Objective criteria ranking framework for renewable energy policy decisions in Nigeria

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Abstract. We present a framework that seeks to improve the objectivity of renewable energy policy decisions in Nigeria. It consists of expert ranking of resource abundance, resource efficiency and resource environmental comfort in the choice of renewable energy options for large scale power generation. The rankings are converted to a more objective function called Resource Appraisal Function (RAF) using dependence operators derived from logical relationships amongst the various criteria. The preferred option is that with the highest average RAF coupled with the least RAF variance. The method can be extended to more options, more criteria, and more opinions and can be adapted for similar decisions in education, environment and health sectors.

1. Introduction

Energy is very important in the economic development of Nigeria as well as in the country’s diplomatic relations with other countries. Nigeria is currently witnessing a near energy crisis as deduced from current energy generation in the country. At present there are 11 power stations; 2 hydro-powers and 9 thermal, with total generating capacity of about 5,486 mW. There are also about 14 thermal stations under construction with projected capacity of about 4832mW [1]. This means that with a population of about 169,000,000 people, the energy per capita will only be 61x10⁻⁶ mW when the new power projects are realized; which is abysmally low when compared to the present energy per capita in other large economies of Africa such as South Africa (energy per capita = 650x10⁻⁶ mW) and Egypt (per capita = 262x10⁻⁶ mW) [1].

The abysmally low public energy generation in Nigeria is the reason for the current over reliance of the populace on petroleum products largely for generator-based electricity production. This is coupled with the use of petroleum as the traditional energy resource for transportation. The domestic price of petroleum products has been increased recently by the government causing a lot of social tension in the country. The diminishing public and household access to energy from the non-sustainable
petroleum-based public energy supply system is affecting economic activities in the country drastically [2, 3, 4], and also contributes to dwindling revenue generation in the country as most people are not willing to pay for unavailable, inadequate or unstable power supply which is presently the case [5].

The precarious energy situation in Nigeria had precipitated several calls for serious diversification of the country’s energy generation especially to the renewable options. Critical resource surveys show substantial renewable energy potentials across the country: A total of 278 unexplored sites for small hydropower plants that would each average between 2 mW and 10 mW when developed has been identified in the country; An average solar energy potential of about 5.5 kWhm\(^{-2}\)day\(^{-1}\) is estimated for the country, while a total biomass abundance of over 56 tones with energy value put at about 7.1x10\(^5\) MJ is estimated [6]. Agbetuyi et al. [7], in a study of 22 stations across the entire country deduced an annual average wind energy of 5458 kWhr\(^{-1}\) using the 10 meter blade rotor and 35,934 kWhr\(^{-1}\) using the 25 meter blade rotor (also see Dike et al. [8] and Okeniyi et al.[9]).

In addition to the major renewable energy resources (i.e. hydro, solar, biomass and wind) which have received very elaborate evaluations in the country, some less fancied renewable energy sources such as geothermal and biogas from various sources, have equally been appraised for integration into the renewable energy mix. Amoo [10] for instance evaluated the energy potential of geothermal sites in Nigeria and concluded that although the geothermal fields were generally of low energy values; their cumulative energy value was potentially considerable with the right technology. In the case of biogas, an appraisal of land-fill gas (LFG) potentials of government-operated landfills in Lagos by Idehai and Akuijeze [11], yielded a yearly energy resource of ~ 646,663.2 mWh, while Mohammed et al. [12], estimated in Lagos alone, a total renewable energy potential of 697.15TJ from crop residue, 455.80TJ from animal waste and 442mW from municipal waste. It has also been shown that the extensive aquatic macrophyte (water hyacinth) ; a plant that covers much of the water body in the Niger Delta area has huge renewable energy potential as a methane biogas resource [13]; the same applies to another plant known as Nipa Palm [14].

The reasonably large renewable energy resource potentials as considered above had served as basis for the articulation of a Renewable Energy Master Plan (REMP) by the Energy Commission of Nigeria (ECN) [15]. Actual development however is still within this policy stage due to lack of political will on the part of the government to do the needful [16]. Although several components which are expected to give boosts to policy implementation especially from the legal perspective have been suggested [17, 18], there are for sure, obvious environmental and economic challenges of executing the REMP in an extensive and all-inclusive form as can be deduced from the study by Okedu [19].

