American Journal of Energy Engineering
2022; 10(1): 10-20
http://www.sciencepublishinggroup.com/j/ajee
doi: 10.11648/j.ajee.20221001.12
ISSN: 2329-1648 (Print); ISSN: 2329-163X (Online)

SciencePG
Science Publishing Group

Selection of Optimal Locations for Electricity Generation Using Concentrated Solar Power Technologies in Ghana

Richmond Kwesi Amoah[1, *], Solomon Nunoo[2], Joseph Cudjoe Attachie[2]

[1]Renewable Energy Engineering Department, University of Mines and Technology, Tarkwa, Ghana
[2]Electrical and Electronic Engineering Department, University of Mines and Technology, Tarkwa, Ghana

Email address:

rkamoah@umat.edu.gh (R. K. Amoah), snunoo@umat.edu.gh (S. Nunoo), jcattachie@umat.edu.gh (J. C. Attachie)
[*]Corresponding author

To cite this article:

Richmond Kwesi Amoah, Solomon Nunoo, Joseph Cudjoe Attachie. Selection of Optimal Locations for Electricity Generation Using Concentrated Solar Power Technologies in Ghana. *American Journal of Energy Engineering*. Vol. 10, No. 1, 2022, pp. 10-20.
doi: 10.11648/j.ajee.20221001.12

Received: February 23, 2022; **Accepted**: March 23, 2022; **Published**: March 29, 2022

Abstract: The selection of an optimum location for the installation of a Concentrated Solar Power (CSP) plant is very vital to its overall performance. Any selected location should suitably satisfy some favourable selection criteria such as high direct normal irradiance, high ambient temperature, lower wind speed, lower level of cloud cover and availability of a source of water. In this paper, the selection of an optimal location(s) for a CSP plant in Ghana is achieved using the Analytical Hierarchy Process (AHP) for the weighting of the selected criteria and then using a set of Multi-Criteria Decision-Making (MCDM) methods for the ranking of the various alternatives. The MDCM methods used in this work include the Vise Kriterijumsa Optimizacija I Kompromisno Resenje (VIKOR), Technique for Order of Performance by Similarity to Ideal Solution (TOPSIS), and Complex Proportional Assessment (COPRAS). The results indicate that VIKOR and COPRAS gave very closely related rankings while some of the rankings for the COPRAS were not closely related as compared to the other two methods. However, all three methods ranked Bawku, a town in the Upper East region of Ghana, as the most suitable location for the installation of a CSP plant. The other suitable locations, i.e., Navrongo, Yendi, Wa, Bolgatanga and Savelugu, for the installation of a CSP plant are in the northern part of the country.

Keywords: Concentrated Solar Power, Direct Normal Irradiation, Analytical Hierarchy Process, Optimum Location, Electricity Generation

1. Introduction

Electricity plays a significant role in the economic growth of every country [1]. The availability of reliable and affordable energy is critical to the development of every country. Ghana, just like many other Sub-Saharan African countries, is rich in renewable energy resources, but have not been able to fully exploit these resources for the generation of electricity, heating, and other purposes [2, 3].

The contributions of renewable energy to the global energy supply have increased significantly over the past few years [4]. The most abundant renewable energy source, the Sun, provides over 150,000 terawatts of power to the earth [5]. However, the solar heat that reaches the surface of the earth is reduced because most of it is scattered, reflected, or absorbed by the atmosphere [6, 7]. Also, about 30% of solar radiation is reflected without being absorbed by the atmospheric components or the surface of the Earth [8]. Consequently, the amount of power received at any location, orientation and time depends upon the relative position of the Sun and the Earth [9].

Solar energy systems have become a viable source of renewable energy over the past few decades [10] and have been widely used in the pharmaceutical, food, paper, textile, and mineral processing industries and homes to provide electricity and heating for most activities [11]. Solar energy comes in two main categories, namely, solar Photovoltaic (PV) and Concentrated Solar Power (CSP).

Among the renewable energy technologies, CSP has shown to be a better alternative for power generation in regions with high direct solar irradiation ranging between

1,800 to 2,100 kW/m^2/year [11-14]. The success of solar energy technologies at any specific location, mainly, depends on the available solar irradiation for that area [15, 16]. The higher the amount of solar irradiation, the more energy that can be obtained. This means the success of solar energy and its applications is dependent on the amount of solar irradiation. It is, therefore, necessary to determine the best possible locations that can support the installation of a CSP plant for the optimum generation of electricity.

The selection of an optimal location is very instrumental in the implementation of a CSP plant. Apart from the Direct Normal Irradiation (DNI), which is the most influential factor that affects the feasibility of the CSP plant, other factors like the geographic location, availability of land, slope of the land, weather profile, availability of a water source, and a connection to the grid play very important roles and must, therefore, be taken into consideration [17-19].

This quest to select an optimal location for the installation of a CSP plant has led many researchers to apply different methods to achieve that aim with varying results. Aragonés-Beltrán, P. et al. applied the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP) to aid the selection for solar thermal power plant projects [20]. The work analysed the criteria for the acceptance or rejection of a project and prioritise a project over another. Lee, H. C. et al. presented a comparative analysis for ranking renewable energy sources used in the generation of electricity in Taiwan [21]. They employed four methods, viz., Weighted Sum Model (WSM), Vise Kriterijumsa Optimizacija I Kompromisno Resenje (VIKOR), Technique for Order of Performance by Similarity to Ideal Solution (TOPSIS), and ELimination Et Choice Translating REality (ELECTRE), in the analysis. Their results showed that hydropower is the best alternative for Taiwan when considering the financial and technical factors, due to its maturity in the technology.

Merrouni, A. A. et al. analysed the suitability of sites for the installation of CSP in Morocco. It was shown that the eastern region of Morocco has more than 65% of its surface area being able to support the installation of CSP [19]. In the selection of an optimum site for solar power in an Iraqi region, Ibrahim, G. et al. employed a set of multi-criteria decision analysis techniques [22]. In their results, the available area was graded as low, moderate and highly suitable. Ghasempour, R. et al. used a set of Multi-Criteria Decision Making (MCDM) rules in the selection of sites for solar power plants. The main criteria considered include economic, environmental, risk, geography, societal and climatic with each including a number of sub-criteria [23].

In this paper, the AHP method was used to prioritise the main criteria considered. The various alternatives were then prioritised using the MCDM approach as used by Ghasempour, R. et al. [23], Koirala, N. et al. [24], Bajaj, M. et al. [25], and Azizkhani, M. et al. [26] in the selection of optimal locations for proposed power plants.

