WIND TURBINE SITE SELECTION IN INDONESIA

BY

GALIH PAMBUDI

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING (LOGISTICS AND SUPPLY CHAIN SYSTEMS ENGINEERING)

SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
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A Thesis Presented

By

GALIH PAMBUDI

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Abstract

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Bachelor of Engineering, Universitas Gadjah Mada, 2016

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Wind farm sites are selected in spacious regions which have more output potential within constraint resources. Due to its spacious terrain, Indonesia has great potential for building wind power plants, providing the perfect settings to generate electricity using wind energy. Keeping in view the reliability and sustainability of wind farm sites, the selection of the most suitable locations for optimal result is of prime concern to generate greater amount of energy with less utilization of resources. In this study, the focus is on proposing a multi-criterion approach to find the most suitable location for building wind farms. Locations from every region of Indonesia were selected based on two levels defined by district level to province level. All districts and provinces are considered as Decision-Making Units (DMUs) which are used to measure the efficiency scores using Dual Data Envelopment Analysis (DDEA) method. Two levels are defined to find the best feasible locations within Indonesia from 165 districts and 33 provinces with major focus on geographical and structural technicality of each DMU. The results show that South Sumatra province has the highest priority potential for the construction of wind power plants, especially in the district of Palembang. West Papua, Papua and Maluku provinces have descending priority based on good infrastructure accessibility and less prone to natural disaster.

Keywords: Dual data envelopment analysis, Wind Power Plant, Site Selection, Decision Making Unit.

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Chapter 1
Introduction

The propose study in the first chapter are divided into four sections. Section 1.1 gives background of the proposed study and show the importance of the research study. Section 1.2 contains details of problem statement of proposed study to define the issue of the research. Section 1.3 gives the objective of proposed study presents the framework of this study. Section. Section 1.4 The advantages of the proposed study provide the benefit of the study to apply in the research area.

1.1 Background

Natural energy resources such as wind energy is renewable, and is freely available which could lead to the sustainability of energy usage. Selecting the most suitable sites which have the optimal wind energy resource is a complicated decision-making process. It is considered as primary concern based on the sustainability and reliability aspects. The selection of the optimal locations is very important including several factors the topography of the area and the usage of the decision support models could fulfill the requisites and shows the optimal outcome. It means modelling, formulation and determining solution of the site problem that can be implemented in establishing facilities in the selected area. Different literatures show that there are different approaches for selecting the optimal location for wind power plant site, as follows Haydar *et al.* [1] defining the optimal area in university for a station of wind observation based on Analytical Hierarchy Process (AHP) approach. Bhatnagar *et al.* [2] the establishment of gas stations and power plants using location factor as multi-criteria. Afshartous *et al.* [3] to determine the location of the coast guard air station based on Improved Optimization Model. Gamboa *et al.* [4] determining wind plant site selection as a multi-criterion used social framework. Choudhary *et al.* [5] determined site selection of thermal power plant based on Fuzzy DEA. As it is evident from the previous studies, the site selection is of prime concern for establishing a facility at some place. It needs multitude factors to be considered, making the decision hard and required complex modeling. In this study, the method based on Dual Data Envelopment

Analysis (DEA) approach with multi-criteria is used as site selection mechanism for wind power plants construction within Indonesia. In Indonesia the energy demand is growing dramatically than population. At present, Indonesia have six main types of power plant use gas, steam turbines, combined cycle, geothermal, diesel engine, and hydro-power where fossil fuel is the major energy generation [6]. In this decades, for genererating the electricity in Indonesia, the resources up to 96% using fossil fuel and just 4% uses renewable energy. Hence, the government policy targets a portion of renewable energy resources to be increased up to 17% in 2025 [7]. The current energy policy in Indonesia is central in Fossil fuel. Decreasing of fossil fuel resources and growing environmental concerns are challanging viewpoint in Indonesia's energy policy which leads to the propose of using renewable energy to increase energy efficiency [8]. Indonesia as a archipelago country, having huge potential for wind power generation because of high wind rate in most of the regions. The criteria of wind turbine site selection should be selected carefully before making decisions.

1.2 Problem Statement

Determining the potential of using the wind power in the possible region is important. In spite of the comprehensiveness in location considered for the optimization of wind power plants, the criteria and the method for the site selection that will be used to compare the potential of the region must be carefully selected. Location problem includes simulation, formulation and model in establish the facility in every region which is likely to have multiple factors and is difficult for the analysis. The quantitative approach must be used to determine the suitable locations.

1.2 Objectives of Propose Study

This study considers an integrated mathematical approach for location optimization of wind plants. Determining all criteria that significantly influences the establishment of a wind farm in Indonesia is important. The implementation of the proposed approach to decide the most suitable location for building of a wind power plant in Indonesia is based on a Dual Data Envelopment Analysis (DEA) for wind farm power plant.

1.4 The Advantages of Propose Study

The advantages of this proposed study hopefully can be used as the alternative approach to decide site selection, generally in any case and especially in wind plant power plant. This proposed study can help improve the reseach which have correlation with location optimization in wind farm location on the other location.

Chapter 2
Literature Review

As a consideration of the literature, the proposed study refers several studies which have been reviewed as a reference. Section 2.1 show the insight of the literature review. Section 2.2 presents research gap which is used in the proposed study. Herewith is further description of the research and the comparison of the previous studies.

2.1 Literature Review

Data envelopment analysis (DEA) is for analyzing the performance efficiency of the comparable units called decision-making units (DMUs) as quantitative method. Every DMU performs the same purpose by using ratio between input and output criteria which are characterized by the modeled system [9]. Several references which have used DEA for site selection such as Ertek *et al*. [10] for determining the efficiency of on-shore wind turbines they provided data centric analysis. Saglam, U [11] The goal of those paper was to evaluate quantitatively efficiencies of 39 states wind power performance for electricity generation by using multi-criteria methods as DEA. Wu *et al.* [12] in China to perform efficiency assessment of wind power plant used based on two stage of DEA. These studies identified potential inefficicient factors and try to seek out the factor which can improve the performance of wind farm. Azadeh *et al.* [9] provided wind farm site selection under uncertainty using Hierarchical Fuzzy DEA. Since traditional DDEA models cannot be used to combine the indicators especially in qualitative data. Sueyoshi *et al.* [13] proposed an approach improvement as Range Adjusted Measure (RAM) which is as integrated of DEA. Seiford *et al.* [14] proposed the results from multi-stage DEA involved the input and output criteria which are validated by Numerical Taxonomy and Principal Component Analysi. In this study, the efficiency of DMUs in the selection of most suitable location for wind farm plant is based on land cost, road accessibility, infrastructure cost, population density, supply demand, natural vulnerability, wind velocity and total area. This research proposes a multi-criterion apporach based on Data Envelopment Analysis (DEA) for analyzing the most feasible wind farm site selection in Indonesia.

According of the literature that have been reviewed, the summary of the case study is shown in Table 2.1. Table 2.2. lists the criteria which are significant influence in the site selection of wind farm. Therefore, the methods based on the quantitative approach that have been used are shown in Table 2.3. Further information shows in the describe as below:

Table 2.1 The summary of case study

No	Author	Year	Case Study
1	Saglam, Ümit [11]	2017	efficiency assessments of 39 state's wind power location using A two-stage data envelopment analysis in the United States
2	Yunna Wu, et al [12]	2016	Efficiency assessment of wind farms location using two-stage data envelopment analysis in China
3	Azadeh, Ali et al [15]	2013	Location optimization of wind power generation systems under uncertainty using hierarchical fuzzy DEA in Iran
4	Azadeh, Ali et al [9]	2010	Location optimization of wind plants by an integrated hierarchical Data Envelopment Analysis in Iran
5	Ertek, Gürdal et al [10]	2012	Insights into the efficiencies of wind turbines using data envelopment analysis

Table 2.2. Summarizes the relevant criteria in the wind farm site selection

No	Author	Year	DMU	Input	Output
1	Saglam, Ümit [11]	2017	39	Total Project Investment ($), Annual Land Lease Payments ($)	Average wind blow, Wind Industry Employment, Annual Water Savings (Gallons), CO_2 Emissions Avoided (Tons)
2	Yunna Wu, et al [12]	2016	42	Auxiliary electricity consumption, Wind power density	Electricity generated, Average wind blow

No	Author	Year	DMU	Input	Output
3	Azadeh, Ali et al [15]	2013	25	Level 1 Land Cost Level 2 Intensity of natural disasters occurrence,	Level 1 Population and human labor, Distance of power distribution networks, Level 2 Average wind blow, Quantity of proper geological areas, Quantity of proper topographical areas, Consumer proximity
4	Azadeh, Ali et al [9]	2010	25	Level 1 Land Cost Level 2 Intensity of natural disasters occurrence,	Level 1 Population and human labor, Distance of power distribution networks, Level 2 Average wind blow, Quantity of proper geological areas, Quantity of proper topographical areas
5	Ertek, Gürdal et al [10]	2012	74	Diameter of Plant	Nominal Wind Speed Nominal Output (kW)

Table 2.3. Summarizes the relevant methods in the wind farm site selection

No	Author	Year	Primary DEA	PCA	NT	Tobit	Hypotheses Testing
1	Saglam, Ümit [11]	2017	v			v	
2	Yunna Wu, et al [12]	2016	v			v	
3	Azadeh, Ali et al [15]	2013	v	v	v		
4	Azadeh, Ali et al [9]	2010	v	v	v		
5	Ertek, Gürdal et al [10]	2012	v				v

Where: DEA (Data Envelopment Analysis), PCA (Principal Component Analysis), NT (Numerical Taxonomy).

