Impact of Electricity Sector in the Human Development of Cameroon Based on Particle Swarm Optimization Technique

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IMPACT OF ELECTRICITY SECTOR IN THE HUMAN DEVELOPMENT OF CAMEROON BASED ON PARTICLE SWARM OPTIMIZATION TECHNIQUE

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ABSTRACT: Having access to electricity is one of the big challenges nowadays. Indeed, electricity plays a major role in the economic and social development in many countries. The United Nations are working to ensure an easy access to safe energy technologies as from 2030. To cope with this point of view, this paper aims to establish an accurate relation between the access to electricity and the Human Development Index (HDI). In this case, we use an optimization technique based on the algorithm of Particle Swarm Optimization (PSO). The document shows an assessment parameter for HDI of 0.68 in 2030. The result obtained is closed of the theoretical value predicted by the Electricity Sector Development Plan. Thus, this helps to appreciate the impact of energy on the social and economic development of Cameroon.

KEYWORDS: Electricity, HDI, PSO, development

1. Introduction

The access to energy services is an answer to basic social needs for a country, thus to its economic development. Indeed, energy, in particular electricity, has an impact on productivity, health, education, water, and communication [1]. In addition, the energy per living and electricity consumption rely highly on economic development and others modern life indicators. These indicators are based on the hypothesis that the electricity consumption depends on life well-being and good health [2]. The essential characteristic of the energy, and the emphasis developed to his access are the main contributors to the economic growth, the reduction of poverty and inequalities [3].

Since decades, the United Nations for Development Project computes the Human Development Index (HDI) as a key indicator to assess the level of development of countries. This social factor classifies countries based not only on the economic growth, but also on the qualitative development. The HDI is a summary of three data series: (1) Health to assess the contribution of material needs such as food, water, homes, hygiene, and medical care. (2) Knowledge which is measured by the average level of people of more than 25 years going to school. It shows the contribution of non-material needs such as the ability to participate to decisions-making in various workplaces. (3) The level of life which consists of elements of good life quality not described by the two previous criteria such as mobility or access to culture. The development of a society depends on the energy consumption and energy production. Thus, energy plays an important role in the quantification of the HDI for developing countries. Furthermore, energy is considered as a requirement to the sustainable development, eradication of poverty and inequality [4][5][6]. Many studies have been developed on the potential impact of such consideration. It is known that the electricity consumption depends highly on the HDI and Gross Internal Product over 120 countries [5]. Studies revealed that countries with high level of electricity consumption are ranked among the best in terms of economic activities and HDI. In some countries, the electricity consumption improves the human development [7]. Furthermore, it is crucial to the welfare of population in developing countries [8]. A correlation study shows a strong dependence between the energy consumption and the HDI for over 120 countries [9]. The study concluded that a slight increase in energy access is associated with improvement in human development for poor countries. Economic crisis and a rise in electricity prices are reported to have harmful welfare consequences among the lower-income group [10]. Though electricity consumption is generally good for both the poor and the rich, however, an increase in electricity prices affects the livelihood of the poor compared to the rich. It is argued that energy poverty based on inadequate access to modern energy services is a direct consequence of income poverty [11]. The inability of the poor to pay for energy services exacerbates poverty situations and widens the inequality gap between the poor and the rich. In a panel of 15 developing countries, it is reported that energy prices induce HDI but electricity consumption has no short-term impact on it [12]. However, in the long term, electricity consumption is found to positively impact HDI. There exist a handful of studies that consider the impact of electricity consumption on poverty, inequality, quality of life or HDI. The few studies reviewed largely point to the view that electricity access is good for the poor. However, the effect of political economy on the nexus between energy consumption and HDI has not been investigated. In developing countries, the government plays a major role in building and pricing energy infrastructure [13], hence, the distribution and access to electricity are more often a political decision. Energy policy, therefore, remains a net political gain rather than efficiency and economic rationality [14]. This is the case in developing countries where the government largely subsidizes the prices of energy. In sub-Saharan Africa, issues of energy are key agenda on political declarations and campaigns. Politicians promise to reduce energy prices and to extend electrification, especially in rural areas.

As a result, government inefficiencies extend to the energy sector especially as leadership appointments in the sector are done by the government. It is argued that energy has become political due to the increasing demand (influenced by economic growth) for energy, especially in emerging economies [15]. This induces an increased cost that encourages the government to subsidize the price in order to improve accessibility and affordability especially to the poor. In this paper, we examine the impact of electricity access, HDI and political system environment on income inequality. We further examine whether governance environment moderates the electricity access- income inequality relationship.