The rest of the paper is organised as follows. Section 2 discusses the resources and methods used, and Sections 3 and 4 present the results and discussions, and conclusions, respectively.

2. Resources and Methods Used

2.1. Solar Resource and Site Assessment for Ghana

Ghana, situated between latitudes 4.87 to 11.06 and longitudes -2.58 to 0.99, covers a land area of about 238,535 km^2. The geographic location, being around the equatorial Sun Belt, makes it capable of exploiting abundant solar energy for many applications ranging from household heating, industrial heating to electricity generation. Ghana mostly has a tropical warm climate and is exposed to a lot of sunshine during most parts of the year. Electricity generation from the sun is mostly achieved using solar PV.

There are two main seasons, namely, the wet and dry seasons. The wet season usually spans from April to October while the dry season spans from November to March. The northern part of the country mostly experiences very high temperatures during most parts of the year, especially the dry season. The southern sector is mostly warm and humid during the wet season and experiences high temperatures during most parts of the year [27].

2.2. Meteorological and Solar Radiation Databases

Solar radiation and other meteorological data can be obtained from ground-based measurements, satellite-derived data and/or from modelled data sets and could be commercially or publicly available [3]. Ground-measured data is obtained from synoptic weather stations installed in specific locations by governmental institutions and other agencies.

2.2.1. NASA SSE

The Surface Meteorology and Solar Energy (SSE) resource of the National Aeronautics and Space Administration (NASA) Atmospheric Science Data Centre is an online site where meteorological data has been collected over 22 years from July 1983 to June 2005. It consists of over 200 satellite-derived meteorology and solar energy metrics having a resolution of 1° and averaged monthly. For regions across the world, where ground measurements are unavailable, researchers have accepted this satellite and model-based database to be sufficiently reliable [28].

2.2.2. NREL NSRDB

The National Solar Radiation Database (NSRDB) of the National Renewable Energy Lab (NREL) is a serially complete collection of hourly and half-hourly values of solar radiation and other meteorological data at a 4 km by 4 km spatial resolution covering 18 years from 1998 to 2015. The NSRDB is obtained using multi-channel measurements from geostationary satellites [29]. This hourly-averaged satellite-derived data have a bias error of approximately +5% for Global Horizontal Irradiance (GHI) and less than +10% for DNI [30].

2.2.3. Meteonorm Database

Meteonorm database, obtained from the Global Energy Balance Archive (GEBA), is widely used as meteorological input for simulations of solar energy applications and buildings.

This database is a combination of a climate database, a spatial interpolation tool and a stochastic weather generator. Additional parameters such as the precipitation, wind speed or radiation parameters like diffuse and DNI are also generated from several solarimetric stations from many different sites [3].

2.2.4. World Radiation Data Centre

The World Radiation Data Centre (WRDC) provides monthly irradiation data for about 1,195 sites around the world. Data was collected from 1964 to 1993. Though this data is available for free, it does not have temperature data and must, therefore, be obtained from a different source [28].

For satellite data, the measurements are less accurate near mountains and large water bodies such as the ocean. The measurements are also made at the top of the atmosphere and, therefore, requires atmospheric models to estimate the measurements on the ground. The NASA satellite data, for instance, has an estimated inaccuracy of about 20% [30] while the WRDC data, which is ground measured, has an estimated inaccuracy of between 6% to 12% [32].

2.2.5. Justification for Choice of Database

From the foregoing, one can deduce that the most reliable data for CSP research is the ground measured data. However, ground data (solar DNI) is not available and therefore, this work utilises satellite data obtained from the NREL NSRDB.

Weather data was extracted from the NREL database and used to evaluate the performance of the CSP plant in the said locations. The data include hourly, daily, and monthly DNI, ambient temperature, wind speed, atmospheric pressure, sun angle, and solar azimuth angle for the complete year (8,760 hours).

2.3. Methodology for the Selection of Optimal Locations

2.3.1. Selection of Criteria and Alternatives

Various criteria have been selected based on their relevance to the implementation of a CSP plant. Some of the criteria to be considered in the selection of an optimal location for the implementation of a CSP plant include geographical parameters such as availability of land, the slope of the land, proximity to a transmission line, good access roads, and meteorological or weather parameters such as DNI, ambient temperature, wind speed, a source of water and cloud cover. Some of these criteria have beneficial importance while others have non-beneficial importance to the overall performance of the CSP plant. Increasing the values of the beneficial (B) criteria will increase the general performance of the plant while increasing values of the non-beneficial (NB) criteria impacts performance negatively.

For the purposes of this paper and to avoid complexities, it is assumed that the land is readily available at the chosen location and that the slope is also appropriate for the installation of the plant. The following criteria have, therefore, been selected based on recent studies available from literature [33, 34] to have an impact on the performance of the CSP plant. These are as follows:

i. DNI (IB): Beneficial (B);
ii. Ambient temperature (T): Beneficial (B);
iii. Wind speed (WN): Non-beneficial (NB);
iv. Cloud cover (CC); Non-beneficial (NB); and
v. Source of water (WT): Beneficial (B).

Direct Normal Irradiance

DNI is the most important criterion to consider when selecting a site for CSP. It is responsible for providing the heat from the sun, which is used to heat the Heat Transfer Fluid (HTF) inside the absorber tubes. Solar collectors utilise the heat component of the sun for this purpose. The higher the DNI, the higher the output power to be generated by the CSP plant. For CSP to be economical, the DNI should be greater than 1,800 kWh/m^2/year (5 kWh/m^2/day) [18].

Ambient Temperature

Aside from the DNI, the ambient temperature also plays a very important role in the output power generated by the CSP plants. The ambient air temperature will affect heat loss, as a lower ambient temperature will increase temperature differences between HTF and ambient and, thus, increase driving potential for heat loss, while the reverse is true for higher ambient air temperatures [35].

Wind Speed

Wind speed, though negatively affects the CSP plant, needs to be considered when selecting a site. Wind speeds higher than 15.64 m/s can cause structural damage to the collector assembly and also tends to decrease the temperatures of the system [18, 36]. Wind speed affects heat loss by increasing the convection coefficient from the outermost Heat Collecting Element (HCE) surface to the surrounding air [35].

Cloud Cover

Cloud cover adversely affects the output of the CSP plants by reducing the solar radiation to lower levels depending on the cloud thickness [36, 37].