2.2 Research Gap

The research gap of this proposed study is wind farm site selection in province of Indonesia using multi-criteria approach based on hierarchical dual Data Envelopment Analysis (DEA). The integrated data envelopment analysis will be applied on two levels of DEA, the first level considers finding the best suitable province in Indonesia and the second level focuses on sub-district within the province based on the distance from remote areas. The possible factors used in the districts level as defined by land cost, population in region, ratio of free usage area, primary road, secondary road, tertiary road, and total cost of infrastructure. In the provinces level as defined by wind velocity, population in province, total area, electricity consumption, less of land slide, flood, earthquake and volcanic eruption. Determining the efficiency for districts and province level based on Hierarchical Dual Data Envelopment Analysis. Hesitant Fuzzy Linguistic Term Set (HFLTS) for determining the weight for importance criteria. The validation of the significant criteria based on Principal Component Analysis (PCA). Finally, comparing three methods for deciding the most suitable location for wind turbine site selection in Indonesia.

Chapter 3
Research Methodology

In this chapter further information about the criteria and methods used in this proposed study is described. Section 3.1 provides description of the possible factors which have influence to the wind farm site selection. Section 3.2 presents the methods which are applied in this proposed study.

3.1 Possible Factors

Based on the literature review, the proposed factors used in this study are districts (Level 1) and provinces (Level 2) of Indonesia as shown in Figure 3.1. The integrated model for wind farm site selection organizes the factors into two levels defined as input and output. The optimization technique is based on Dual Data Envelopment Analysis method to find the most efficient location. The integrated level criteria are developed to select the most suitable location in term of province of Indonesia.

Fig.3.1 Maps of provinces in Indonesia

3.1.1 Level 1 Criteria

The objective of using level 1 criteria is to determine the most suitable province in Indonesia for establishment of wind farm plant based on the efficiency of the location. The Level 1 criteria are:

Land cost by districts in Indonesia: the land cost has become an important criterion due to the unprecedented increase in Indonesian population, which must be included for site selection. For selecting a wind farm site, it requires more spacious area as compared with other energy sources. Table 3.1 shows the comparison of the amount of the land required for the construction of each kind of facility [16]. Area required for wind farm is up to 9900 km^2/GW/year which is 283 times more than coal plant. Its means that the land cost is the main important criterion for wind farm site selection. Figure 3.2 shows the data of land costs in some districts in Indonesia.

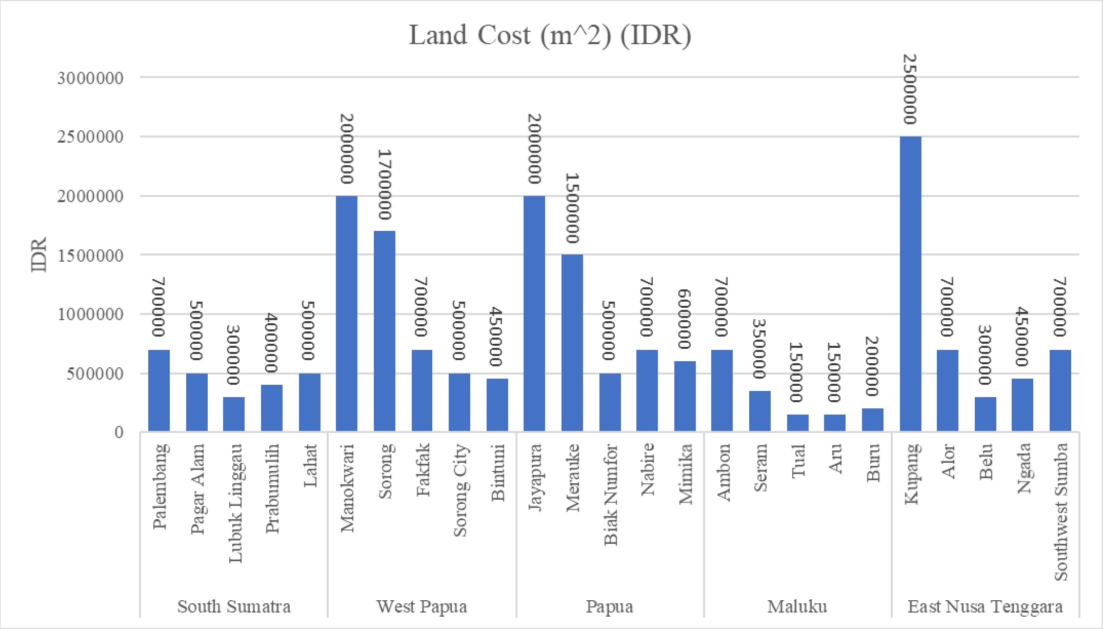

Fig.3.2 Land cost of districts in Indonesia

Table 3.1 Comparison of the land requirement in different power plant [16]

Technology	**Land use in km2/GW per year**
Biomass	25,600
Wind power plant	9,900
Hydroelectric	7,900
Solar PV	630
Coal	35
Oil	20
Natural gas	20
Nuclear	10

The type of road infrastructure: Good road accessibility to the constructed facility is one of the most importance considered factor for reliable, timely transportation and distribution of goods to and from the facility. Different road facilities (i.e., primary, secondary and tertiary roads) have different distribution lead time which can affect the accessibility to the facility. Data of the road infrastructure are shown in Figure 3.3. Primary and secondary roads are main roads and can be used for the transportation of heavy goods. On contrary to this, tertiary roads are mostly used as connectors to the primary and secondary roads such as, small bike roads and village roads. Hence, for timely distribution of goods to and from the wind farm need the most effective routes. In this study, primary and secondary road infrastructures are used as a preference indicator for wind power plant construction.

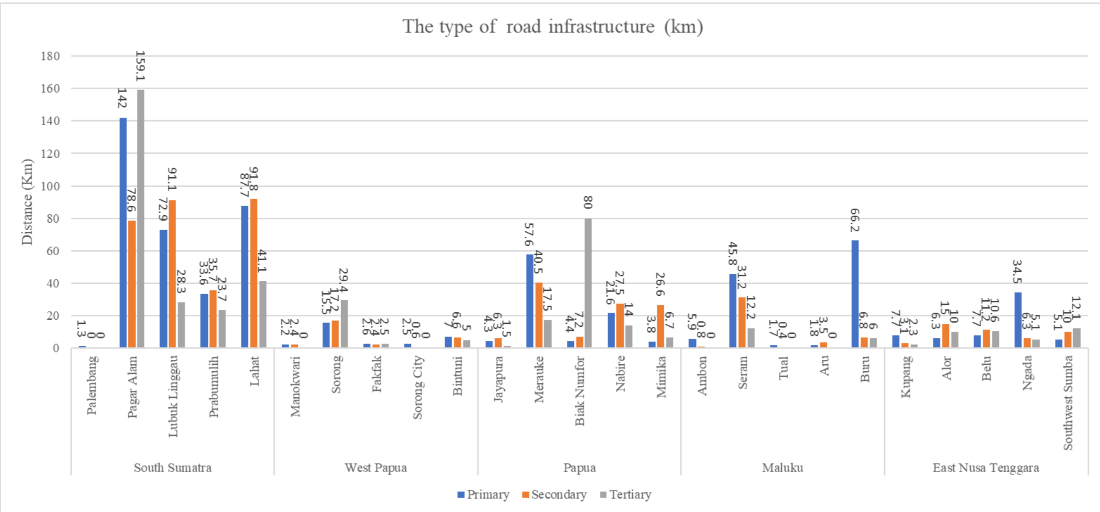

Fig.3.3 Types of road infrastructure

Relevant data, especially types of road infrastructure within each district in every province of Indonesia, will be used. Firstly, finding the ArcGIS Maps for every district from the Ministry of Public Works and Public Housing of Indonesia's data representing the infrastructures maps in every region such as types of road as well as natural resources. By using the ArcGIS, national roads, province roads are defined as primary road, in the maps are shown as dark red line. The district and regional roads are considered as secondary road type represented as light red line on the maps. The tertiary road is one of important criterion which should be careful determined and set, due to the limited resources in ArcGIS. They can be determined by looking for village roads or small roads which are less than 3.6 m in width. In here, the types of road infrastructure by ArcGIS maps and google maps. Fig. 3.4. represents the difference types of primary roads and secondary roads.

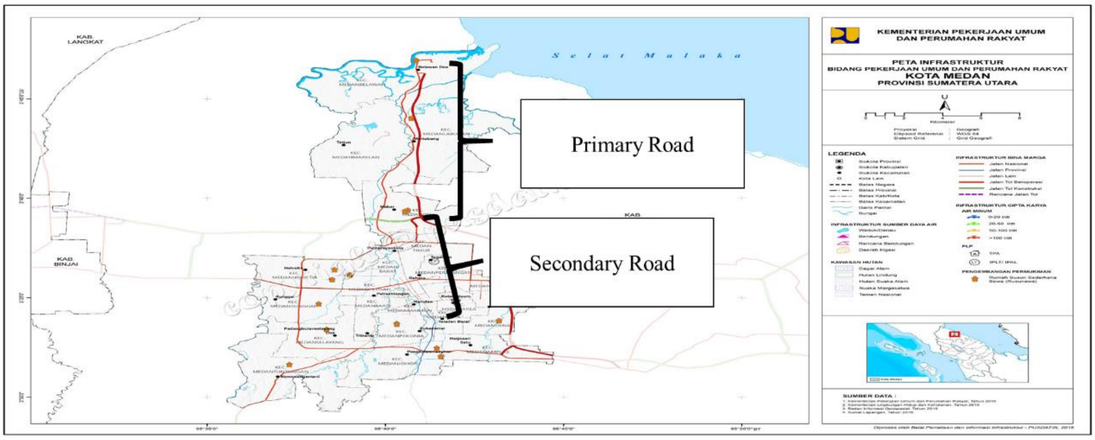

Fig.3.4 Types of road infrastructure in Medan North Sumatra

The border point between the primary and secondary roads is used to determine the distance of the roads. Fig.3.5 shows the distance of primary and secondary roads in Medan Region. It shows that primary road as the significance distance in Medan City is 18.6 km and for secondary road is 9.8 km. The distance is based on a spotted location in remote region which is suitable to establish a wind farm. Due to the good infrastructure in the main region of Medan, there is no need for tertiary road so this region just have 0 km of it and do not need to build additional infrastructures.