Government seeming inertia for large scale development of renewable energy in the country could then be persisting due partly to the obvious scarcity of technical resources to achieve elaborate diversification. This problem can largely be addressed by optimizing the logic of choice [20, 21], through the construction of objective frameworks that draw from both science and economics to enhance renewable energy development policy decisions.

From basic renewable energy economics [22], such an objective framework for renewable energy choices must be interfaced with the following major issues as previously noted [21], which in a more recent study, such as [23], are described in terms of ecological, economic and social sustainability indicators:

- Resource abundance or availability
- Financial and technical capacity
- Environmental concerns

2. The criteria framework

Following the above issues, the development of methodologies for energy decision framework by criteria ranking had been introduced [20, 21]. The present method is specific to renewable energy
options and introduces more parameters geared towards raising the objectivity and reliability of the method.

The following underlying parameters and functions are required in the new framework:

2.1 Resource Appraisal Criteria (RAC)

The Resource Appraisal Criteria (RAC) are the key factors identified as the basis for making choices on the use of a renewable energy option for large scale energy power generation (or for small scale generation as the case may be) in a country. For clarity these are:

- **Resource Abundance** (represented by symbol; α) - referred to as the level of natural abundance of the renewable energy resource.
- **Resource Economy** (represented by symbol; β) - referred to as the cost efficiency of the resource energy conversion process i.e. energy output generated from the invested cost. This criterion is obviously determined by technological capacity.
- **Resource Environmental Sustainability or Resource Environmental Comfort** (represented by symbol; ϵ) - referred to as the aggregated environmental impacts of utilizing the resource for energy generation.

2.2 Resource Appraisal Parameter (RAP)

As previously proposed in Nwofor et al. [21], we define an objective parameter called Resource Appraisal Parameter (Ƞ), a function of the energy resource criteria ($\mu_i$) i=1, 2, 3…n criteria as:

$$\text{Ƞ} = f(\mu_i)$$

(1)

For the three RAC considered in this work, we assign for Resource Abundance ($\mu_1 = \alpha$), for Resource Economy ($\mu_2 = \beta$) and for Resource Environmental Sustainability (Resource Comfort) ($\mu_3 = \epsilon$), Equation 1 can then be written as:

$$\text{Ƞ} = f(\alpha, \beta, \epsilon)$$

(2)

2.3 Criteria Weighting Parameters (CWP) and Aggregated Weighted Parameter (AWP)

RAP is essentially weighted in the various criteria with Criteria Weighting Parameters (CWP) of weights, $\omega_1, \ldots, \omega_n$. The CWP is presented in the form of number ranking between 1 - 5 as follows; Very Low ranking (VL) - 1, Moderately Low ranking (ML)-2, Average ranking (A) – 3, Moderately High ranking (MH) – 4, and Very High ranking (VH) – 5, specific to a given locality such as state, region or country reflecting expert perceptions, such that it’s magnitude increases with expert opinion preferences as given from the weights assigned.

In addition we expect the appraisal parameter for an energy option such as solar, tide, biomass or nuclear to be additive for all criteria, hence by applying the weights, we have the Aggregated Weighted Parameter (AWP) for an option as:

$$\text{Ƞ}_i = \sum_{i=1}^{n} \omega_i \mu_i$$

(3)

Or in the present case as:

$$\text{Ƞ}_i = \omega_\alpha \alpha + \omega_\beta \beta + \omega_\epsilon \epsilon$$

(4)

2.4 Logical Dependence Operator (LDO)

The Logical Dependence Operator (LDO) denoted by $\Omega$, is introduced to infuse objectivity to the CWP, by a simple process of “interdependence” mapping analogous to logical mapping, which in general terms, translates a temporal relation based on mutually causal dependencies [24]. The LDO allows for the synchronization of the expert-assigned weights to more global expectations thereby checking the inherent subjective nature of the preference ranking method.

One key outcome of the dependence mapping framework is the fact that although renewable energy resources are said to be environmental friendly, they are not exploited and utilized at zero impact to the environment. LDO is therefore derived by exploiting the logical interdependence of the different criteria (see figure 1).
From figure 1, economy ~ efficiency (β) is directly derived from abundance (α), i.e.
\[ \Omega (\alpha) \rightarrow \beta \] (5)
This is obvious from first principles since efficiency; \[ \beta = \frac{\text{Energy Output}}{\text{Cost Input}} \], and energy is a function of mass (abundance), β has a first order dependence on α; and resource abundance determines resource efficiency and not vice versa.

