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# A New Hybrid Modelling Approach for an Eco-Industrial Park Site Selection

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Countries across the world have undertaken measures to raise efficiencies of industrial operations to reduce greenhouse gas (GHG) emissions. An Eco-Industrial Park (EIP) that promotes industrial symbiosis effectively cuts down on GHG emissions from industrial processes. An EIP is a complex multi-criteria spatial initiative that requires a location with the facilities and features to host clusters of industries that collaborate to synergise resources, ultimately reducing carbon emissions. To make EIP site selection optimal and precise, this study presents a hybrid fuzzy-analytic hierarchy process (F-AHP) and geographic information system (GIS) model that was tested using six criteria for EIP site selection defined by Boolean logic. The GIS was used to generate the 2019 Land Use Land Cover (LULC), Euclidean distance, and reclassified raster layers of Tanjung Langsat Industrial Area (TLIA) spatial data. The criteria weights were assessed using F-AHP (triangular fuzzy numbers), and sensitivity analysis (SA) was used to check for any weight variation. The 2 % and 3 % changes in SA are insignificant when compared to the original weight. Waterbodies, roads, residential, industries, surface temperature, and slope have weight importance of 28, 22, 15, 14, 12, and 7 %. In the northern part of TLIA, the GIS-FAHP hybrid model produced the best (dark green 5 %) suitable EIP site, the second-best (light green 45 %) and moderately-suitable (yellow 25 %) sites surround the best site, while the low (light brown 15 %) and unsuitable (red 10 %) locations are near to the coast. The designed hybrid model approach demonstrates that TLIA is suitable for EIP development. The hybrid tool was developed for the selection of greenfield sites and the conversion of brownfield industrial parks to EIP status. The economic, environmental, social, and technical status of any site evaluated and accepted for EIP development is important to reduce carbon emissions.

## 1. Introduction

Globally, the pursuit of industrial activities to expand the economy has spurred carbon emissions and the effort to prevent it in response to climate change has become an important task. In 2013, China carbon emissions increased by 58 %, India's soared to 17 %, 20 % in the United States, and 11 % in the European Union (Zarin et al., 2021). The current task is to ensure sustainable economic growth and environmental interest (Zong et al., 2018). With the 2015 Paris Agreement, the international community ratified a treaty to reduce man-made GHG emissions (Shine et al., 2020). To comply, Iskandar Malaysia launched a low-carbon emission plan to reduce GHG emissions by 2025 through the development of Eco-Industrial Parks (EIP), which can contribute 20 to 40 % to national GHG emissions reduction targets (Cruz et al., 2021). The Kwinana EIP in Australia, which focuses on mining and mineral processing manages emissions and waste to reduce pollution (Stucki et al., 2019). The Kalundborg symbiosis in Denmark, the first global bottom-up industrial symbiosis, involves refinery, Portland cement, pharmaceuticals, water recycling, and liquid fertilizer (Valentine, 2016). South Korea's Ulsan Mipo and Onsan Industrial Park, a top-down EIP is into Vehicle and shipbuilding, oil refineries, non-ferrous metals,

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fertilizer, and chemicals symbiosis (Park et al., 2016). EIP as a new type of industrialization is to accomplish a green project.

Many industrial parks have been abandoned or are underutilised mainly due to improper or lack of comprehensive site selection, promoting GHG emissions, and there is the need to convert these parks into EIP. The initial success of EIP development is its suitable site selection (UNIDO, 2016), and it is a complex spatial multicriteria project (Sellitto and Murakami, 2018). This necessitates the usage of Geographical Information System (GIS) (Cui et al., 2019) and Multi-Criteria Decision-Making (MCDM) technologies (Kamali et al., 2017). GIS is a geospatial technology that maps, investigates, and evaluates actual issues by combining geographical elements with attribute data (Zong et al., 2018). MCDM uses multi-objective decision analysis (MODA) and multi-attribute decision-making (MADM) to subjectively and objectively evaluate criteria quantities against assembly of decision-makers issues, and guarantee judgments on uncertain decisions (Rikalovic et al., 2014). Combining GIS and MCDM is to identify the best EIP location, whose theory is to encourage a cluster of industries to practice industrial symbiosis to reduce adverse effects on the environment and improve economic productivity.