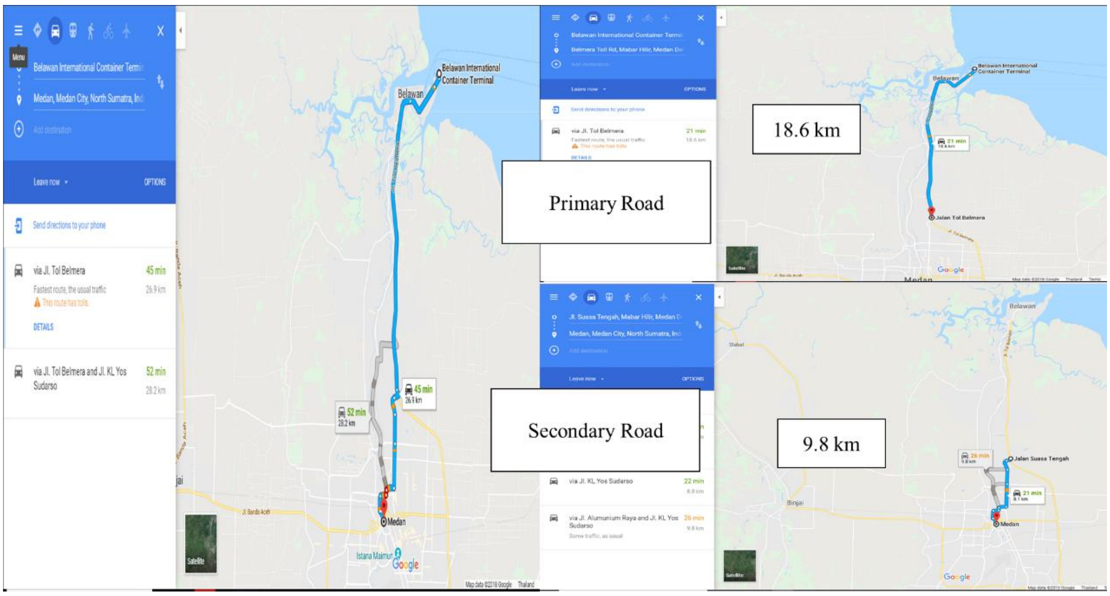

Fig.3.5 Distance of the primary and secondary road infrastructures in Medan

Total cost of infrastructure (IDR): The construction of the infrastructure requires a lot of capital cost incurred. So, selection of the site with less incurring cost for building new roads to access the facility is also very much important to avoid extra expenses thus increasing the overheads of the construction projects. The data in this study is shown in Figure 3.6 which are the sites selected by the minimum capital cost for the construction of tertiary roads with the shortest distance. In other words, if in any case the construction of the infrastructure is inevitable and unavoidable, tertiary roads are given preference over primary and secondary roads. In our approach we prefer the construction of tertiary road as compared with secondary road if the width of the dispatching vehicle is up to 5m. As the average width of the tertiary roads in Indonesia is up to 3.6m and we included 1.4m to accommodate the convenience of shipment. So, the minimum cost of infrastructure is another input criterion in DDEA model.

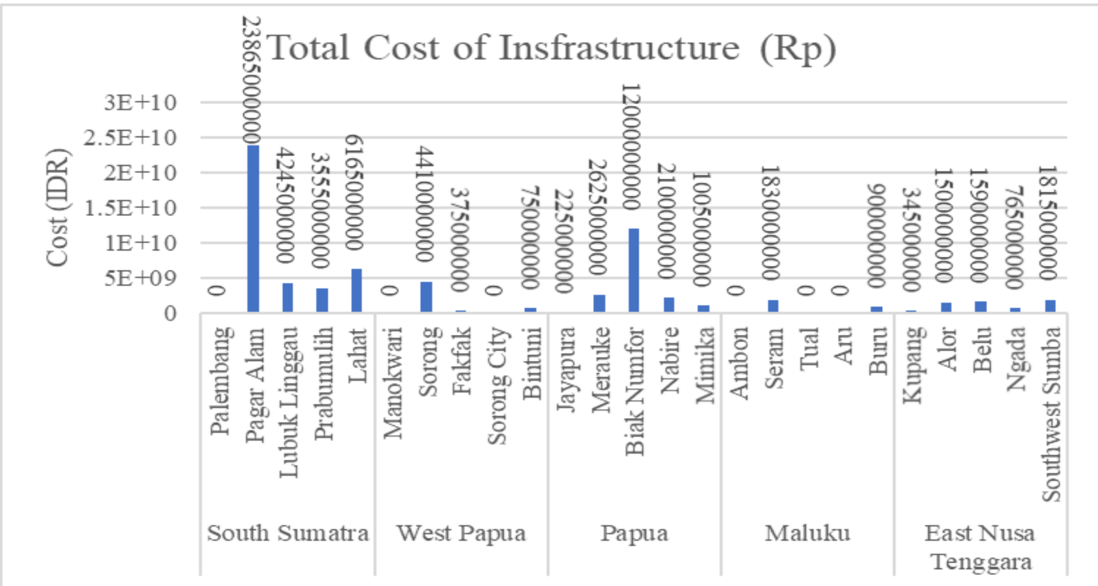

Fig.3.6 Total cost of infrastructure data

The total cost of infrastructure for each region is collected based on Widarno, B et al (2015). The included components are labors, materials, tools and equipment as shown on Table 3.2. as cost analyst for each 1 m length of road. As a result, the total area of 1 m^3 is approximately 150,000 (IDR) (1 USD as 13,994.25 IDR). As an example, from Fig.3.6. consider one of regions in South Sumatra where the selected region to build infrastructure is Pagar Alan. In Pagar Alan, there are up to 159.1 km as tertiary road and needed to expand the road for shipping the wind power materials to the location. The total cost for building tertiary roads in Pagar Alan is 159.1 x 1000 m x 150,000 IDR which is 23,865,000,000 IDR.

Table 3.2 Cost analyst for 1 m length of road infrastructure

No	Component	Dimension	Coefficient	Cost (IDR)	Total cost (IDR)
A	Labors				
1	Labor	Hour	0.221	7,500	1,651
2	Foreman	Hour	0.0314	12,500	393
B	Materials				
1	Aggregate B class	1m x 3.6m	1.2	140,000	68,000
C	Equipment and tools				
1	Wheel loader	Hour	0.0314	375,000	11,775
2	Dump truck	Hour	0.1655	150,000	24,825
3	Motor grader	Hour	0.0092	355,000	3,266
4	Vibratory loader	Hour	0.008	316,365	25,310
5	Pneumatic tire loader	Hour	0.0115	345,725	2,976
6	Water tanker	Hour	0.0383	153,240	5,870
7	Assisted tools	Hour	1		
D	Total cost of labor per m^3				145,066

Population by district in Indonesia: for maintenance and operational technicality in case of emergency the wind power plant should be established in regions with easily available human resources. It can likely decrease the resources management for the transportation cost of labors, accommodation of labors and expert availability when needed. The choice of a centered place with easy accessibility of human resources is an important output indicator in the DDEA modal calculation. Figure 3.7 shows the population in districts of Indonesia.

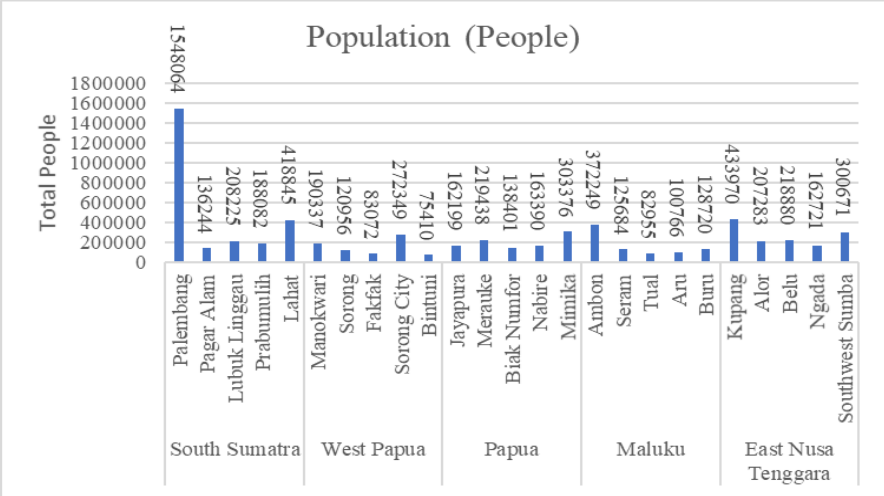

Fig.3.7 Data of population in districts

Ratio of free usage area: Areas with greater value of free area usage ratio near to one are considered more suitable for establishment of the wind power plants. The free usage area means the ratio between total area divided by population in each region. The more available land is preferred and used as output in DDEA modal calculation. Figure 3.8 shows the data of the free usage area ratio.