Hence, studying this indicator is of a vital scientific interest. Several researches aim to present a relation between this parameter and the energy development of a country. Cameroon, a developing country, and which is the study case, shows a low progression of this human factor. This justifies the various projects launched in the country to improve the access to electricity and thus the development.

The aim of this work is to show the dependency of development with energy sector by computing the HDI in 2030. Indeed, the result obtained is closed to the theorical value predicted by the Electricity Sector Development Plan. To reach our purpose, we use the data series of electricity production and consumption transversally related to the HDI and irregularly spaced in time. The series data are from 1990 to 2019. The quantitative evidences of impact of electricity on the economic development justify this study. To achieve our goal, we use the optimization technic PSO, to predict the value of the HDI in 2030.

Furthermore, this paper is structured as follow: Section 2 presents the material and methodology used; Sections 3 and 4 describe the results and conclusion respectively.

2. Data description and Methodology

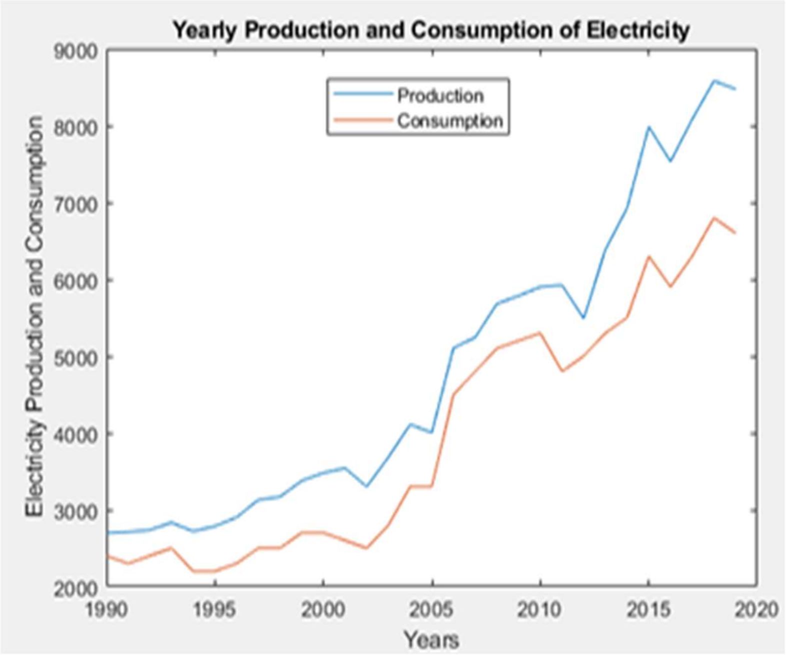
2.1. Electricity consumption and production in Cameroon

Cameroon, a developing country, have had in 2019 a total electricity consumption of 5600GWh and 8505GWh electricity production. This shows an increase of 3399GWh in terms of production, compared to 2006 when ***Electricity Sector Development Plan*** (***ESDP***) has been launched.

Figure 1 shows the yearly electricity consumption and production in Cameroon from 1990 to 2019 [16]. It is interesting to note that the production is the sum of both renewable and conventional energy sources. The various sources are: biofuels, natural gas, oil, hydroelectricity, photovoltaic which part on the total production is less than 1% [16]. It presents the predominance of production over consumption within the years. Nevertheless, the country is still suffering from energy deficit. It would therefore be interesting to focus on the impact of electricity production and consumption on the human development by computing the HDI, especially in 2030. This will help to show a significant dependency of social development with energy, namely electricity both in terms of production and consumption.