In the site selection assessments of industrial regions, several research techniques such as the expert system, fuzzy logic, GIS, and MCDM techniques have been applied (Puente et al., 2007). GIS, ANP, and Fuzzy-DEMATEL have been used to assess the feasibility of industrial land (Arabsheibani et al., 2016). To rank an industrial location, Taibi and Atmani, (2017) used the GIS, FAHP (trapezoidal membership function), and decision criteria. GIS, Delphi, and FAHP were utilised to assess a land region for industrial site selection (Ahmadipari et al., 2018). Gao et al. (2019) examined the regional water ecosystem risk in Shenzhen using GIS and FAHP.

There has been no research into the hybrid modelling method for selecting a suitable EIP site. This study aims to provide research students, decision-makers and EIP developers with a hybrid modelling approach that is both effective and uncomplicated to be used to study the suitability of EIP sites for selection. To achieve this aim, the GIS, Boolean logic, F-AHP [triangular fuzzy numbers (TFNs)], and WOA are used to acquire and process, select the criteria, assess the criteria weight of importance, and overlay the spatial layers and the weights. This is to provide the reliability of the criteria selected as true for EIP site selection, consider the spatial and geographical characteristic of the data, deal with uncertainty, and provide accuracy in EIP site selection.

## 2. Methodology

The tools employed are the Boolean logic, the EarthExplorer free software, Kompsat–3 imager, ArcMap (GIS) 10.3 software (its extensions – Spatial Analyst, 3D Analyst), WOA, the ArcGIS (Ahmadipari et al., 2018) and Microsoft (MS) Excel for F-AHP evaluation.

Tanjung Langsat Industrial Area (TLIA) with an area of 20.23428 km2 (Kanniah et al., 2015) was identified as a study area. It is located at longitude 1°28′N 104°01′E about 8 km from the Pasir Gudang Industrial Area, Johor Bahru district, Southeast of Johor, Malaysia. The GIS was used in capturing, collecting, analysing, and preparingthe spatial criteria data. Some of the criteria were applied to PLANMalaysia, and others were downloaded using the EarthExplorer via the Shuttle Radar Topography Mission (SRTM) of the United States Geological Survey (USGS) and Operational Land Imager (OLI) Landsat (GISGeography, 2019). The maps of the factors were subjected to screening by the Boolean logic. Kompsat-3 Imager obtained the land use land cover (LULC) of the TLIA. Euclidean distance and reclassified raster layers were prepared. F-AHP weighed the criteria using Microsoft Excel. The pairwise comparison matrix was constructed and the criteria weight importance using the TFNs with the lower, middle, and upper (l, m, u) weights organized. The F-AHP geometric average is shown in Eq(1), relative fuzzy weight in Eq(2), defuzzification in Eq(3), and normalization in Eq. (4).

Geometric average: Obtaining the reciprocal products of l1….ln, m1….mn and u1……un

$$\tilde{R}_1 = (\tilde{\alpha}_{i1}.\tilde{\alpha}_{i2}.\tilde{\alpha}_{i3}.\ldots.\tilde{\alpha}_{ix})^{\frac{1}{x}} \quad (1)$$

where $\tilde{\alpha}_{i1}$ = 1st fuzzy component; $\tilde{\alpha}_{i2}$ = 2nd fuzzy component; $\tilde{\alpha}_{ix} = x^{th}$ = fuzzy component; $\tilde{R}_1$ = geometric average

Relative fuzzy weights: Evaluate the inverse of $\tilde{R}_1$'s average, inverse in descending order by each $\tilde{R}_1$

$$\tilde{w}_1 = \tilde{R}_1.\left(\tilde{R}_1.\tilde{R}_2.\tilde{R}_3.\ldots.\tilde{R}_x\right)^{-1} \quad (2)$$

where: $\tilde{R}_1$ = 1st geometric average, $\tilde{R}_2$ = 2nd geometric average, $\tilde{R}_x = x^{th}$ geometric average, $\tilde{w}_1$ = fuzzy weight

Defuzzification: Assess the average of $\tilde{w}_1$ for each row

$$D_i = \frac{l_i + m_i + u_i}{3}, i = 1, \dots \dots .., x \quad (3)$$

where: $D_i$ = crisp weight, l = smaller weight, m = middle weight, and u = higher weight.
Weight normalization: Calculate the ratio of the summation $D_i$ to each $D_i$ to get the summation to be equal to 1.

$$N_i = \frac{D_i}{\sum_{j=1}^{x} D_j}, j = 1, \dots \dots, x \quad (4)$$

where $\sum_{i=1}^{x} N_1 = 1, i = 1, \dots \dots \dots, x$

Eqs. (1) - (4) were applied on the criteria and the alternatives based on each criterion and obtained the overall priority vector (OPVec). The sensitivity analysis (SA) was performed on OPVec to determine any significant changes in the criteria weight because the GIS-WOA significantly depends on the MCDM criteria weights. The GIS with its WOA extension was used where all the criteria and LULC layers, and F-AHP weight percent influence are incorporated and overlay.