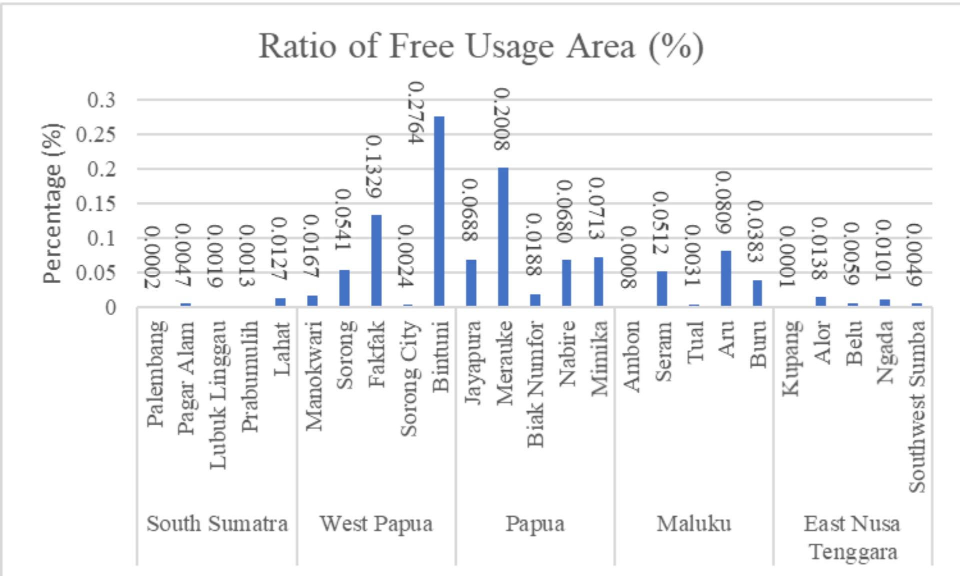

Fig.3.8 Ratio of free usage area

3.1.2 Level 2 Criteria

In the second level, the criterion of DDEA is to find the most appropriate province in Indonesia for constructing wind power plants based on the geographical and technical structures as input and output indicators for DDEA modal calculation. The indicators in this level are mentioned as below:

Electricity consumption: This criterion based on the consumption of the electricity which have been recorded in every province by Giga Watt per Hour (GW/h) including general activity of electricity usage which are shown on Figure 3.9.

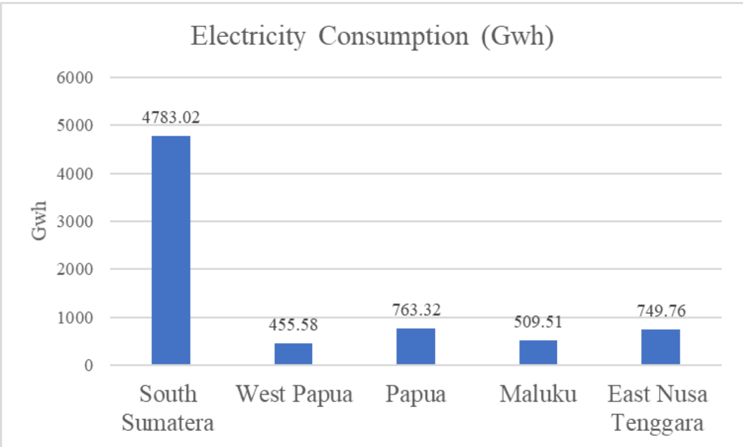

Fig.3.9 Data of electricity consumption in Indonesia's Provinces

Natural disaster: The probability occurrence of natural disasters in the region have significant impact on wind farm site selection. The damage caused by natural disasters such as flooding, volcanic eruption, earth quakes, and land sliding have menaces effect on site selection. Figure 3.10. shows the data of natural disasters in provinces of Indonesia. These disasters may accumulate extra cost of maintenance, thus increasing the maintenance and operational overheads of wind power plants. Selection of the safe sites is very core fundamental in decision making for selecting locations for new facility. These four main parameters (i.e., flooding, volcanic eruption and earth quakes, land sliding) are included in the list of natural disasters as input indicator.

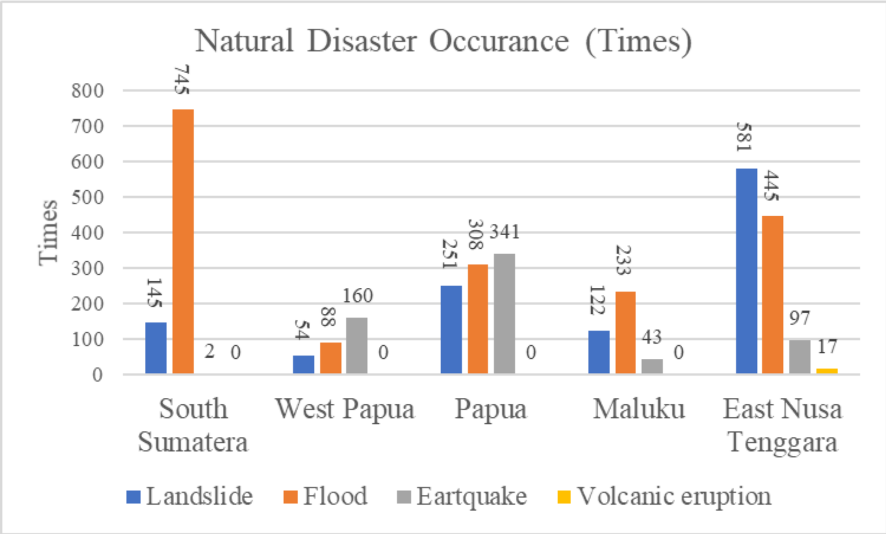

Fig.3.10 Data of natural disaster in provinces

Wind velocity: The wind velocity is the most important and primary criteria which must be included in the model. Every province has different wind rate based on the geographical features. Areas with greater wind velocity are the most suitable locations for economic growth of energy generation. Based on the data on Figure 3.11 shows that several provinces have varieties of wind velocities. Low wind speed (LWS) and high wind speed (HWS) are based on different configurations such as wind resources, aerodynamics, and structural design/ analysis [17]. The aerodynamics loads are smaller per unit length for the LWS blades but the increased span means that total forces are closer or larger than the equivalent HWS blade. Due to that for construction a wind farm in Indonesia should use the technology namely low speed wind turbines. The design on LWS and HWS blades differ in the blade's lengths and the magnitude of aerodynamic loads [17]. Average wind speed in provinces on Indonesia are including in low to medium of wind speed according to Table 3.3. Low and medium wind speed sites are mostly classified on Class II-IV. The design of low speed wind farm mostly based on the blades structural design where blades typically lengthened versions up to 39 m. The materials for modern wind blades are primarily glass fiber reinforced polymer structures.

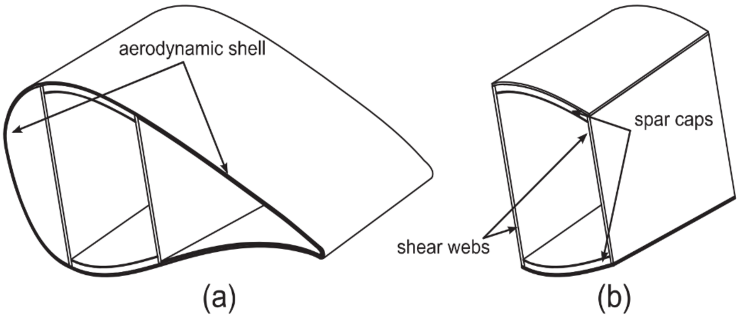

Fig.3.11 Gravity loading; a. full blade; b. spar-only simplification

A wind turbine blade in low wind speed is a cantilever which is shown on Figure 3.11. Gravity loading causes edgewise bending, as illustrated in Figure 3.12, the direction shows reverse twice per full rotation and on the maximum loading condition as flap-wise bending when the wind direction is perpendicular on the blade [17].

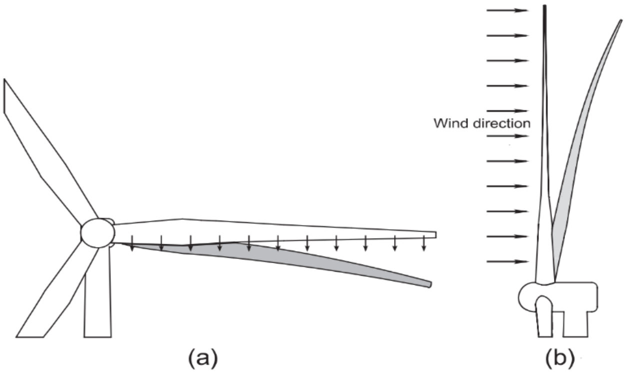

Fig.3.12 Blade loading cases; a. edgewise bending; b. flap-wise bending

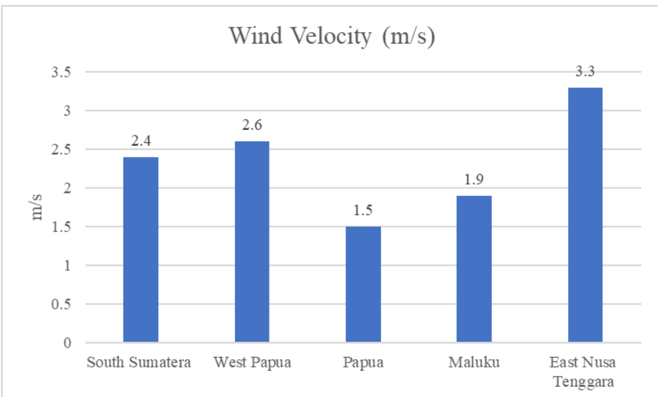

Fig.3.13 Data of wind velocity in provinces of Indonesia

Table 3.3 Wind class definitions [17]

Parameter (m/s)	Class I	Class II	Class III	Class IV
Average wind speed	10	8.5	7.5	6

Total area: Every province has different land use activities such as industrial zones, housing schemes, available landscapes with respect to the total area of the province. The province which has more spacious area is preferred. Because of the importance of the available land it is considered as a great influential indicator in site selection as output parameter.