Figure 1

Annual electricity production and consumption in Cameroon from 1990 to 2019



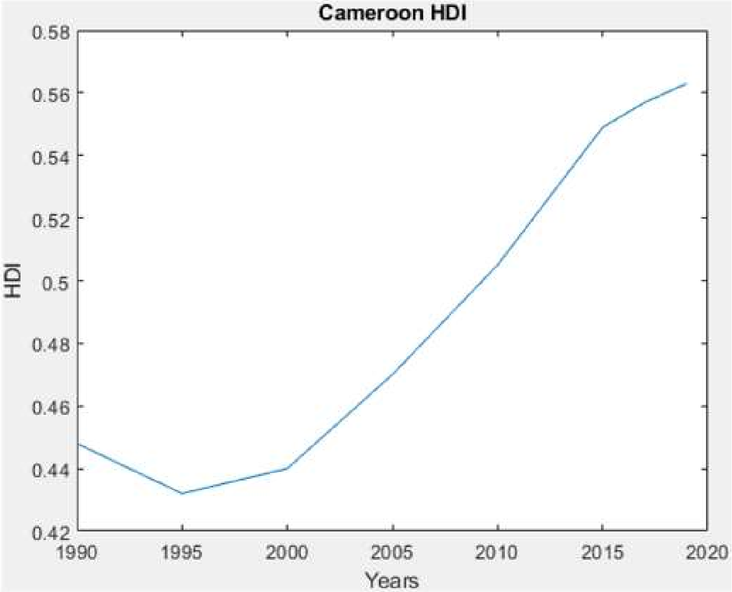
2.2. Human Development Index in Cameroon

In 2019, the HDI in Cameroon was 0.53. This ranks the country 153rd among the 189 countries in the World. It increased by 0.115 compared to 1990 when the country has not yet launched major development projects.

Figure 2 shows the evolution of the HDI in Cameroon from 1990 to 2019 [17]. Knowing the HDI consists of three elements namely: health, knowledge and level of life, the correlation of this factor with electrical energy (both production and consumption) is very great in Cameroon, developing country. It shows a necessity to emphasize on the energy sector to increase the economy.

Figure 2

Evolution of HDI in Cameroon from 1990 to 2019



2.3. Generalities on Human Development Index

In general, the Human Development Index (HDI_{yz}) is used as a statistical tool to scale a nation's general achievement in its social and financial measures. HDI is the sum of elements “y” and control approach “z” evaluated based on given equation. In this paper, consider that a division of yearly surplus energy can be used by small workshops, new trades, employment that can reform the standard of living and consequently the HDI. The surplus energy which is generated by non-conventional sources which cannot be utilized, i.e., surplus energy is energy generated during every hour by non-conventional sources such as biomass generator, wind turbines and PV system which cannot be consumed by AC load because AC load is less than production and it is as of now secured. Such surplus energy can't be stored in the battery bank of the system since it is completely charged. Part of the surplus energy can be utilized by AC additional loads which were not considered when the load was characterized. Thus, surplus energy generates new business and jobs. The author developed an equation for logarithmic dependence by using 128 nations' data through the various parameters [18].

$$HDI = 0.091 \ln\left[P_{LY}/_{C}\right] + 0.0724 HDI_{y,z} = 0.0978 \ln\left[\frac{P_{LOAD} + \min\left(f_{max_{SE}}.P_{SE}, f_{max_{PLOAD}}.P_{LOAD}\right)}{n_{HUMAN}}\right] - 0.0319 f_{max_{SE}} \tag{1}$$

Where:

$P_{LY/C}$ = Yearly electricity Consumption per capita in kWh/yr/person

$f_{max_{SE}}$ = Element of maximum surplus energy which may be utilized for AC additional load

$f_{max_{PLOAD}}$ = Element to increase yearly AC load in order that the maximum surplus energy utilized by the additional AC load may not be superior to that product

P_{SE}= Yearly surplus energy of the system in kWh/yr

n_{HUMAN} =Number of humans which consume the generated power through the hybrid system.

2.4. PSO Approach

Particle swarm optimization algorithm is a stochastic optimization technique based on swarm, which was proposed by Eberhart and Kennedy (1995). PSO algorithm simulates animal's social behavior, including insects, herds, birds and fishes. These swarms constitute a cooperative way to find food, and each member in the swarms keeps changing the search pattern according to the learning experiences of its own and other members.

PSO performance is comparable to genetic algorithms or ant colony algorithm since it is faster and less complicated; it has also successfully been applied to a wide variety of problems. It is simple to implement and is a very efficient global optimizer for continuous variable problems [19].