In the F-AHP, the decision-making problem was defined and decomposed into a hierarchical structure as shown in Figure 1. The procedure of the GIS-WOA and F-AHP site selection and modelling is shown in Figure 2.

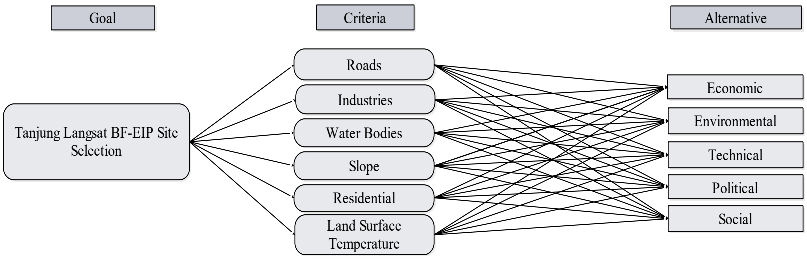


*Figure 1: Framework of TLIA EIP Criteria Site Selection*

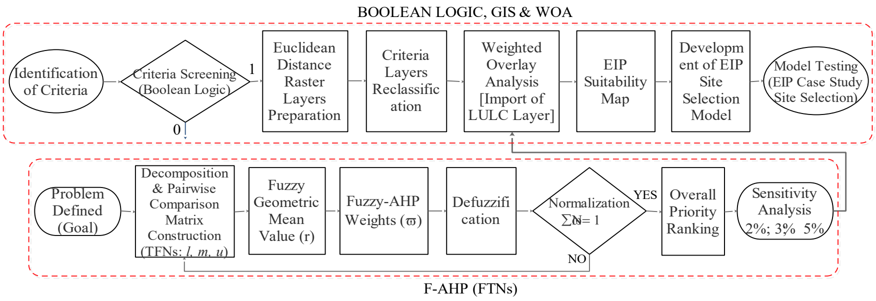


*Figure 2: GIS and F-AHP methodology flowchart*

## 3. Results and discussion

Based on the associated data from each input criteria map, the Boolean logic used the binary form of 0, 1 (false or true) in which it filtered and identified the category of each criterion and determined the factors suitable for the EIP site. Six criteria were defined as acceptable for an EIP site selection analysis which are roads, existing industries, waterbodies, slope, residential and land surface temperature. The study area is shown in Figure 3a, which presents the LULC of 2019 of TLIA in Figure 3b obtained at below 10 % cloud cover. The LULC shows a waterbody, forest, agricultural land, built-up areas, and bare soil. The spatial layers were prepared and converted into raster formats. Euclidean distance estimates the space between two correct points. The Euclidean distances were processed by setting their rasters output cell size to 30 m. The distances to EIP from roads were considered between 500 – 1,000 m, industries at 250 m, waterbodies not exceeding 1,000 m, residential areas between 2,000 – 5,000 m. The concentration of slope was put at 10 % and land temperature at 28 °C. For priority and ease of suitability analysis, the criteria layers were reclassified at a resolution of 300 dpi, and the different scales connected with each criterion were transformed to a common scale. The criteria were reclassified into 5 regions (1-5), the closest criteria got the largest preference value and the farthest got the smallest value. The EIP site map output was categorised as very-highly-suitable, highly-suitable, moderately-suitable, low-suitable, and unsuitable sites based on the reclassification groupings. Due to too many maps, Figures 3c and 3d are representatives of the maps of Euclidean distances and Figures 3e and 3f are reclassified layers. Figures 3c and 3d show roads and existing industries, while Figures 3e and 3f show slope and surface temperature layers. These are input spatial layers into the database in the GIS.