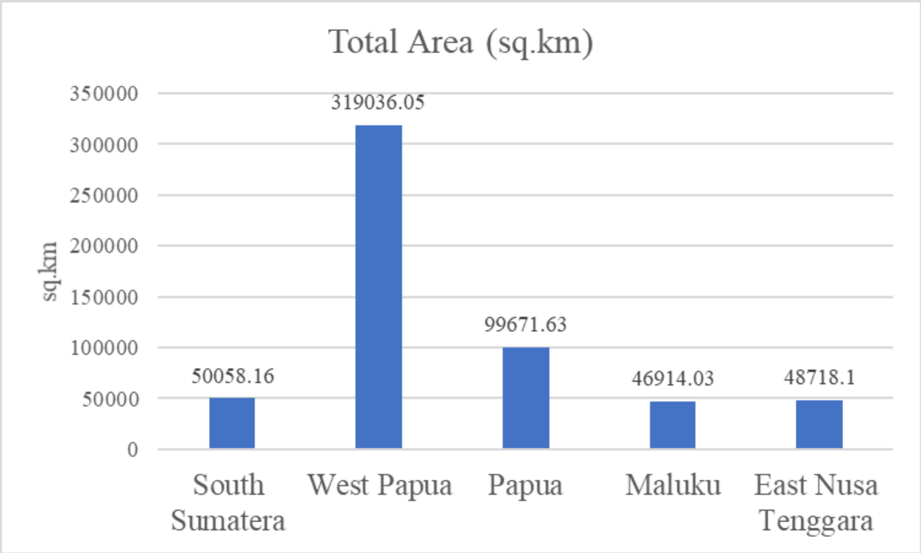

Fig.3.14 Data of total area in provinces in Indonesia

Population by province in Indonesia: Generally, higher population in a province is preferred hence it implies a higher supply for electricity. Areas with more human being are given priority in order to minimize the cost of energy distribution to the far or bounder places.

3.2 Methodology

In this study have a multi-criteria approach to find the most suitable location for establishment of wind farms. Based on this study, the concept of location as efficiency in sub-region is defined for wind plants location. Figure 3.15. presents the flow chart of this proposed study. The proposed study is starting by defining of input and output factors that already mention before, finding the data and analyst it, then measuring the amount of the decision-making unit to verify the amount of input and output. Location analysis by Dual Data Envelopment Analysis (DEA) in two level and combine it to get the rank of the DEA results, after that would like to validate the result of DEA using principal component analysis model to verify the significant influence of the criteria to the DMU rank. The location optimization of the wind plant by DEA model are shown by the most suitable location in sub-region of province in Indonesia.

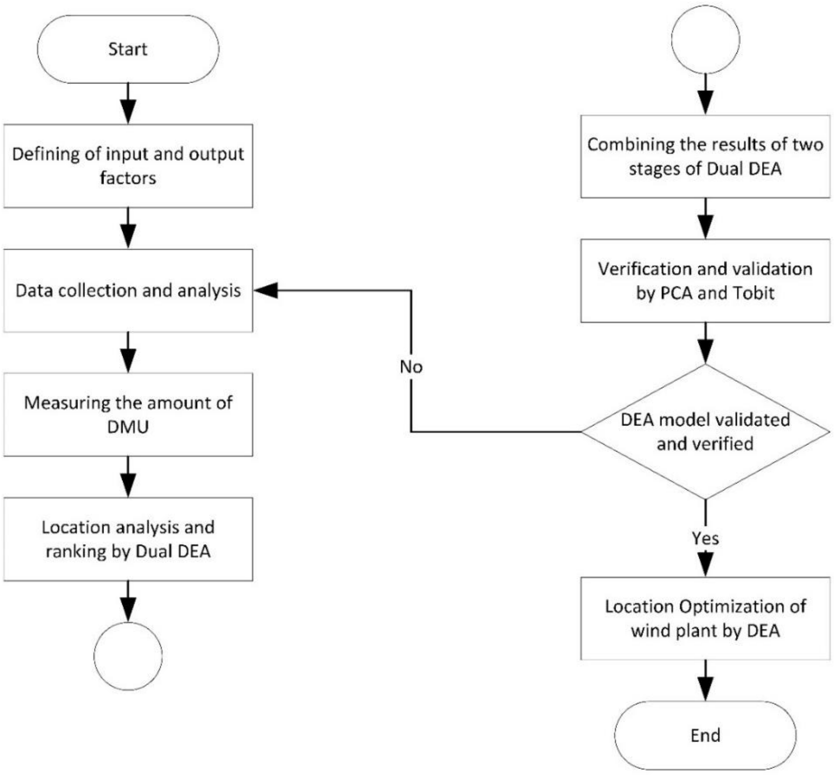

Fig.3.15 Flow Chart of the Proposed Study

The propose methodologies which are used in this research topics are explaining briefly as below.

3.2.1 Dual Data Envelopment Analysis

This research considering multi-criteria approach to find the most suitable location for founding a wind farm. Hence, this propose study consider location based on the provinces and districts in Indonesia and find the appropriate location. Every province and district in here become the decision-making units (DMUs) which are used to measure efficiency score. Data envelopment analysis is a non-parametric and multivariate method to measure DMUs implementaion. In this research, the method based on the hierarchical dual form of DEA (DDEA) is used. The DMUs are calculated using a mathematical method as Linear programming using empirical data of inputs and output, then measure the performance scores using the ratio between input and output to compare the performance scopes generated. The measure of efficiency for DMU is given by following linear programming [18].

$$\begin{aligned} & Minimize\,\theta \\ & s.t. \sum_{j=1}^{n} \lambda_j X_{ij} \leq \theta X_{io}, i = 1, 2, ..., m \\ & \sum_{j=1}^{n} \lambda_j Y_{rj} \leq \theta Y_{ro}, r = 1, 2, ..., s \\ & \lambda_j \geq 0, \forall j \end{aligned} \quad (1)$$

where:

θ : the efficiency of DMU,

λ_j : weight given to DMU,

i : input of DMU i,

r : output of DMU r.

3.2.2 The Hierarchical Model for two Level DDEA

In this section, the hierarchical of total efficiency scores from two levels of DDEA is illustrated. In Level 1, all districts are considered, where the districts in province k is represented by a set J_k using index j_k. Level 2 as provinces level, where there are K provinces, and each province is given by a subscript k. Combining results from both levels consists of three steps [9], which are explained as follows:

Step 1: Normalize in Level 1 by scaling each efficiency value by the average efficiency of group k.

$$f_{kj_k} = e_{kj_k} / \overline{e}_k, \overline{e}_k = \left(\sum_{j_k \in J_k} e_{kj_k} \right) \Big/ |J_k| \quad (2)$$

$|J_k|$ represents the number of members in set J_k.

Step 2: Calculate the combine efficiency by multiplying the scaled value of f_{kj_k} with the efficiency of Level 2 (e_k).

$$g_{kj_k} = f_{kj_k} \times e_k \quad (3)$$

Step 3: Scaling the value of g_{kj_k} . h_{kj_k} is the total score between two levels.

$$h_{kj_k} = g_{kj_k} \times R, R = \min_{k,j_k} \left\{ 1/g_{kj_k} \right\} \quad (4)$$

3.2.3 Fuzzy Primary Data Envelopment Analysis

In the scope of the study, wind turbine site selection which is one of the most important problems related to sustainable energy have many alternatives and multi criteria decision-making. Due to the uncertainty of decision makers in criteria choices, the hesitant decision-making approach based on hesitant fuzzy linguistic term sets (HFLTS) is chosen for solution of the complex problem. The upper bound and lower bound weight ratio between criteria are used for calculating on hierarchical primary data envelopment analysis. The algorithm hesitant fuzzy linguistic term sets are proposed by Yavuz et al [19] which provides the capability to deal with hesitancy of decision makers in assessment. The main of HFLTS is aim to advance flexibility and completeness of linguistic importance based on the fuzzy linguistic approach. Linguistic term is relating to language name which is used mostly in fuzzy to define the uncertainty relation. Context free grammar such as at most, between and so on is the figure for dealing with uncertainty relation. This algorithm combines the linguistics term sets with context free grammar to handle the complexity of multi-criteria problems with hierarchical structure using fuzzy approach.

The steps of the algorithm are shown as below,

Step 1. Defining the linguistic term sets S .

S = {no importance (*n*), very low importance (*vl*), low importance (*l*), medium importance (*m*), high importance (*h*), very importance (*vh*), absolute importance (*a*)}.

Step 2. Defining the context-free grammar G_H.

G_H = {lower than, greater than, at least, at most, between, and}.

Step 3. Collecting the preference relations provided by experts (p^k).

Step 4. Transforming the preference relations into HFLTS.

Step 5. Obtaining the envelope between pesimistic and optimistic preference relation.

$\overline{\chi} = \Delta\left(\frac{1}{n}\sum_{i=1}^{n}\beta_i\right)$, β_i = round assigns in integer number.

Step 6. Computing the pessimistic and optimistic collective preference by linguistic aggregation.

Step 7. Build the intervals utilities for the collective preference

Step 8. Normalize the collective interval vector to get the weight scores.

Ten experts from academician, NGO on renewable energy, Integrated energy and environmental planning and policy of Indonesia, Engineers in wind turbine project in Indonesia, and Technical officer at ASEAN Center for Energy have been asked to evaluate the wind turbine site selection criteria in Indonesia using their expertise by filling the fuzzy questionnaire.

