generation cost and CO_2 emission for the different alternatives is presented Table 10. The cost component was spread into three parts as follows: investment, fixed operation/maintenance and variable operation/maintenance cost. The total cost component of alternative A is US$48 billion with CO_2

emission of 48.2 mega-tonnes. This cost showed a decrease of about US$2 billion from the targeted cost of US$50 billion with CO_2 emission exceeding the targeted bench mark of 38.6 mega-tonnes indicating a 25% increase. Alternative B yielded a reduced emission of 21.5 mega-tonnes but with an increased cost of $72.8 billion dollars. Alternative C and D yielded the same result with both maintaining the targeted emission value of 38.6 mega-tonnes at a cost of $49.5 billion dollars which is slightly less than the targeted cost.

Table 10. Resulting pay-off table of MPGEP I

	COST (US Dollars)				**EMISSION (Tones)**
Alternatives	Investment	O/M fixed	O/M variable	Total	
A	4.47E+10	3.60E+08	2.84E+09	4.80E+ 10	4.82E+07
B	6.74E+10	9.29E+08	4.44E+09	7.28E+10	2.15E+07
C	4.62E+10	3.88E+08	2.91E+09	4.95E+10	3.86E+07
D	4.62E+10	3.88E+08	2.91E+09	4.95E+10	3.86E+07

Added capacity by each technology in year 2030 is shown in Table 11. Here added capacity for nuclear technology is zero (0) for alternative A, while 3376, 1000, 2500, 5000 and 8000 MW where added capacity for Hydro, Wind, Nuclear, SC, CC and Coal technology respectively. Coal technology had zero (0) added capacity in alternative B while Hydro, Wind, Nuclear, SC and CC technology recorded 8500, 1000, 5000, 2500 and 2876 MW respectively. Both alternative C and D had zero (0) added capacity for nuclear technology while Hydro, Wind, SC, CC and coal had 6670, 1000, 2500, 5000 and 4707 MW respectively.

Table 11. Technology added by MPGEP I

	Added capacity (MW) by technology at year 2030					
Alternatives	**Hydro**	**Wind**	**Nuclear**	**SC**	**CC**	**Coal**
A	3376	1000	0	2500	5000	8000
B	8500	1000	5000	2500	2876	0
C	6670	1000	0	2500	5000	4707
D	6670	1000	0	2500	5000	4707

IV. Discussion

Without considering emission trading, alternative A provides the best result in terms of cost effectiveness. Here, 8000MW of coal technology is proposed for addition while only 3376MW of hydro power technology is proposed. This clearly shows that coal power technology is more cost effective than hydro power technology. Nuclear power technology was completely discouraged in this case. The choice of wind, SC and CC technology was fully recommended by the model. Alternative B proposes the addition of 5000MW of nuclear power while increasing hydro power capacity to 8500MW with a reduction of combined cycle (CC) technology to 2876MW. Being that the budgetary constraints representing the available fund for capacity addition and the CO_2 emission constraint has to be considered, alternative C and D provided the best compromise with respect to the targeted goals. In C and D, nuclear power technology was discouraged while only 4707 MW capacity of coal power was recommended for addition. The percentage generation capacity in terms of technology is shown in Figure 1.

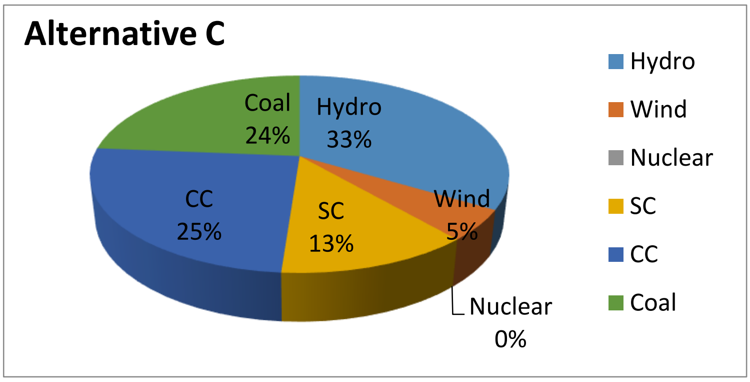

Fig. 1. Generation capacity by technology (Alternative C solution)

3.2 Test and result of MPGEP II

The model consists of ninety (90) decision variables and one hundred and eleven (111) constraints. Lingo optimization program was installed on a laptop computer and used to solve the model. Core i3 dell laptop computer under windows 8 operating system was used in this case. Three (3) seconds was recorded as the

average computational time. Fifteen (15) year planning horizon at three (3) year interval was used in the analysis as well as a discounting rate of 5% indicating the inflation rate of investment and generation cost.
Pay-off table of electricity generation cost and CO_2 emission for the different alternatives is presented as shown in Table 12. The cost component was spread into three parts as follows: investment, fixed operation & maintenance and variable operation & maintenance cost. The total cost component of alternative A is US$42.2 billion with CO_2 emission of 174 mega-tonnes. This cost showed a decrease of about US$7.8 billion from the targeted cost of US$50 billion with CO_2 emission exceeding the targeted bench mark of 150 mega-tonnes indicating a 16% increase. Alternative B yielded a reduced CO_2 emission of 97.1 mega-tonnes but with an increased cost of US$67.9 billion. Alternative C and D yielded the same result with both having reduced value of 146 mega-tonnes from the targeted emission value of 150 mega-tonnes at a cost of US$40 billion indicating a US$10 billion less than the goal. The cost and emission value of alternative C and D was considered satisfactory haven met the goals while satisfying the demand.