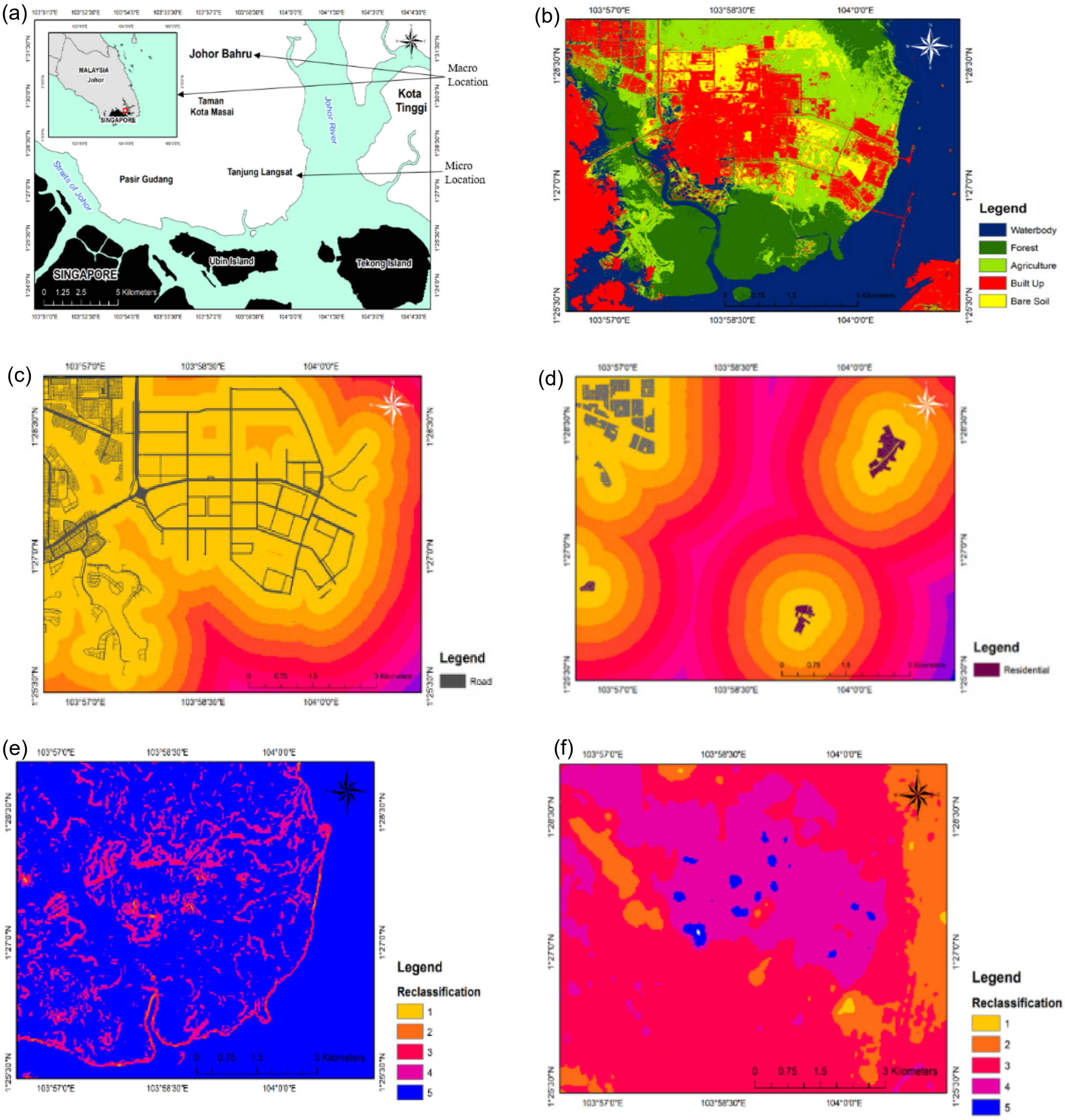


*Figure 3: (a) Map of TLIA, (b) Land Use Land Cover of TLIA 2019, (c) Roads Euclidean Distance, (d) Residential Area Euclidean Distance,(e) Slope Reclassified, (f) Land Surface Temperature Reclassified*

As shown in Figure 4a waterbodies weigh the highest rank, followed by roads, residential, existing industries, surface temperature and slope. Waterbodies close to the EIP site facilitate sea transportation of bulky materials, residential use, industrial cleaning and cooling (Gao et al., 2019). Roads reduce transportation costs and residential areas close to EIP site provides skilled/unskilled workforce (Rikalovic et al., 2018b). Existing industries enable industrial symbiosis, while good sunshine in an area provides an optimal temperature for solar RE (Kamali et al., 2017). A concentration of slope above 10 % can increase road and building construction costs (Fang and Partovi, 2021). The SA of 2 and 3 % show no significant change except for roads and water bodies under 5 % that are slightly above the original weight. The slight changes are characteristics of MCDM tools (Rikalovic et al., 2018b), the original weights were used in the TLIA EIP site suitability analysis. WOA was performed with the LULC, Euclidean distance, reclassified raster layers, and the overall criteria weight from F-