Step 9. For every input and output (q, r), the weight ratio v_q / u_r must be bounded by L_{qr} (lower bound) and U_{qr} (upper bound) as $L_{qr} \leq v_q / u_r \leq U_{qr}$. The example of the weight ratio is the relation on lower bound as pessimistic in district level between land cost and population in region is 3.00 and upper bound is 4.20 (see Table 4.8). The lower bound weight ratio is (land cost (LC)/population in region (PinR)) ≥ 3.00. The upper bound weight ratio is similar as (LC/PinR) ≤ 4.20. The same procedure is carried to all criteria to calculate the priorities.

The fuzzy set can be in combined into the primary Data Envelopment Analysis is determined by Amy H.I Lee at al [20]. In the early stage the fuzzy analytic hierarchy process is applied to extract expert's questionnaire to set the pairwise comparison values which have been introduced from step 1 to step 9. The bounded weight ratio is designed to measure the data envelopment analysis (DEA) efficiency of a specific DMU. DMU is a unit under evaluation in here as provinces and districts level. The primary data envelopment analysis can be expressed by [20]:

$$\text{Max}\,\frac{\sum_{r=1}^{R} u_r Y_{rk'}}{\sum_{q=1}^{Q} v_q X_{qk'}} \tag{5}$$

Subject to $\frac{\sum_{r=1}^{R} u_r Y_{rk'}}{\sum_{q=1}^{Q} v_q X_{qk'}} \leq 1$

$$\frac{u_r}{\sum_{q=1}^{Q} v_q X_{qk}} \geq \varepsilon, r = 1,...r'..., \mathrm{R}$$

$$\frac{v_q}{\sum_{q=1}^{Q} v_q X_{qk}} \geq \varepsilon, \mathrm{q} = 1,...\mathrm{q}'..., \mathrm{Q}$$

$$L_{qr} \leq \frac{v_q}{u_r} \leq U_{qr}, r = 1,...R, q = 1...Q$$

Where v_q is the weight given to the *q*-th input and u_r is the weight output to the *r*-th output. $X_{qk'}$ is the amount of the *q*-th input of the *k'*-th DMU, $Y_{rk'}$ is the amount of the *r*-th output. Q is the number of inputs and R is the number of outputs and K is the DMUs.

3.2.4 Principal Component Analysis

Reducing the number of variables under study and consequently ranking and analysis of decision-making units (DMUs). The objective of PCA [12] is to reduce ineffective indicators and also as a ranking methodology for determination the efficiency of different units from the results of DEA. Discussing about principal component analysis in here using IBM SPSS for knowing the importance of component. The illustration how to find the importance criteria is applied in district level. The first step, knowing how many components to extract in the analysis and looking on the Scree plot by going to Analysis menu then dimension reduction and choose factor analysis is illustrated in Fig. 3.16.

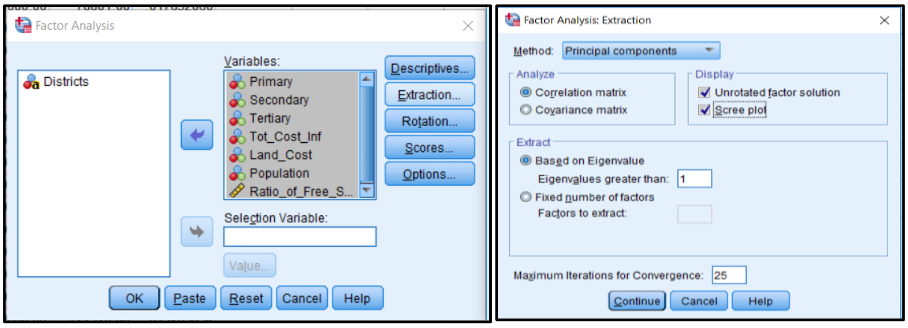

Fig.3.16 Extraction of Factor analysis in district level

Scree plot help to look for how many components should be extracted is shown in Fig 4.17.

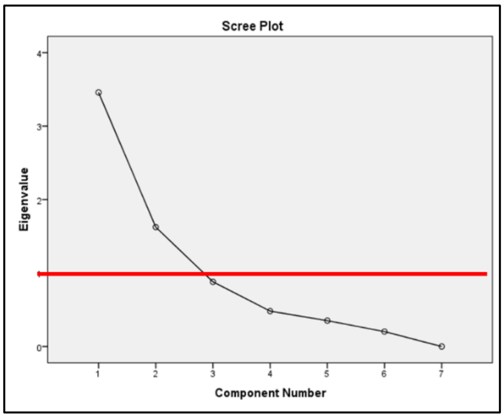

Fig.3.17 Scree Plot of district level

Looking at the break seems to be at about after the first three components so the first three components definitely look like meaningful legitimate components and then there's a specific estrade component and it looks like the third component might be something worth extracting. There is a more sophisticated approach to evaluate how many components should extract an analysis in parallel analysis.

Based on the scree plot, will be extracted total for three eigen values consisting of two eigen values which have values greater than 1 and one eigen value close to 1 from the analysis that's why have to do it in three steps to analyze again in dimension reduction. Choosing analyze with correlation matrix due to the variable are measured in different units, this implies normalizing all variables using division by their standard deviation is given in Fig. 3.18.

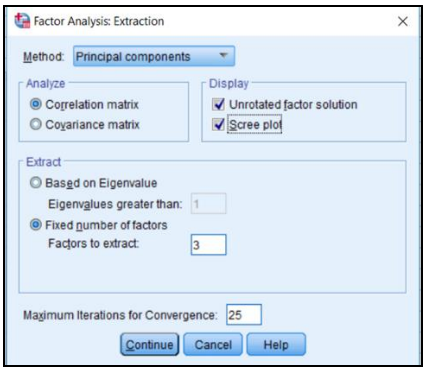

Fig.3.18 Extraction Box

The next step is chosen descriptive box and checklist on Coefficient, KMO and Bartlett's test of sphericity, and Univariate Descriptive is shown in Fig. 3.19. Going to get the descriptive box to look at correlation matrix on Coefficient and KMO and Bartlett's test of sphericity as ferocity to tell whether should actually be doing of component analysis to begin with and would typically want to look at univariate descriptive x in any case.

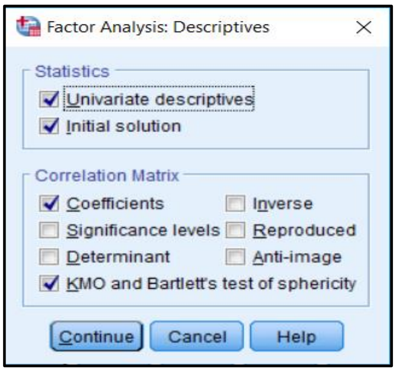

Fig.3.19 Descriptive Box

Rotation Box is chosen for the next step is illustrated in Fig. 3.20. Choosing Direct Oblimin as the rotation method. Direct Oblimin is an approach to produce an oblique factor rotation that means the factors solution can be actually correlated with each other and mostly used as familiar. If the factor solution is the most appropriate an orthogonal uncorrelated effective solution then yield can be shown as a more or less oblique orthogonal factor solution. Correlations between the three components that have been extracted.

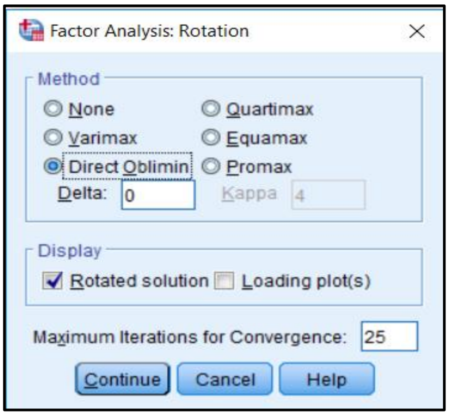

Fig.3.20 Rotation Box

Another options that's good is wanting to sort the components factor loadings more accurately. In this case to be sorted by size which makes it much easier to interpret a component pattern matrix is given in Fig. 3.21 on Options Box.

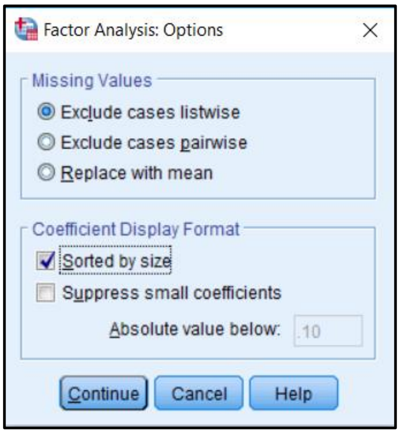

Fig.3.21 Options Box

After interpreting the results, the significance criteria are obtained by principal component analysis are used to measure the efficiency of the location both on district level and province level. The multi-criteria approach based on the hierarchical Dual Data Envelopment Analysis in Sub Section 3.2.1 and 3.2.2 are used to measure efficiency score.

Chapter 4
Results and Discussion

4.1. Data Envelopment Analysis Results

In the proposed hierarchical Dual Data Envelopment Analysis model, 33 provinces at Level 2 and 165 districts at Level 1 in Indonesia are used to define DMUs for wind farm sites. The data are collected from the Statistical Department of Indonesia, Internal Ministry of Indonesia, Indonesian Agency for Meteorology, Climatology, and Geophysics, and The National Land Agency of Indonesia. Overall data are mentioned in the Appendix A. Measuring the data assessment based on DDEA and hierarchical methods from section 3.2.1 and 3.2.2. Level 1 calculates for measuring the performance score for districts level. Level 1 becomes the basic level for combining with the score from Level 2 where is provinces level.