The PSO algorithm consists of three main steps as follows:

- Evaluate the fitness of each particle
- Update individual and global best finesses and positions
- Update velocity and position of each particle

Each particle remembers the best fitness value it has achieved during the operation of algorithm. The particle with the best fitness value compared to other particles is also calculated and updated by iterations. The process is repeated until some stopping criteria, such as number of iteration or predefined target fitness value, are met. The position of each particle in the swarm is updated using the following equation:

$$x_{k+1}^{i} = x_{k}^{i} + v_{k+1}^{i} \qquad (2)$$

Where x is particle position and v is particle velocity in iteration k. The velocity is calculated as follows:

$$v_{k+1}^{i} = k \times [v_{k}^{i} + c_1 r_1 \left(p_{k}^{i} - x_{k}^{i}\right) + c_2 r_2 \left(p_{k}^{g} - x_{k}^{i}\right) (3) \qquad k = \frac{2}{2-\emptyset-\sqrt{\emptyset^2-4\emptyset}} \quad (4)$$

$$\emptyset = c_1 - c_2 \emptyset > 4 \; (5)$$

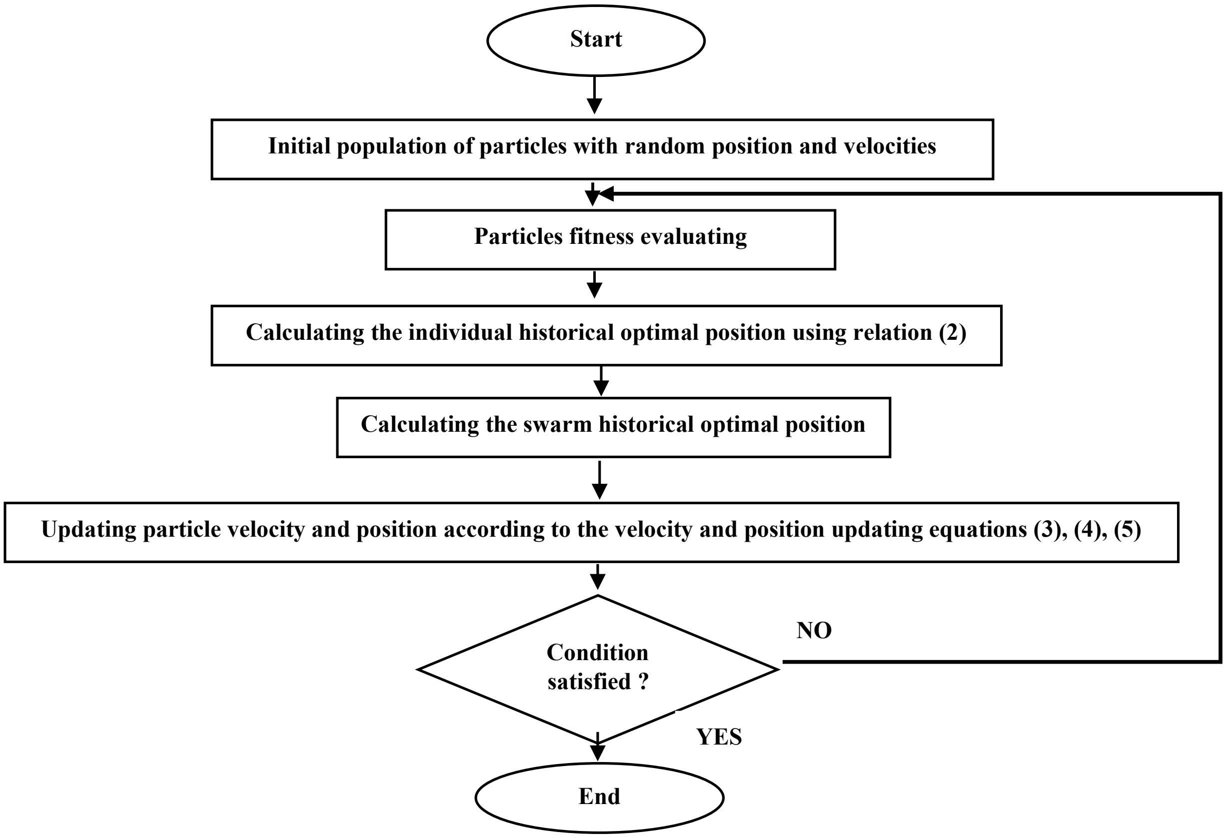
Where,

- p^i is the best individual particle position and p^g is the best global position, c_1 and c_2 are cognitive and social parameters, r_1 and r_2 are random numbers between 0 and 1.
- v_k^i, called inertia, it makes the particle move in the same direction and with the same velocity.
- $c_1r_1(p_k^i - x_k^i)$, is the cognitive component, causing the particle return to a previous position in which it has experienced high individual fitness.
- $c_2r_2(p_k^g - x_k^i)$, is the social component, causing the particle tend to return to the best region the swarm has found so far and to follow the best neighbor direction. If $c_1 >> c_2$ then each particle is much attracted to individual best position, in the contrary, if $c_2 >> c_1$, then particles are more attracted to global best position. In this study the value of certain parameters is optimized by using PSO.