Source of Water

A source of water is essential in the operation of a CSP plant. Water is needed for steam generation, cooling and cleaning purposes [38]. The surface of the mirrors needs to be cleaned periodically to increase the optical efficiency of the entire plant. Therefore, proximity to a source of water would be a great advantage to the setting up of a CSP plant. Ghana has many water bodies within different locations of the country as shown in the hydrological map in Figure 1 [39].

The alternatives represent the various possible locations where a CSP plant can be installed. They include locations from across the country, i.e., from the northern sector through the middle belt to the coast. Selection of an optimal location is done by assessing the various geographical, weather, and meteorological factors. A location with a very high DNI but lacking in the land needed for the installation would not be appropriate. A location with high ambient temperatures without a source of water would not be appropriate for the implementation of a CSP plant. It is, therefore, necessary to critically assess the relationships between each of the criteria with respect to each other and with respect to the specific location. The various alternatives used in this paper are listed in Table 1. Each alternative has been provided with its corresponding criteria values.

Figure 1. *Map of Ghana showing various Major Water Bodies.*

Table 1. *Decision Criteria and their Respective Values.*

Alternatives	IB (kWh/m^2/day)	T (°C)	WN (m/s)	CC (%)	WT (%)
A1 (Accra)	2.13	27.0	2.50	53.0	35
A2 (Bawku)	4.25	27.3	2.00	45.1	25
A3 (Bolgatanga)	4.03	27.0	2.94	48.0	20
A4 (Cape Coast)	2.86	26.7	2.10	59.6	35
A5 (Ho)	2.88	26.4	1.70	55.4	40
A6 (Keta)	2.87	27.3	3.00	46.7	30
A7 (Kete Krachi)	3.08	27.2	1.80	53.4	40
A8 (Kintampo)	3.41	26.1	1.80	52.9	35
A9 (Koforidua)	2.59	26.0	1.70	56.9	20
A10 (Navrongo)	4.12	27.8	2.00	48.3	20
A11 (Obuasi)	2.60	25.6	1.50	59.2	20
A12 (Savelugu)	3.75	27.5	1.90	50.3	20
A13 (Sunyani)	2.97	26.0	1.80	60.8	25
A14 (Takoradi)	2.39	26.8	1.80	52.4	40
A15 (Tamale)	3.51	27.4	1.90	50.3	20
A16 (Wa)	3.98	26.6	1.90	48.0	20
A17 (Yendi)	3.59	27.4	1.80	50.3	20

2.3.2. Using the Analytic Hierarchy Process

The AHP was used as the basis for determining the criteria for selecting the optimal location. The AHP is a decision-making tool used to solve problems with multiple criteria involving complex scenarios [24, 25]. AHP begins with the decomposition of a problem into a hierarchy of criteria to enable it to be easily analysed independently. The AHP can transform empirical comparisons into numeric values for further processing and comparison [40]. In AHP, the decision-maker (DM) performs pair-wise comparisons, and then the pair-wise comparison matrix and the eigenvector are derived to specify the weights of each parameter in the problem, which further helps in ranking the alternatives. Since all the criteria have specific impacts on the outcome of the analysis, the degree of impact of each criterion must be determined. The numerical ratings of the criteria used in the comparison to measure their relative importance and their definitions are described in Table 2 [41].

Table 2. *Scale of Relative Importance.*

Numerical Rating	Definition
1	Equal importance
3	Somewhat more important
5	Much more important
7	Very much more important
9	Absolutely more important
2, 4, 6, 8	Intermediate values

Developed in the 1970s by Thomas L. Saaty [42, 43], the AHP is used to solve complex decision problems [44]. It begins with the development of a pairwise comparison matrix from which the consistencies of the criteria can be determined. The following are the steps used on AHP [45] and further described by the flowchart in Figure 2 [46]:

i. Form a pairwise comparison matrix (m = n × n) for the criteria.
ii. Establish a normalised pairwise comparison matrix.
iii. Compute the average cross rows to obtain the relative weights in the range of 0 to 1.
iv. Find the Consistency Ratio (CR) using Equation (17).
v. If CR ≤ 0.1 (10%), the degree of consistency is satisfactory. Otherwise, there are inconsistencies, and the decision-making judgements must be reviewed until a CR of less than or equal to 0.1 is achieved.

2.3.3. Using the Multi-Criteria Decision-Making Methods

MCDM is a set of concepts, methods and techniques developed to help decision-makers to make complex decisions in a more systematic and structured way [20]. MCDM techniques have been frequently employed in the planning and policies of Renewable Energy (RE) sources [44]. MCDM techniques have also been used in the selection of optimal locations for various renewable energy projects [47-49]. Among the MCDM techniques, the VIKOR, TOPSIS, and Complex Proportional Assessment (COPRAS) methods have been very effective in the selection processes [50, 51]. These methods have, therefore, been employed in this paper to select the best locations for the installation of a CSP plant. The various criteria selected for each alternative is fed into the formulae for the various MCDM methods.

VIKOR Method

The VIKOR method was developed by Serafim Opricovic in 1998 to solve decision problems requiring different criteria [49]. It determines the compromise order list, the compromise solution, and the weight stability ranges for the preferred stability in the obtained compromise solution with the initial (given) weights.

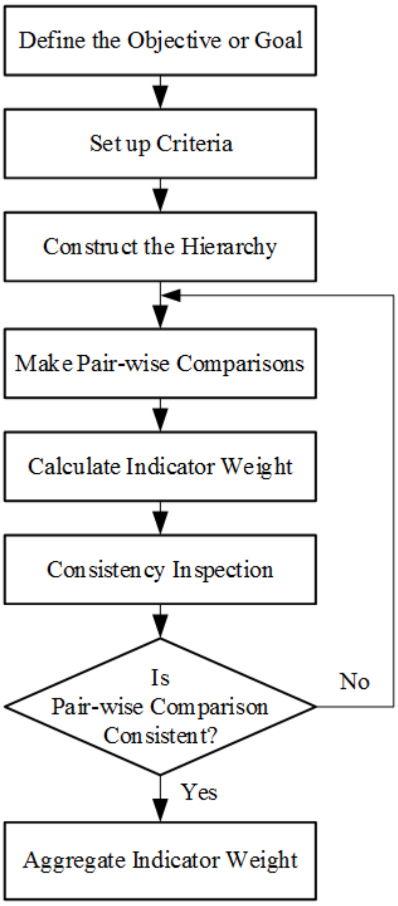

Figure 2. *Flowchart of the AHP.*

It focuses on ordering and selecting a range of alternatives in the presence of conflicting criteria and offers a multi-criteria ranking index based on the measure of "closeness" to the "ideal" solution [21, 24-26, 52]. It determines the compromise ranking list and the compromise solution obtained with the initial weights obtained. This method focuses on ranking and selecting from a set of alternatives in the presence of conflicting criteria. It involves the following steps [53]:

i. Determine the best (f_i^*) and the worst (f_i^-) values for each criterion using Equations (1) and (2), respectively [54]. Where j represents the alternatives (j = 1, 2, 3, …, m) and i represents the criteria (i = 1, 2, 3, …, n).