Table 12. Resulting pay-off table of MPGEP II

	COST (US Dollars)				**EMISSION (Tonnes)**
Alternatives	Investment	O/M fixed	O/M variable	Total	
A	3.41E+10	1.04E+09	7.13E+09	4.22E+10	1.74E+08
B	5.65E+10	1.96E+09	9.49E+09	6.79E+10	9.71E+07
C	3.44E+10	1.16E+09	4.41E+09	4.00E+10	1.46E+08
D	3.44E+10	1.16E+09	4.41E+09	4.00E+10	1.46E+08

Added capacity by each technology in year 2030 is shown in Table 13. Here, added capacity for nuclear technology is zero (0) for alternative A, while 3376, 1000, 2500, 5000 and 8000 MW where added capacity for Hydro, Wind, Nuclear, SC, CC and Coal technology respectively. Coal technology recorded a 2097MW added capacity in alternative B while Hydro, Wind, Nuclear, SC and CC technology recorded 8379, 700, 4000, 2000 and 2700 MW respectively. Both alternative C and D had zero (0) added capacity for nuclear technology while Hydro, Wind, SC, CC and coal had 6000, 1000, 0, 5000 and 7876 MW respectively.

Table 13. Technology added by MPGEP II

	Capacity (MW) added by technology (2030)					
Alternatives	**Hydro**	**Wind**	**Nuclear**	**SC**	**CC**	**Coal**
A	3376	1000	0	2500	5000	8000
B	8379	700	4000	2000	2700	2097
C	6000	1000	0	0	5000	7876
D	6000	1000	0	0	5000	7876

V. Discussion

Without considering emission trading, alternative A provides the best result in terms of cost effectiveness, here 8000MW of coal technology is proposed for addition while only 3376 MW of hydro power technology is proposed. This clearly shows that coal power technology is more cost effective than hydro power technology. Nuclear power technology was completely discouraged in this case. The choice of wind, SC and CC technology was fully recommended by the model. Alternative B proposes the addition of 4000MW of nuclear power while increasing hydro power capacity to 8379MW with a reduction of combined cycle (CC) technology to 2700MW. Being that the budgetary constraints representing the available fund for capacity addition and the CO_2 emission constraint has to be considered, alternative C and D provided the best compromise with respect to the targeted goals. In C and D, nuclear power technology was discouraged while 7876MW capacity of coal power was recommended for addition.

The two goal programming solution methods gave same results in all objectives. This further confirms the fact that no two goal programming solution method is better than the other, but the choice of one over the other is base on the user preference.

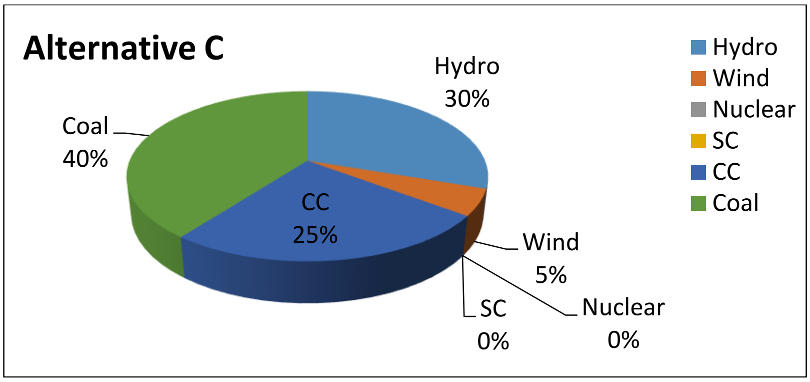

Fig. 2. Generation capacity by technology (Alternative C solution)

VI. CONCLUSION

Single-period and multi-period multi-objective power generation expansion planning models MPGEP I and MPGEP II respectively has been proposed. The MPGEP II model is an extension of MPGEP I model. The same methodology of solution for MPGEP I was used for solving MPGEP II and the results obtained were satisfactory. Each of the model considers two objectives which are: the cost function and the CO_2 emission function. The ideal solution of each objective was obtained as alternative A and B, and two goal programming technique (i.e., equal weighted and lexicographic method) was used to generate the best compromise solution for the two conflicting objectives based on the targeted goals. Both MPGEP I and MPGEP II model takes into account multiple evaluation aspect, demand side management issues and the modularity of expansion possibilities. The MPGEP I model is considered an approximation of the MPGEP II model while the MPGEP II model is the actual representation or the closest to the real problem. Therefore, the technological mix of MPGEP II model can serve as a reference for the decision maker in the power expansion planning problem.

VII. RECOMMENDATIONS

1. The MPGEP II model is recommended for use in the power generation planning problem of any nation.
2. An extension of the MPGEP II model to include more objectives like; risk analysis and system reliability of the different generating technology are recommended.
3. Demand side uncertainty can also be included in the model.

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