Figure 3 below describes the flowchart of the PSO:

Figure 3

Flowchart of the particle swarm optimization algorithm



2.5. PSO based approach for calculating HDI

In this section, we compute the HDI using the relation (1). Knowing this factor depends on electricity, let us express **HDI** **Practical** as an electrical linear function of the HDI such that:

HDI **Practical = Alpha** * HDI(x,y);

Where:

x and y denote respectively the two parameters $f_{max_{SE}}$ and $f_{max_{PLOAD}}$.

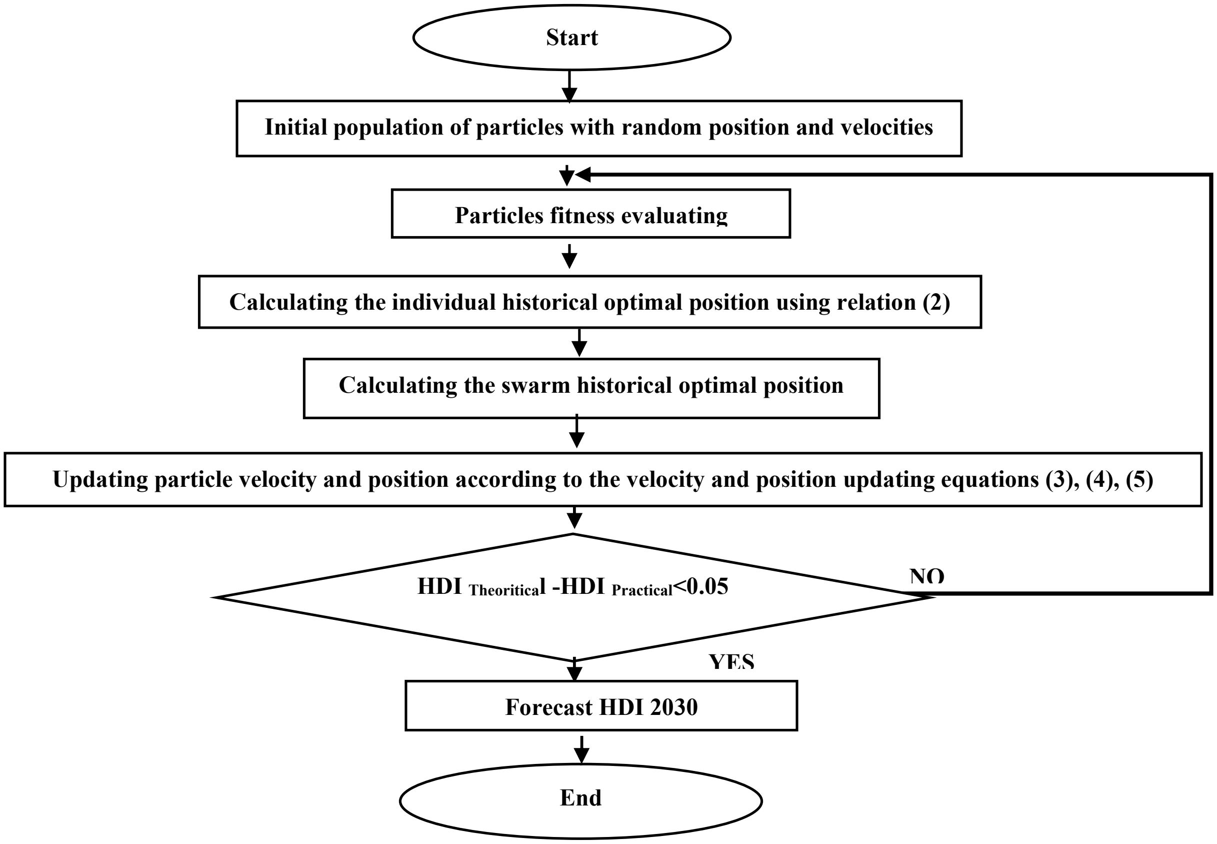
Alpha denotes the linear dependency coefficient of the HDI with the electricity.