$$f_i^* = \max_i f_{ij}, \qquad f_j^- = \min_i f_{ij} \tag{1}$$

$$f_i^* = \min_i f_{ij}, \qquad f_j^- = \max_i f_{ij} \tag{2}$$

ii. Calculate the S_j and R_j values using Equations (3) and (4), respectively [54, 55].
Where S_j represent the utility measure and R_j represent the regret measure for the alternatives.

$$S_j = \sum_{i=1}^{n} \frac{W_i\left(f_i^* - f_{ij}\right)}{\left(f_i^* - f_i^-\right)} \tag{3}$$

$$R_j = \max_i \left[\frac{W_i\left(f_i^* - f_{ij}\right)}{\left(f_i^* - f_i^-\right)}\right] \tag{4}$$

iii. Calculate the Q_j values using Equation (5) [54, 55]. Where Q_j is the weight of the maximum group utility.

$$Q_j = \frac{v\left(S_j - S^*\right)}{\left(S^- - S^*\right)} + (1-v)\left(R_j - R^*\right)\left(R^- - R^*\right) \tag{5}$$

where, W_i = weights of the criteria; f_i* = ideal (best) solution; f_i^- = worst solution; and

$$S^* = \min S_j;\ S^- = \max S_j;$$

$$R^* = \min R_j;\ R^- = \max R_j$$

v is introduced as the weight of the strategy of 'most of the attributes' (or 'the maximum group utility') and (1 – *v*) is the weight of the individual regret. The value of *v* lies between 0 and 1 but a value of 0.5 is usually preferred [55].

iv. Rank the alternatives using the values of S, R and Q in ascending order such that the lowest value represent the best alternative.

TOPSIS Method

With TOPSIS, the alternatives are ranked according to the distance between the positive and negative ideal solutions [56, 57]. The best alternative should have the shortest distance from the positive-ideal solution and the farthest distance from the negative-ideal solution [52].

The following steps are involved in the TOPSIS method [21, 52, 53, 57]:

i. Normalise the decision matrix using Equation (6) [56, 57].
Where r_{ij}, X_{ij}, i, and j represent the normalised matrix, the intersection of each alternative and criterion, the number of criteria and the number of alternatives respectively.

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{j=1}^{n} X_{ij}}} \tag{6}$$

ii. Determine the weighted normalised decision matrix, v_{ij}, by multiplying each entry by its corresponding weight obtained by the AHP as expressed in Equation (7).

$$v_{ij} = w_j ? r_{ij} \tag{7}$$

iii. Determine the positive-ideal and negative-ideal solutions.

iv. Calculate the Euclidean distance from the positive- (D_i^+) and negative-ideal solutions (D_i^-) using Equations (8) and (9), respectively [56, 57].

$$D_i^+ = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^+\right)^2} \quad (8)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^-\right)^2} \quad (9)$$

v. Calculate the closeness to the ideal solution (CC_i^*) using Equation (10) [50].

$$CC_i^* = \frac{D_i^-}{D_i^- + D_i^+} \quad (10)$$

vi. Determine the order of all alternatives based on their relative closeness to the ideal solution. Larger CC_i* represents a better success of the alternative.

COPRAS Method

The COPRAS method is used to evaluate the superiority of one alternative over the other and makes it possible to compare alternatives. The ideal best and ideal worst solutions from different alternatives are selected. The following steps are used:

i. Normalise the decision matrix from Equation (11) [50].

$$r_{ij} = \frac{X_{ij}}{\sum_{j=1}^{m} X_{ij}} \quad (11)$$

ii. Determine the weighted normalised performance matrix (y_{ij}) by multiplying normalised decision matrix (r_{ij}) by the corresponding criteria weight:

$$y_{ij} = r_{ij} \times w_j \quad (12)$$

iii. Calculate the sums of the weighted normalised values for both beneficial (S_{+i}) and non-beneficial criteria (S_{-i}), expressed in Equations (13) and (14) respectively.

$$S_{+i} = \sum_{j=1}^{n} y_{+ij} \quad (13)$$

$$S_{-i} = \sum_{j=1}^{n} y_{-ij} \quad (14)$$

iv. Determine the significance of the alternatives by defining the characteristics of the positive and negative alternatives.

v. Determine the relative significance or priorities of the alternatives (Q_i), as expressed in Equation (15) where the alternative with the highest relative significance value is the best choice among the candidate alternatives [50, 58].

$$Q_i = S_{+i} + \frac{\sum_{i=1}^{m} S_{-i}}{S_{-i}\sum_{i=1}^{m}\left(\frac{1}{S_{-i}}\right)} \quad (15)$$

vi. Now, calculate the quantitative utility, U_i, for the alternatives from Equation (16) where Q_{max} is the maximum relative importance value.

$$U_i = \frac{Q_i}{Q_{max}} \times 100\% \quad (16)$$

vii. Obtain the rankings from the highest value to the lowest value of the U_i, where the highest value has the best ranking.

3. Results and Discussion

3.1. Finding the Comparison Matrix, Consistency Index and Consistency Ratio

The pairwise comparison matrix is obtained by determining the relative weight of each criterion to the other as shown in Table 3. When an attribute is compared with itself, a value of 1 is assigned. Therefore, the entries of the major diagonal are all assigned 1. The rest of the entries are obtained based on an extensive literature search to determine the relative importance of each criterion on the performance of the CSP plant.

Table 3. *Pairwise Comparison Matrix.*

SN	Description	1	2	3	4	5
		IB	T	WN	CC	WT
1	IB	1.00	3.00	6.00	8.00	4.00
2	T	1/3	1.00	5.00	7.00	3.00
3	WN	1/6	1/5	1.00	1.00	1/4
4	CC	1/8	1/7	1.00	1.00	1/5
5	WT	1/4	1/3	4.00	5.00	1.00
	Sum	1.88	4.68	17.00	22.00	8.45

The normalised matrix is obtained from the pairwise comparison matrix by dividing the value of each cell in the column of Table 3 by the total column sum and this is shown in Table 4. The eigenvectors are displayed in the "Weight" column of Table 4. The eigenvector values determine the weight of that criterion relative to the total result [40] and are calculated by finding the average of the sum of the row values of the corresponding criterion in that row. A weight assigned to a criterion indicates the relative importance of that criteria to the overall performance. The DNI had the highest percentage weight of 47.3%, indicating that it has the greatest impact on the performance of a CSP plant.