The score of efficiency at the provincial level are shown in Table 4.1. The province efficiency represents the priority of each province based on the location resources.

Table 4.1 Efficiency and ranking of provinces (Level 2)

No	Province	Efficiency	No	Province	Efficiency
1	West Papua	1.000	18	East Kalimantan	0.500
2	Papua	1.000	19	Riau	0.408
3	Maluku	1.000	20	East Java	0.449
4	East Nusa Tenggara	1.000	21	Southeast Sulawesi	0.423
5	Gorontalo	0.991	22	Jambi	0.457
6	South Sumatra	0.949	23	DI Yogyakarta	0.329
7	West Kalimantan	0.808	24	Central Sulawesi	0.387
8	West Sulawesi	0.791	25	West Sumatra	0.319
9	Lampung	0.816	26	Bengkulu	0.397
10	North Maluku	0.842	27	North Sulawesi	0.344
11	Central Kalimantan	0.744	28	DKI Jakarta	0.362
12	South Sulawesi	0.761	29	Bali	0.331
13	South Kalimantan	0.695	30	Banten	0.258
14	Riau Islands	0.656	31	Central Java	0.207
15	Aceh	0.525	32	West Nusa Tenggara	0.207
16	North Sumatra	0.525	33	West Java	0.063
17	Bangka Belitung Islands	0.536			

The 165 districts efficiency and rankings as Level 1 from 33 provinces of Indonesia are given in Table 4.2. It shows that the most suitable district for establishing a wind power plant is in Palembang, one of district in province of South Sumatra. The location of this districts is on the remote of the province, one of the public facilities as good transportation infrastructure to ship wind power plant materials by both river and road transportation is mainly advantages. The geographical location also giving benefit to the regions due to Palembang is less occur able to natural disasters. The wind rate as natural resources with a decent average wind speed that can be used for economical electricity generation.

Table 4.2 Efficiency score of districts (Level 1)

Province	**District**	**Eff**	**Rnk**	**Province**	**District**	**Eff**	**Rnk**
Aceh	Lhokseumawe	0.348	73	West Nusa Tenggara	Mataram	0.179	120
	Banda Aceh	0.338	75		Bima	0.478	48
	Langsa	0.330	76		Dompu	0.234	102
	Subulussalam	0.099	152		East Lombok	0.702	25
	Sabang	0.854	15		Sumbawa	0.537	42
North Sumatra	Medan	0.403	60	East Nusa Tenggara	Kupang	0.201	109
	Tebing Tinggi	0.123	142		Alor	0.251	94
	Tanjung Balai	0.126	140		Belu	0.467	50
	Pematangsiantar	0.190	115		Ngada	0.248	95
	Padang Sidempuan	0.183	118		Southwest Sumba	0.370	65
West Sumatra	Padang	0.564	38	West Kalimantan	Pontianak	0.950	12
	Bukit Tinggi	0.069	158		Singkawang	0.158	129
	Payakumbuh	0.175	121		Bengkayang	0.267	88
	Pariaman	0.120	143		Landak	0.358	67
	Solok	0.098	154		Kubu Raya	0.495	46
Riau	Pekanbaru	0.162	127	Central Kalimantan	Palangka Raya	0.054	161
	Dumai	0.100	150		Seruyan	0.389	61
	Kampar	0.114	146		Gunung Mas	0.406	59
	Rokan Hilir	0.509	44		South Barito	0.211	107
	Siak	0.593	36		Pulang Pisau	0.497	45

Province	District	Eff	Rnk	Province	District	Eff	Rnk
Jambi	Jambi	0.156	132	South Kalimantan	Banjarmasin	0.380	63
	Sungaipenuh	0.166	123		Banjarbaru	0.203	108
	Merangin	0.200	110		Balangan	0.127	139
	Sarolangun	0.199	111		Barito Kuala	0.621	32
	Tebo	0.268	86		Tabalong	0.412	58
South Sumatra	Palembang	1.000	1	East Kalimantan	Balikpapan	0.096	155
	Pagar Alam	0.136	137		Samarinda	0.116	144
	Lubuk Linggau	0.338	74		Bontang	0.219	104
	Prabumulih	0.256	93		Paser	0.297	81
	Lahat	0.420	57		Tarakan	0.244	96
Bengkulu	Bengkulu	0.665	27	North Sulawesi	Manado	0.561	39
	Kaur	0.275	84		Bitung	0.240	101
	Rejang Lebong	0.661	28		Tomohon	0.155	133
	Seluma	1.000	1		Minahasa	0.358	69
	Kepahiang	0.704	24		Kotamobagu	0.164	124
Lampung	Bandar Lampung	0.431	55	Central Sulawesi	Palu	0.130	138
	Metro	0.257	92		Parigi Moutong	0.356	70
	Pesawaran	0.912	13		Donggala	0.212	106
	Tanggamus	0.535	43		Banggai	0.424	56
	Mesuji	0.474	49		Poso	0.641	30
Bangka Belitung Islands	Pangkal Pinang	0.164	125	South Sulawesi	Makasar	0.990	11
	Bangka	0.281	83		Palopo	0.618	33
	Belitung	0.163	126		Sidrap	0.743	17
	West Bangka	0.192	114		Parepare	0.453	53
	East Belitung	0.144	135		Maros	0.719	22
Riau Islands	Batam	0.266	89	Southeast Sulawesi	Kendari	0.046	164
	Bintan	0.061	159		Baubau	0.656	29
	Tanjungpinang	0.262	90		Muna	0.366	66
	Lingga	0.159	128		Kolaka	0.724	19
	Karimun	0.213	105		Wakatobi	0.303	79
DKI Jakarta	South Jakarta	0.111	147	Gorontalo	Gorontalo City	0.354	71
	Central Jakarta	0.138	136		North Gorontalo	0.537	41
	East Jakarta	0.242	99		Bone Bolango	0.385	62
	West Jakarta	0.145	134		Pohuwato	0.810	16
	North Jakarta	0.185	117		Boalemo	0.609	34

Province	District	Eff	Rnk	Province	District	Eff	Rnk
West Java	Bandung	0.275	85	West Sulawesi	Mamuju	0.460	52
	Bogor	0.108	149		Majene	0.314	78
	Sukabumi	1.000	7		Polewali Mandar	1.000	1
	Tasikmalaya	0.633	31		Mamasa	0.728	18
	Cimahi	0.157	130		North Mamuju	0.267	87
Central Java	Semarang	0.243	98	Maluku	Ambon	0.687	26
	Jepara	0.867	14		Seram	0.348	72
	Pekalongan	0.440	54		Tual	0.719	21
	Surakarta	0.092	156		Aru	1.000	1
	Magelang	0.482	47		Buru	0.547	40
DI Yogyakarta	Yogyakarta	0.024	165	North Maluku	Ternate	0.100	151
	Sleman	0.190	116		Sula	0.156	131
	Bantul	0.181	119		Morotai	0.225	103
	Kulon Progo	0.076	157		Tidore	0.196	112
	Gunung Kidul	0.577	37		Halmahera	0.172	122
East Java	Surabaya	0.462	51	West Papua	Manokwari	0.301	80
	Pasuruan	0.373	64		Sorong	0.110	148
	Malang	0.193	113		Fakfak	1.000	7
	Kediri	0.282	82		Sorong City	0.705	23
	Probolinggo	0.721	20		Bintuni	1.000	7
Banten	Tangerang	0.124	141	Papua	Jayapura	0.358	68
	Serang	1.000	1		Merauke	0.243	97
	Lebak	1.000	7		Biak Numfor	0.260	91
	Cilegon	0.319	77		Nabire	0.240	100
	Pandeglang	1.000	1		Mimika	0.606	35
Bali	Denpasar	0.116	145				
	Gianyar	0.052	162				
	Buleleng	0.098	153				
	Bangli	0.049	163				
	Klungkung	0.054	160				

Both efficiency between Level 1 and Level 2 are combined as hierarchical score using hierarchical model for two level DMU in sub section of 3.2.2. Hierarchical Score means the final score of hierarchical for two level of district and province as the combination of efficiency score by both levels using DDEA. The ranking of province is based on full efficiency. The result shows that the best location is in The South

Sumatra province, especially in Palembang district. West Papua, Papua, and Maluku provinces also have high efficiency scores which are shown on Figure 4.1.