These parameters are determined using the PSO and the error of convergence of the algorithm is set at 5%.

Figure 4 presents the flowchart to evaluate the HDI based on PSO algorithm:

Figure 4

Flowchart for the computation of the HDI parameters using PSO



3. Results and discussions

This section presents the optimal values of the parameters of the model to compute the HDI of Cameroon as a case study using PSO optimization technique. The values obtained argue the fact that development of a country relies on electricity sector, especially the electricity production. MATLAB (2009a) has been used in implementing this work. For PSO, the population size, swarm size and class size have been taken as 100 and the number of iterations is 150. The maximization of multi-objective function (Fmulti-objective) is considered for each iteration using PSO; hence the optimal solutions are obtained according to the best value of the multi-objective function. The error for the exit condition is set at a maximum of 0.05. To find the minimum value of the multi-objective function (Fmultiobjective) is the main objective and the significance of feasibility for the objective indices is determined by the best value of (Fmulti-objective). Different simulation cases are shown below:

3.1. Case 1: Different values of iterations

This section presents the results obtained for different values of iterations of the algorithm in Table 1. In this case, we will set the number of populations at 100 and the limit of convergence at 0.05.

Table 1

The HDI function parameters and results of simulation for various cases of iterations

Cases	Number of iterations	Parameter x	Parameter y	HDI 2030
Case 1	50	0.90687	0	0.6810
Case 2	100	0.94842	0.015492	0.6813
Case 3	1000	0.90804	0.00497888	0.6816

Results show that increasing the number of iterations has an impact on the results. Furthermore, it becomes less accurate when the number of iterations is higher. Like what, taking the number of iterations at 100 can be more reliable.

3.2. Case 2: According to population

In this section, the results obtained according to population are presented in Table 2. In this case, we will set the number of iterations at 100 and the limit of convergence at 0.05.

Table 2

The HDI function parameters and results of simulation for various cases of populations

Cases	Number of populations	Parameter x	Parameter y	HDI 2030
Case 1	50	0.95721	0.0048749	0.6796
Case 2	100	0.94842	0.015492	0.6813
Case 3	1000	0.94247	0.12376	0.6811

Results show that increasing the population also has an impact on the results. Also, we notice that it becomes less accurate when the population is higher. Like what, taking the population at 100 can be more reliable.

3.3. Case 3: Different values of limit of convergence

In this section, the results obtained for different values of limit of convergence are presented in Table 2. In this case, we will set the number of iterations at 100 and the limit of convergence at 0.05.

Table 3

The HDI function parameters and results of simulation for various cases of number of limits of convergence

Cases	Limit of convergence	Parameter x	Parameter y	HDI 2030
Case 1	0.1	1	0	0.7398
Case 2	0.07	0.97104	0.056749	0.7102
Case 3	0.05	0.94842	0.015492	0.6813

Results show that decreasing the limit of convergence also has an impact on the results. Also, we notice that it becomes more accurate when the limit of convergence is lower. Like what, taking the limit of convergence at 0.05 can be more reliable.

From all the 3 cases studied above, we can notice that we have accurate results with a number of iterations at 100, a number of populations at 100 and a limit of convergence at 0.05. Moreover, the analysis shows that the development depends mainly on electricity production. Henceforth, this justifies the various projects launched in the country to improve the energy production, thus the development index in the country. The HDI in 2030 is then evaluated at 0.68 compared to the value predicted by the ESDP which predicts it at 0.70, regarding the context of the country.

Furthermore, knowing the parameter x is related to the electricity produced, we hence can validate the assertion mentioned on relation between development and electricity production.

4. Conclusion

This paper presents the correlation that exists between human development of a country and the energy sector. The work is based on an optimization technique, the Particle Swarm Optimization. Using the formula of the HDI, the algorithm computes the two parameters x and y related to the energy production and consumption. A summary of results obtained by considering the data of HDI, electricity production and consumption in Cameroon from 1990 to 2019 and involving three different cases are discussed. Optimal configurations of parameters have been obtained using PSO for the objective function involving various separate objectives. The social parameter HDI attributes is explored in the optimal design of system. The results indicate that in all cases the best solution is obtained. We then predict the value of the HDI on 2030 which gives approximately 0.70, closed of the value presented in the EDSP.

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