Table 4. *Normalised Matrix.*

	IB	T	WN	CC	WT	Weight
IB	0.533	0.642	0.353	0.364	0.473	47.3%
T	0.178	0.214	0.294	0.318	0.355	27.2%
WN	0.089	0.043	0.059	0.045	0.030	5.3%
CC	0.067	0.031	0.059	0.045	0.024	4.5%
WT	0.133	0.071	0.235	0.227	0.118	15.7%

Table 5 contains the values for the calculation of the CR and CI, which are obtained as follows:

i. The value of each cell of the criterion in each column of Table 5 is obtained by multiplying its corresponding value in Table 3 by the weight of that criterion obtained in Table 4; and

ii. Now, the sum of the criteria in the rows of Table 5 is calculated and obtained as shown.

Table 5. *Values for CR and CI Calculation.*

	IB	T	WN	CC	WT	SUM
IB	0.47	0.82	0.32	0.36	0.63	2.60
T	0.16	0.27	0.27	0.32	0.47	1.48
WN	0.08	0.05	0.05	0.05	0.04	0.27
CC	0.06	0.04	0.05	0.05	0.03	0.23
WT	0.12	0.09	0.21	0.23	0.16	0.80

The consistency ratio is obtained by using Equation (17).

$$CR = \frac{CI}{RI} = \frac{\text{Consistency index}}{\text{Random consistency index}} \quad (17)$$

The consistency index is obtained from Equation (18) [59].

$$CI = \frac{\lambda_{max} - N}{N - 1} \quad (18)$$

where, λ_{max} = the maximum eigenvalue; and N = the number of criteria.

The maximum eigenvalue is obtained by dividing the values of the sum of each criterion in Table 5 by the corresponding weight of the criterion in Table 4 and dividing the total by the numerical value of the number of criteria. This is shown in Equation (19).

$$\lambda_{max} = \frac{\left(\frac{2.60}{0.473} + \frac{1.48}{0.272} + \frac{0.27}{0.053} + \frac{0.23}{0.045} + \frac{0.80}{0.157}\right)}{5} \quad (19)$$

$$= 5.248$$

$$CI = \frac{5.248 - 5}{5 - 1} = 0.062$$

The random consistency index for 5 number of criteria is 1.12 as shown in Table 6 [43].

Table 6. *Values of the Random Consistency Index.*

N	CI
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Therefore, the consistency ratio is obtained to be:

$$CR = \frac{0.062}{1.120} = 0.055$$

CR = 0.055, which implies that the degree of consistency is satisfactory.

3.2. Results for Ranking with the VIKOR Method

The VIKOR ranking indicated that Bawku (A2) was the best location for the construction and implementation of a CSP plant, while Accra (A1) was the worst location. It could be seen from Table 7 that Navrongo, Savelugu, Bolgatanga, Yendi and Wa corresponds to ranks from 2 to 6, respectively.

Table 7. *Ranking of Alternatives by the VIKOR Method.*

Alternatives	Sj	Rj	Qj	Rank
A1	0.669139	0.472966	0.868537	17
A2	0.197301	0.117829	0.000000	1
A3	0.364318	0.157105	0.185749	4
A4	0.548110	0.310105	0.544712	12
A5	0.515226	0.305643	0.512746	11
A6	0.505892	0.307874	0.508596	10
A7	0.369577	0.261024	0.336164	8
A8	0.469692	0.210020	0.342553	9
A9	0.790748	0.370342	0.819036	15
A10	0.212988	0.157105	0.067550	2
A11	0.837450	0.368111	0.852373	16
A12	0.334793	0.157105	0.162688	3
A13	0.681422	0.285565	0.614287	13
A14	0.570062	0.414961	0.709486	14
A15	0.400690	0.165092	0.225403	7
A16	0.388071	0.157105	0.204301	6
A17	0.379302	0.157105	0.197453	5

3.3. Results for Ranking with the TOPSIS Method

Table 8 shows the ranking results for the TOPSIS method. Bawku (A2) and Accra (A1), respectively, showed to be the best and least desired places where CSP can best be implemented. Other locations that also showed to be promising include Navrongo, Wa, Bolgatanga, Savelugu and Kintampo.

Table 8. *Ranking of Alternatives by the TOPSIS Method.*

Alternatives	Di+	Di-	CCi*	Rank
A1	0.005533	0.020640	0.788617	17
A2	0.000413	0.074525	0.994488	1
A3	0.000859	0.066257	0.987203	4
A4	0.002415	0.032959	0.931740	11
A5	0.002291	0.038303	0.943574	10
A6	0.002575	0.029455	0.919609	13
A7	0.001666	0.043377	0.963010	9
A8	0.000923	0.049463	0.981689	6
A9	0.004078	0.018017	0.815443	16
A10	0.000745	0.069788	0.989439	2
A11	0.004048	0.018881	0.823444	15
A12	0.001025	0.057026	0.982345	5
A13	0.002419	0.030933	0.927465	12
A14	0.004201	0.029404	0.874997	14
A15	0.001386	0.048764	0.972371	8
A16	0.000818	0.064845	0.987546	3
A17	0.001247	0.051596	0.976397	7

3.4. Results for Ranking with the COPRAS Method

Table 9 represents the results obtained from ranking with the COPRAS method. Bawku ranked highest indicating the best option among the selected locations for the implementation of CSP for electricity generation while Keta showed to be the least desired location. Yendi, Wa, Obuasi, Kintampo and Ho were also locations proven to support CSP implementation based on the COPRAS method.