AHP. The output map in Figure 4b produced by the GIS-MCDM model showing two very-highly-suitable EIP sites in the northern part. A highly-suitable site is marked light green colour covering a large area, while a moderately-suitable site shown in yellow colour also covers a large area within the first two best sites.
As EIP site selection criteria are factors that determine its goal, alternatives are characteristics that support the criteria to achieve the objectives. The economic, environmental, social, technical, and political characteristics were assessed simultaneously with the criteria and obtained 27, 23, 20, 17, and 13 %. The percent weight indicates that the economic aspect of the EIP site must first be studied, followed by the environmental, social, technical, and political aspects. The GIS-WOA-F-AHP model produced suitable sites with simplicity and high accuracy. This shows the robustness of the Boolean logic, GIS, WOA, and F-AHP tools for EIP site suitability selection.Most single traditional MCDM methods have shortcomings, and to solve this problem, it is possible to use a cutting-edge approach (Chumaidiyah et al., 2020). Two or more MCDM tools from the same or different groupings can be integrated. Scoring, proximity, paired comparisons, performance, consumer services, and ambiguity interpretation are the groupings. This combination spurs the advantages of either technique, removing the limitations of each approach to producing efficient and accurate results. In this study, the state-of-the-art is acknowledged where the hierarchy-fuzzy logic (pairwise comparison and uncertainty groups), Boolean logic and GIS (geospatial technology) are combined, and realistic results are obtained.

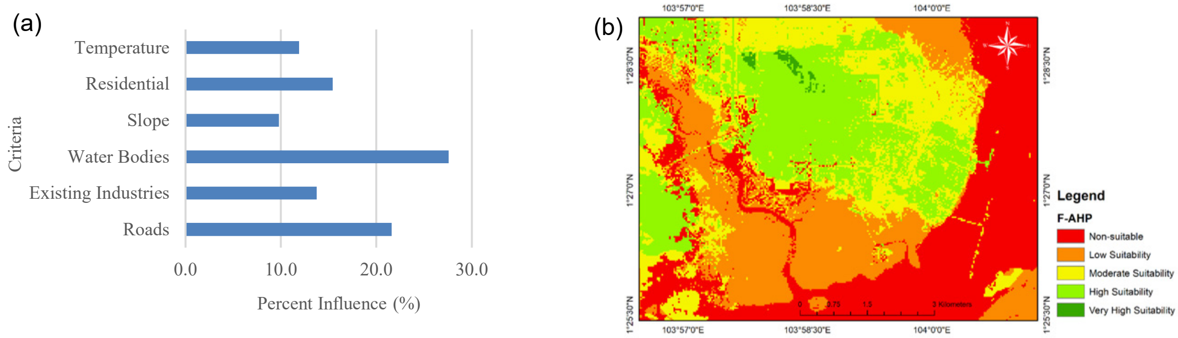


*Figure 4: (a)Criteria Weight of Importance, (b)WOA Suitable EIP Site Output*

## 4. Conclusions

The spatial criteria for a suitable EIP site were acquired, analysed, and the Euclidean distance and reclassified raster layers were produced using Boolean logic and GIS. The six criteria weights were assessed using the F-AHP (TFN) for percent influence and ranking. The results were used to design a hybrid modelling method that is effective and simple for the selection of a suitable EIP site. EIP objectives are to create symbiosis among clusters of industries, enhance resource efficiency, reduce carbon emissions, and mitigate global warming. The results of the criteria weight importance show waterbodies, roads, residential areas, existing industries, surface temperature, and slope ranked 28, 22, 15, 14, 12, and 7 %. The model was tested on TLIA where an EIP site suitability map with two very-highly-suitable sites (5 %), extensive highly-suitable sites (45 %) and moderately-suitable sites (25 %) were identified. The hybrid model used the pairwise comparison, uncertainty, and geospatial groups which each used the strength and enhanced the flaw of one another forming state-of-the-art tools demonstrating efficiency in the EIP site selection. The suitability site selection by the hybrid model has discovered TLIA to have a vast viable EIP site, allowing for industries synergy, clean manufacturing, and fiscal, environmental, social benefits, as well as industrial sustainability to curb GHG emissions. The model is designed for greenfield and brownfield EIP site selection. The government, researchers, EIP developers/investors can simply use it for EIP site analysis. It is suggested that artificial intelligence can be combined with the model for further study on EIP site suitability.

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