On the other hand, improved efficiency of energy utilization -from improved technology- reduces stress on the environment. Miniaturization for instance which these days comes with improved technology reduces the space used up for solar and wind installations. In the case of tidal power generation, improved technology may reduce coastal flooding, and would reduce geological failures in the case of geothermal reservoirs, \( \epsilon \) therefore depends on \( \beta \) in the first order, i.e.;
\[ \Omega (\beta) \rightarrow \epsilon \] (6)
And by using equation 5 in equation 6, \( \epsilon \) depends on \( \alpha \) in the second order, i.e.
\[ \Omega^2(\alpha) \rightarrow \epsilon \] (7)

Although therefore we may see environmental friendliness as the basis for renewable energy development, abundance and economy of utilization (technical capacity) may be much more important criteria for accepting a given renewable energy resource.

2.5 Resource Appraisal Function (RAF)
Using \( \epsilon \) as basis criteria, and assigning the highest power of the weighting parameter corresponding to the given criteria interdependence mapping, the transformation: \( \text{CWP} \rightarrow LDO \) will yield: \( \omega_\alpha \rightarrow \Omega^2 \), \( \omega_\beta \rightarrow \Omega \), \( \omega_\epsilon \rightarrow 1 \).

\( LDO \) converts the weighted Resource Appraisal Parameter (RAP) to a function, which we call the Resource Appraisal Function (RAF).

Hence equation 4 becomes:
\[ \eta_i = \Omega^2 \alpha + \Omega \beta + \epsilon \] (8)

3. Sample implementation of the framework

Figure 2 is a program implementation scheme of the proposed criteria ranking framework. It begins with identification of the resource appraisal criteria (RAC) for the problem. Then the initial ratings of experts are assimilated into a resource appraisal parameter (RAP). The operational flexibility of the method permits at these two stages the imputation of more options, ranking criteria and expert opinions. The criteria weighting parameters (CWP) i.e. weights are applied and the results summed up in the aggregated weighted parameters (AWP). Without any established logical interdependence of the criteria the AWP might be averaged at this stage for the number of opinions and used to inform decision; otherwise, the logical dependence operator (LDO) is derived and imputed to generate the resource appraisal functions (RAF) which are then used to arrive at the decisions.

Table 1 is a sample decision response table from three experts on each of the 4 renewable energy options being considered for Nigeria. The table shows the preferences in the opinions in the assigned weights (\(\alpha, \beta, \text{ and } \epsilon\)), the evaluated Resource Appraisal Parameter (\(\eta_i\)) the Average (\(<\eta>\)) and the Variance (\(\text{VAR}\)) for the three opinions. The opinion with the highest series maximum for the RAF is the preferred option. The significance of the variance in the method is that it signifies the level of agreement in the opinions. Hence lower series variance accompanying large RAF is important.

In figure 2, the plots of the RAF derived using the operator function on RAP is shown for the same energy options. Fig 2 shows similar trends in the maximum value of the RAP and RAF. However, a slight modulation of the RAP is obvious in the plotted RAF reflecting a more universal logic in the appraisal. The variance can easily be evaluated from the plots.

4. Conclusion and outlook

The “Objective Criteria Ranking (OCR) Framework” has been introduced. The method aims at enhancing the objectivity of renewable energy decisions in Nigeria by ranking the important choice criteria for renewable energy options objectively. It basically employs a generating function called the Resource Appraisal Function with all the parameters and functions used for its determination fully explained and a sample graphics result using three opinions on four renewable energy options have been provided.

The framework introduced in this paper is inherently robust since it can be expanded for more energy options, more criteria, and more expert opinions and can also with suitable modifications be used for decision making in other sectors such as education, health and environment. This later possibility requires one to appreciate the tenets of the general decision problem, to which the presented methodology belongs.