Table 9. *Ranking of Alternatives using the COPRAS Method.*

S_{+i}	S_{-i}	Min S_{i-}/S_{i-}	Q_i	U_i	Rank
0.046	0.0066	0.8109	0.4313	81.3150	15
0.061	0.0054	0.9880	0.5305	100.000	1
0.057	0.0070	0.7609	0.4189	78.9630	16
0.052	0.0063	0.8482	0.4551	85.7990	14
0.054	0.0054	0.9782	0.5185	97.7540	6
0.051	0.0070	0.7579	0.4110	77.4860	17
0.056	0.0055	0.9685	0.5161	97.3010	7
0.056	0.0055	0.9729	0.5188	97.7940	5
0.045	0.0055	0.9647	0.5027	94.7620	12
0.059	0.0056	0.9592	0.5143	96.9500	9
0.044	0.0053	1.0000	0.5193	97.8920	4
0.055	0.0055	0.9687	0.5154	97.1660	8
0.049	0.0059	0.9068	0.4801	90.5100	13
0.050	0.0054	0.9775	0.5142	96.9430	10
0.053	0.0055	0.9687	0.5133	96.7660	11
0.057	0.0054	0.9896	0.5268	99.3120	3
0.054	0.0053	0.9969	0.5274	99.4200	2
Min (S_{i-})*sum S_{i-} = 0.040013			Sum = 15.8176		

3.5. Comparison of the Ranking for the Three Methods

The equations for the three methods were programmed in Microsoft Excel and the rankings were obtained as shown in Table 10.

The initial results indicate that for all the three methods, Bawku (alternative A2) was ranked as the best location that could support the installation of a CSP plant. It could also be realised that the locations with the best rankings, namely, Bawku, Navrongo, Yendi, Wa, Bolgatanga and Savelugu, are all found in Northern Ghana, where the irradiation levels are usually high compared to the other places assessed. These places also have relatively lesser amounts of cloud cover. The locations with high numerical values in the rankings, such as Accra, Obuasi, Koforidua and Takoradi have comparatively lower irradiation levels and also higher levels of cloud cover. These results indicate that building a CSP plant in locations in the Northern sector of the country would produce higher power output than locations in the Southern sector.

Table 10. *Results from Ranking of Alternatives using the Three Methods.*

Alternatives	Latitude	Longitude	VIKOR	TOPSIS	COPRAS
A1	5.31	-1.98	17th	17th	15th
A2	5.11	-1.25	1st	1st	1st
A3	5.56	-0.20	4th	4th	16th
A4	5.92	0.99	12th	11th	14th
A5	6.09	-0.26	11th	10th	6th
A6	6.21	-1.66	10th	13th	17th
A7	6.60	0.47	8th	9th	7th
A8	7.34	-2.33	9th	6th	5th
A9	7.79	-0.05	15th	16th	12th
A10	8.06	-1.73	2nd	2nd	9th
A11	9.40	-0.84	16th	15th	4th
A12	9.44	-0.01	3rd	5th	8th
A13	9.62	-0.83	13th	12th	13th
A14	10.06	-2.50	14th	14th	10th
A15	10.79	-0.85	7th	8th	11th
A16	10.90	-1.09	6th	3rd	3rd
A17	11.06	-0.24	5th	7th	2nd

Further analyses from Table 10 indicate that the rankings for the VIKOR and TOPSIS methods were more closely related than that of the COPRAS method. It could be seen that the 1st, 2nd and 3rd rankings for the two methods were the same. The COPRAS method, however, showed relatively different rankings.

4. Conclusions

CSP plants utilise radiation from the sun, which is a clean source of energy, and therefore, has minimal adverse effects on the environment. With global warming concerns on the rise worldwide, it is prudent for governments to adopt the CSP systems in place of the fossil-fired thermal power plants, which pollute the environment in diverse ways.

Currently in Ghana, there is no known grid-connected CSP plant. This paper successfully determined some locations in Ghana where CSP plants could be installed. Bawku, a town in Northern Ghana was selected as the best option. Additionally, other areas, such as Bolgatanga, Navrongo, Tamale, Wa and Yendi, which are also located in Northern Ghana, were found to be favourable for the installation of a CSP plants. Thus, one can safely conclude that compared to Southern Ghana, CSP plants can best be installed in Northern Ghana, which have favourable weather conditions for such installations.

Future work will provide a technoeconomic assessment of siting a CSP plant in Bawku.

References

[1] Wang, Z., Zhang, B. and Wang, B., 2018. Renewable energy consumption, economic growth and human development index in Pakistan: evidence from simultaneous equation model. Journal of cleaner production, 184, pp. 1081 – 1090.

[2] Adobea Oduro, M., Gyamfi, S., Sarkodie, S. A. and Kemausuor, F., 2020. Evaluating the success of renewable energy and energy efficiency policies in Ghana: matching the policy objectives against policy instruments and outcomes. Renewable Energy-Resources, Challenges and Applications, 519 pp.

[3] da Silva, M. K., Narvaez, D. I., de Melo, K. B. and Villalva, M. G. (2018), "Comparative Analysis of Transposition Models applied to Photovoltaic Systems using Meteonorm and NASA SSE databases", 13th IEEE International Conference on Industry Applications, pp. 237-241.

[4] Ji, Q. and Zhang, D., 2019. How much does financial development contribute to renewable energy growth and upgrading of energy structure in China?, Energy Policy, 128, pp. 114-124.

[5] Aziz, M. S., Mufti, G. M. and Ahmad, S. (2017), "Wind-hybrid Power Generation Systems Using Renewable Energy Sources-A Review", International Journal of Renewable Energy Research, Vol. 7, No. 1, pp. 111 - 127.

[6] Abood, Z. M. and Al-Taai, O. T. (2018), "Study of Absorbance and Emissivity Solar Radiation by Clouds, Aerosols and some Atmospheric Gases", Journal of Applied and Advanced Research, Vol. 3, No. 5, pp. 128 - 134.

[7] Kalogirou, S. A. (2014), Solar Energy Engineering – Processes and Systems, 2nd Edition, Academic Press, Oxford, UK, 819 pp.

[8] Blanco, M. and Santigosa, L. R. (2016), Advances in Concentrating Solar Thermal Research and Technology, Woodhead Publishing Series in Energy, Madrid, Spain, 1st edition, 496 pp.

[9] Haghdadi, N., Copper, J., Bruce, A. and MacGill, I. (2017), "A Method to Estimate the Location and Orientation of Distributed Photovoltaic Systems from their Generation Output Data", Renewable Energy, Vol. 108, pp. 390 - 400.

[10] Hossain, M. F., Hossain, S. and Uddin, M. J. (2017), "Renewable Energy: Prospects and Trends in Bangladesh", Renewable and Sustainable Energy Reviews, Vol. 70, pp. 44 – 49.

[11] Farjana, S. H., Huda, N., Mahmud, M. P. and Saidur, R. (2018), "Solar Process Heat in Industrial Systems – A Global Review", Renewable and Sustainable Energy Reviews, Vol. 82, pp. 2270 – 2286.

[12] Ahmadi, M. H., Ghazvini, M., Sadeghzadeh, M., Alhuyi Nazari, M., Kumar, R., Naeimi, A. and Ming, T. (2018), "Solar Power Technology for Electricity Generation: A Critical Review", Energy Science and Engineering, Vol. 6, No. 5, pp. 340 – 361.

[13] Islam, M. T., Huda, N., Abdullah, A. B. and Saidur, R. (2018), "A Comprehensive Review of State of the Art Concentrating Solar Power Technologies: Current Status and Research Trends", Renewable and Sustainable Energy Reviews, Vol. 91, pp. 987 - 1018.

[14] Ghazouani, K., Skouri, S., Bouadila, S. and Guizani, A. A. (2018), "Thermal Study of Solar Parabolic Trough Concentrator", The 9th Proceedings International Renewable Energy Congress, Hammamet, Tunisia, pp. 1 – 4.

[15] Zhang, Y., Ren, J., Pu, Y. and Wang, P., 2020. Solar energy potential assessment: A Framework to Integrate Geographic, Technological, and Economic Indices for a Potential Analysis. Renewable Energy, 149, pp. 577-586.

[16] Agyekum, E. B., Velkin, V. I. and Hossain, I., 2019, November. Comparative Evaluation of Renewable Energy Scenario in Ghana. In IOP Conference Series: Materials Science and Engineering (Vol. 643, No. 1, p. 012157). IOP Publishing.

[17] Elmohlawy, A. E., Kazanjan, B. I. and Ochkov, V. F. (2018), "Modelling and Performance Prediction of Solar Parabolic Trough Collector for Hybrid Thermal Power Generation Plant under Different Weather Conditions", In AIP Conference Proceedings, Vol. 2047, No. 1, pp. 1 – 10.

[18] Liaqat, K., Anss, M., Ali, A. and Mengal, A. N. (2018), "Modelling and Simulation of a 100 MW Concentrated Solar Thermal Power Plant using Parabolic Trough Collectors in Pakistan", IOP Conference Series: Materials Science and Engineering, Vol. 414, No. 1, 7 pp.

[19] Merrouni, A. A., Elalaoui, F. E., Ghennioui, A., Mezrhab, A. and Mezrhab, A. (2018), "A GIS-AHP Combination for the Sites Assessment of Large-scale CSP Plants with Dry and Wet Cooling Systems, Case Study: Eastern Morocco", Solar Energy, Vol. 166, pp. 2 – 12.

[20] Aragonés-Beltrán, P., Chaparro-González, F., Pastor-Ferrando, J. P. and Pla-Rubio, A. (2014), "An AHP (Analytic Hierarchy Process)/ANP (Analytic Network Process)-based Multi-criteria Decision Approach for the Selection of Solar Thermal Power Plant Investment Projects", Energy, Vol. 66, No. 1, pp. 222 – 238.

[21] Lee, H. C. and Chang, C. T. (2018), "Comparative Analysis of MCDM Methods for ranking Renewable Energy Sources in Taiwan", Renewable and Sustainable Energy Reviews, Vol. 92, No. 1, pp. 883 – 896.

[22] Ibrahim, G. R. F., Hamid, A. A., Darwesh, U. M. and Rasul, A., 2021. A GIS-based Boolean logic-analytical hierarchy process for solar power plant (case study: Erbil Governorate—Iraq). Environment, Development and Sustainability, 23 (4), pp. 6066 – 6083.

[23] Ghasempour, R., Nazari, M. A., Ebrahimi, M., Ahmadi, M. H. and Hadiyanto, H. (2019), Multi-Criteria Decision-making Approach for Selecting Solar Plants Site and Technology: A Review", International Journal of Renewable Energy Development, Vol. 8, No. 1, pp. 1 – 11.

[24] Koirala, N., Dhakal, R. and Pudasaini, S. (2021), "An AHP Based Approach for Evaluating Renewable Energy Source for Investment Decision", 3rd International Conference on Engineering and Technology, Kantipur Engineering College, Dhapakhel, Lalitpur, Nepal, 6 pp.

[25] Bajaj, M. and Singh, A. K. (2020), "An Analytic Hierarchy Process-based Novel Approach for Benchmarking the Power Quality Performance of Grid-integrated Renewable Energy Systems", Electrical Engineering, Vol. 102, No. 3, pp. 1153 – 1173.

[26] Azizkhani, M., Vakili, A., Noorollahi, Y. and Naseri, F. (2017), "Potential Survey of Photovoltaic Power Plants using Analytical Hierarchy Process Method in Iran", Renewable and Sustainable Energy Reviews, Vol. 75, pp. 1198 – 1206.

[27] Himanka, H. (2014), "A Capital Budgeting Worksheet for Solar power plant investment in ECOWAS region), Bachelor's Thesis, University of Applied Sciences, 73 pp.

[28] Tahir, Z. R. and Asim, M., 2018. Surface measured solar radiation data and solar energy resource assessment of Pakistan: A review. Renewable and Sustainable Energy Reviews, 81, pp. 2839-2861.

[29] Madaeni, S. H. (2013), "Estimating the Capacity Value of Concentrating Solar Power Plants with Thermal Energy Storage: A Case Study of the Southwestern United States", IEEE Transactions on Power Systems, Vol. 28, No. 2, 11 pp.

[30] Habte, A., Sengupta, M. and Lopez, A. (2017), "Evaluation of the National Solar Radiation Database: 1998 – 2015 (No. NREL/TP-5D00-67722). National Renewable Energy Lab. (NREL), Golden, CO (United States).

[31] Bakirci, K. and Kirtiloglu, Y. (2018), "Prediction of Diffuse Solar Radiation using Satellite Data", International Journal of Green Energy, Vol. 15, No. 2, pp. 76 – 79.

[32] Urraca, R., Huld, T., Gracia-Amillo, A., Martinez-de-Pison, F. J., Kaspar, F. and Sanz-Garcia, A. (2018), "Evaluation of Global Horizontal Irradiance Estimates from ERA5 and COSMO-REA6 Reanalyses using Ground and Satellite-based Data", Solar Energy, Vol. 164, No. 1, pp. 339 – 354.

[33] Zhuang, X., Xu, X., Liu, W. and Xu, W. (2019), "LCOE Analysis of Tower Concentrating Solar Power Plants using Different Molten-salts for Thermal Energy Storage in China", Energies, Vol. 12, No. 7, 17 pp.