A Decision Problem generally involves making of choices from a number of options or alternatives for the purpose of prompting action on a problem. It draws from the truism that whereas theoretically, the existence of a “best” decision might be argued, a “most objective” decision would not be in contention once the logic is established. One of the earliest formalizations of the Decision Problem is found in Participatory Appraisal which as a bottom-up framework [25, 26], utilizes community-based solutions to decision matters as had been used extensively in health as in [27], and in rural agricultural decision problems as in [28]. For decision problems in specialized areas such as education, health and the environment, expert opinion is however preferred and decisions can be reached by aggregating expert opinions ranking; analogous to having a team of doctors in an operating theatre as against just one [29, 30].
Identify Resource Appraisal Criteria (RAC) for options under consideration RAC → α, β, ε

Rate appraisal criteria using expert opinions

RAP → η = f (α, β, ε )

Apply CWP i.e. weights (ω₁...ωₙ ) and aggregate

AWP→ηᵢ = ωᵦα + ωββ + ωₑε

Average ηᵢ for m opinions and compute opinion Variance

RAW SCORE →<η> and VARIANCE

Impute LDO (Ω)

RAF→ηᵢ = Ω²α + Ω β + ε

FINAL DECISION

This loop may include more options, criteria and opinions

Without impute from LDO

Figure 2. Program implementation scheme of the Objective Ranking Framework

Table 1. Decision Response Table from three experts for 4 renewable energy options in Nigeria (adapted from Nwofor et al. [21])

| Resource Option | Expert Opinion | α  | β  | ε  | ηᵢ | <η> | (VAR)² |
|-----------------|----------------|----|----|----|-----|------|--------|
| Biomass         | 1              | 5  | 4  | 5  | 14  |      | 2.10   |
|                 | 2              | 4  | 1  | 3  | 8   | 10.3 | 1.32   |
|                 | 3              | 4  | 2  | 3  | 9   |      | 0.75   |
| Hydro           | 1              | 3  | 4  | 4  | 11  |      | 0.23   |
|                 | 2              | 2  | 4  | 5  | 11  | 10.6 | 0.23   |
|                 | 3              | 3  | 3  | 4  | 10  |      | 0.34   |
| Solar           | 1              | 5  | 3  | 5  | 13  |      | 0.80   |
|                 | 2              | 5  | 1  | 5  | 11  | 11.6 | 0.30   |
|                 | 3              | 4  | 2  | 5  | 11  |      | 0.30   |
| Wind            | 1              | 2  | 1  | 3  | 6   |      | 0.80   |
|                 | 2              | 3  | 1  | 5  | 9   | 7.3  | 0.90   |
|                 | 3              | 3  | 2  | 2  | 7   |      | 0.20   |
The following possible applications of OCR in education, health and environment, may then suffice:

- **Education**: OCR can be applied in educational decision making in developing countries. In Nigeria, a good example exists in early childhood education in which Sooter [31], had identified access (availability of affordable education), content (curriculum provisions), and teacher competence as major issues. Given the scarce resources in the country, OCR can be usefully applied in appraising the three criteria for the purpose of prioritizing intervention in an objective manner.

- **Health**: The health sector like education is highly specialized and so many issues are decided on the basis of decision optimization. An example is found in Gnanlet and Gilland, [32], which discussed the optimal resource levels required to meet health care demands in a hospital.

**Figure 3.** Graphics results of the implementation of the framework using the data of Table 1

Data Plots: blue-opinion series 1; red-opinion series 2; green-opinion series 3
setting within sequential and simultaneous criteria paradigms— with very useful conclusions. In Nigeria where the issue of health financing has become highly vexed especially with regard to sourcing of required funds (see for instance, [33]), OCR will come handy in choosing whether to anchor funding on government, private enterprises or on external aid agencies. OCR might equally be adopted by the political class in choosing their target social group for health care insurance financing.

- **Environment:** With regard to environmental issues, OCR is easily applicable. One area of need in a country like Nigeria is waste management where the cost of effectively managing waste is far above the resources committed for the process as had been argued by Fadare and Afon [34]. There is a range of policy choices available to individuals, groups and governments with regard to waste management. These include disposal by incineration, landfill, or recycling. But the various waste disposal choices are commonly constrained by social conditions such as poverty. Hence the search for sustainability in the sector in the country should not just be based on environmental concerns alone but be linked with purchasing power as well [35, 36]. Decisions on waste disposal policy in various areas in the country can therefore be optimized using OCR.

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