[34] Li, Y., Liao, S., Rao, Z., Liu, G. A. (2014), "Dynamic Assessment-based Feasibility Study of Concentrating Solar Power in China", Renew. Energy, Vol. 69, No. 1, pp 34 – 42.

[35] Patnode, A. M. (2006), "Simulation and performance evaluation of parabolic trough solar power plants".

[36] Kumar, S., Agarwal, A. and Kumar, A. (2021), "Financial Viability Assessment of Concentrated Solar Power Technologies under Indian Climatic Conditions", Sustainable Energy Technologies and Assessments, Vol. 43, No. 1, 12 pp.

[37] de Lima, F. J. L., Martins, F. R., Costa, R. S., Gonçalves, A. R., dos Santos, A. P. P. and Pereira, E. B. (2019), "The Seasonal Variability and Trends for the Surface Solar Irradiation in North-eastern Region of Brazil", Sustainable Energy Technologies and Assessments, Vol. 35, No. 1, pp. 335 – 346.

[38] Soomro, M. I., Mengal, A., Memon, Y. A., Khan, M. W. A., Shafiq, Q. N. and Mirjat, N. H. (2019), "Performance and Economic Analysis of Concentrated Solar Power Generation for Pakistan", Processes, Vol. 7, No. 9, 26 pp.

[39] Anon. (2013), "Ghana River Map", www.mapsofworld.com, Accessed: October 21, 2021.

[40] Vargas, R. V. (2010), "Using the Analytic Hierarchy Process to select and Prioritise Projects in a Portfolio", In PMI Global Congress, Vol. 32, No. 3, pp. 1 – 22.

[41] Ghaleb, A. M., Kaid, H., Alsamhan, A., Mian, S. H. and Hidri, L., 2020. Assessment and Comparison of various MCDM Approaches in the selection of manufacturing process. Advances in Materials Science and Engineering, 16 pp.

[42] Harker, P. T. (1987), "Incomplete Pairwise Comparisons in the Analytic Hierarchy Process", Math Model 9: 837–848. https://doi.org/10.1016/0270-0255(87)90503-3

[43] Saaty T. L. (1990), "How to make a Decision: the Analytic Hierarchy Process", European Journal of Operations Research, 48: 9–26. https://doi.org/10.1016/0377-2217(90) 90057-I

[44] Solangi, Y. A., Shah, S. A. A., Zameer, H., Ikram, M. and Saracoglu, B. O. (2019), "Assessing the Solar PV Power Project Site Selection in Pakistan: Based on AHP-fuzzy VIKOR Approach", Environmental Science and Pollution Research, Vol. 26, No. 29, pp. 30286 – 30302.

[45] Al Garni, H. Z. and Awasthi, A. (2017), "Solar PV Power Plant Site Selection using a GIS-AHP Based Approach with Application in Saudi Arabia", Applied Energy, Vol. 206, pp. 1225 - 1240.

[46] Liu, S., Zhao, Q., Wen, M., Deng, L., Dong, S. and Wang, C. (2013), "Assessing the impact of hydroelectric project construction on the ecological integrity of the Nuozhadu Nature Reserve, southwest China", Stochastic Environmental Research and Risk Assessment, Vol. 27, No. 7, pp. 1709 – 1718.

[47] Pohekar, S. D. and Ramachandran, M. (2004), "Application of Multi-criteria Decision Making to Sustainable Energy Planning—A Review", Renewable and Sustainable Energy Reviews, Vol. 8, No. 4, pp. 365 – 381.

[48] Tahri, M., Hakdaoui, M. and Maanan, M. (2015), "The Evaluation of Solar Farm Locations applying Geographic Information System and Multi-Criteria Decision-Making Methods: Case Study in Southern Morocco", Renewable and Sustainable Energy Reviews, Vol. 51, No. 1, pp. 1354 – 1362.

[49] Shao, M., Han, Z., Sun, J., Xiao, C., Zhang, S. and Zhao, Y. (2020), "A Review of Multi-criteria Decision-making Applications for Renewable Energy Site Selection", Renewable Energy, Vol. 157, No. pp. 377 – 403.

[50] Mousavi-Nasab, S. H. and Sotoudeh-Anvari, A. (2017), "A comprehensive MCDM-based approach using TOPSIS, COPRAS and DEA as an auxiliary tool for material selection problems", Materials & Design, Vol. 121, pp. 237 - 253.

[51] Emovon, I. and Oghenenyerovwho, O. S. (2020), "Application of MCDM Method in Material Selection for Optimal Design: A Review", Results in Materials, Vol. 7, No. 1, 21 pp.

[52] Hezer, S., Gelmez, E. and Özceylan, E. (2021), "Comparative Analysis of TOPSIS, VIKOR and COPRAS Methods for the COVID-19 Regional Safety Assessment", Journal of Infection and Public Health, Vol. 14, No. 1, pp. 775 – 786.

[53] Shekhovtsov, A. and Sałabun, W. (2020), "A Comparative Case Study of the VIKOR and TOPSIS Rankings Similarity", Procedia Computer Science, Vol. 176, No. 1, pp. 3730 – 3740.

[54] Sałabun, W., Wątróbski, J. and Shekhovtsov, A., 2020. Are MCDA methods benchmarkable? a comparative study of TOPSIS, VIKOR, copras, and PROMETHEE ii methods. Symmetry, 12 (9), p. 1549.

[55] Chatterjee, P. and Chakraborty, S. (2016), "A comparative analysis of VIKOR method and its variants", Decision Science Letters, Vol. 5, No. 4, pp. 469 - 486.

[56] Patel, A., Jha, S., Soni, R. and Fuse, K. (2020), "Comparative Study of MCDM techniques COPRAS and TOPSIS for Selection of Electric Motorcycles", In 2020 IEEE 7th international conference on industrial engineering and applications, pp. 54 – 59.

[57] Wang, P., Zhu, Z. and Wang, Y. (2016), "A Novel Hybrid MCDM Model combining the SAW, TOPSIS and GRA Methods based on Experimental Design", Information Sciences, Vol. 345, No. 1, pp. 27 – 45.

[58] Pamučar, D. S., Božanić, D. and Ranđelović, A. (2017), "Multi-criteria decision making: An example of sensitivity analysis", Serbian Journal of Management, Vol. 12, Issue 1, pp. 1 - 27.

[59] Yang, Z., Yuan, X., Wang, J., Inoue, A. and Deng, M. (2007), "Safety Assessment for Power Plants using Analytical Hierarchy Process and System Functionality", In IEEE International Conference on Networking, Sensing and Control, pp. 680 – 684.