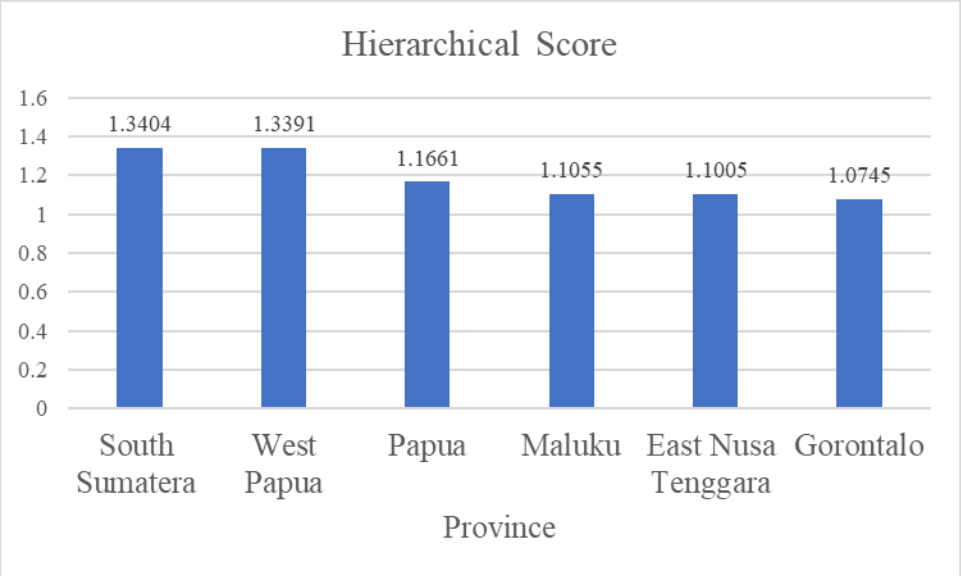

Fig.4.1 Hierarchical Score

Table 4.3 Detail of hierarchical score for provinces level

Province	**The most influence district**	**Eff District**	**Rank of Dist.**	**Eff**	**Hierarchical Score**	**Ranking**
South Sumatera	Palembang	1.000	1	0.949	1.3404	1
West Papua	Fakfak	1.000	7	1.000	1.3391	2
Papua	Mimika	0.606	35	1.000	1.1661	3
Maluku	Aru	1.000	1	1.000	1.1055	4
East Nusa Tenggara	Belu	0.467	50	1.000	1.1005	5
Gorontalo	Pohuwato	0.810	16	0.991	1.0745	6
West Kalimantan	Pontianak	0.950	12	0.808	0.9024	7
West Sulawesi	Polewali Mandar	1.000	1	0.791	0.7802	8
Lampung	Pesawaran	0.912	13	0.816	0.7796	9
North Maluku	Morotai	0.225	103	0.842	0.7532	10
Central Kalimantan	Pulang Pisau	0.497	45	0.744	0.6971	11

Province	The most influence district	Eff District	Rank of Dist.	Eff	Hierarchical Score	Ranking
South Sulawesi	Makasar	0.990	11	0.761	0.6149	12
South Kalimantan	Barito Kuala	0.621	32	0.695	0.6015	13
Riau Island	Batam	0.266	89	0.656	0.4984	14
Aceh	Sabang	0.854	15	0.525	0.3848	15
North Sumatera	Medan	0.403	60	0.525	0.3447	16
Bangka Belitung Island	Bangka	0.281	83	0.536	0.3061	17
East Kalimantan	Paser	0.297	81	0.500	0.2888	18
Riau	Siak	0.593	36	0.408	0.2517	19
East Java	Surabaya	0.462	51	0.449	0.2421	20
South East Sulawesi	Kolaka	0.724	19	0.423	0.2414	21
Jambi	Tebo	0.268	86	0.457	0.2038	22
DI Yogyakarta	Gunung Kidul	0.577	37	0.329	0.201	23
Central Sulawesi	Poso	0.641	30	0.387	0.188	24
West Sumatera	Padang	0.564	38	0.319	0.1821	25
Bengkulu	Seluma	1.000	1	0.397	0.1766	26
North Sulawesi	Manado	0.561	39	0.344	0.1493	27
DKI Jakarta	East Jakarta	0.242	99	0.363	0.1415	28
Bali	Denpasar	0.116	145	0.331	0.125	29
Banten	Serang	1.000	1	0.258	0.0874	30
Central Java	Jepara	0.867	14	0.207	0.0591	31
West Nusa Tenggara	East Lombok	0.702	25	0.207	0.0518	32
West Java	Sukabumi	1.000	7	0.063	0.0064	33

4.2 The Hierarchical Model for two Level DDEA Results

The methodology for combining the results of two levels between province and district levels using three steps procedure from section 3.2.2. The hierarchical scores show the Dual DEA Results based on province level. Firstly, collecting two levels efficiency. Then using first step to normalize every district with average districts in one province. Repeating for every province, in here showing for 5 dominant provinces which will discuss further with another methodology in the following sub section. After normalizing the district efficiency, then combining with province level by multiplying it with province efficiency which will give the hierarchical score for every district. The last step is scaling the hierarchical district score with the highest one in each province to get the maximize one. Finally, the hierarchical score for each province is determined by averaging the results from the third step. The detail results are shown in Table 4.4.

Table 4.4 Hierarchical score for five dominant provinces

Province	**Prov Eff**	**District**	**Dist Eff**	**Step 1**	**Step 2**	**Step 3**	**Hierarchical Score**
South Sumatra	0.949	Palembang	1.000	2.325	2.208	4.874	1.340
		Pagar Alam	0.136	0.316	0.300	0.090	
		Lubuk Linggau	0.338	0.786	0.747	0.557	
		Prabumulih	0.256	0.595	0.565	0.319	
		Lahat	0.420	0.978	0.928	0.862	
West Papua	1.000	Manokwari	0.301	0.483	0.483	0.233	1.339
		Sorong	0.110	0.176	0.176	0.031	
		Fakfak	1.000	1.605	1.605	2.576	
		Sorong City	0.705	1.131	1.131	1.280	
		Bintuni	1.000	1.605	1.605	2.576	
Papua	1.000	Jayapura	0.358	1.049	1.049	1.100	1.166
		Merauke	0.243	0.713	0.713	0.508	
		Biak Numfor	0.260	0.760	0.760	0.578	
		Nabire	0.240	0.703	0.703	0.495	
		Mimika	0.606	1.775	1.775	3.150	
Maluku	1.000	Ambon	0.687	1.041	1.041	1.083	1.105
		Seram	0.348	0.527	0.527	0.278	
		Tual	0.719	1.089	1.089	1.187	
		Aru	1.000	1.514	1.514	2.293	
		Buru	0.547	0.828	0.828	0.686	
East Nusa Tenggara	1.000	Kupang	0.201	0.653	0.653	0.427	1.101
		Alor	0.251	0.818	0.818	0.669	
		Belu	0.467	1.519	1.519	2.308	
		Ngada	0.248	0.805	0.805	0.649	
		Southwest Sumba	0.370	1.204	1.204	1.450	

4.3 Fuzzy Primary Data Envelopment Analysis Results

Due to a lot remaining for the expert to decide with their subjective judgement and expertise. Ten experts have been informed with the objective information and asked to fill the significance of decision-making criteria using their expertise. After the importance degree and the context free grammar are built in the first and the second steps which are shown in the Table 4.5, then collecting preference relations were collected from experts. The fuzzy questionnaire based on importance degree and context free grammar to apply with the criteria in Level 1 and Level 2 are designed. In here we do not show all relations matrices here, we show one example for all steps. The illustration here is one of seven main criteria in district level. For province level, we show the result as well in the following steps to combine the results by HFLTS to get the hierarchical score using data envelopment analysis method.

Table 4.5 Importance degree and context free grammar on HFLTS

Number	Importance Degree
0	No importance (n)
1	Very low importance (vl)
2	Low importance (l)
3	Medium importance (m)
4	High importance (h)
5	Very high importance (vh)
6	Absolute importance (a)

Context free grammar
lower than
greater than
at least
at most
between
and

The expert evaluation data shows in Table 4.6. is the one of expert evaluation of the main criteria in district level with respect to the goal. Firstly, shows as discreate sets and then converted to intervals. For example, the first expert preference the land cost (LC) in relation to population in region (PinR) is “at least low importance” in relation of linguistic terms and can be expressed in the discreate set as {low importance (l), absolute importance (a)} as the interval set term [l,a], similarity for all relation term set between every criteria in one expert linguistic evaluations. These evaluations are proposed for ten experts for every level. After converting the relations term to interval, the data were collected to determine envelops based on expert evaluations which are shown in Table 4.7.

Table 4.6 Pairwise evaluations of one expert in main criteria on level 1

	LC	PinR	RF	PR	SR	TR	TCI
Expert1's Linguistic Evaluations							
LC	-	at least l	between l and m	is m	between l and m	between l and m	is l
PinR	at most h	-	is vh	between h and vh	between h and vh	at most vh	between h and vh
RF	between m and h	is vl	-	between h and vh	between h and vh	at most h	between vl and l
PR	is m	between vl and l	between vl and l	-	is h	is vh	between h and vh
SR	between m and h	between vl and l	between vl and l	is l	-	is h	is l
TR	between m and h	at least vl	at least l	is vl	is l	-	is vl
TCI	is h	between vl and l	between h and vh	between vl and l	is h	is vh	-

Table 4.7 Obtained envelops for HFLTS

E1	**LC**	**PinR**	**RF**	**PR**	**SR**	**TR**	**TCI**
LC	-	[l,a]	[l,m]	[m,m]	[l,m]	[l,m]	[l,l]
PinR	[n,h]	-	[vh,vh]	[h,vh]	[h,vh]	[n,vh]	[h,vh]
RF	[m,h]	[vl,vl]	-	[h,vh]	[h,vh]	[n,h]	[vl,l]
PR	[m,m]	[vl,l]	[vl,l]	-	[h,h]	[vh,vh]	[h,vh]
SR	[m,h]	[vl,l]	[vl,l]	[l,l]	-	[h,h]	[l,l]
TR	[m,h]	[vl,a]	[l,a]	[vl,vl]	[l,l]	-	[vl,vl]
TCI	[h,h]	[vl,l]	[h,vh]	[vl,l]	[h,h]	[vh,vh]	-

In the interval set for every evaluation represent the pessimistic in left hand site and optimistic in right hand side as [P,O]. In here we show the calculation for pessimistic and optimistic preference using two operations. The scale of the importance degree is shown in Table 4.5. to the linguistic terms. Table 4.8. shows the pessimistic and optimistic values. For instance, we show one of the examples for pessimistic and optimistic preference by land cost (LC) with respect to Population in Region (PinR) criteria is calculated as follows:

Pessimistic preference.

$$P^-_{L_{12}} = \Delta\left(\frac{1}{10}\left(\Delta^{-1}(l,2)+\Delta^{-1}(vl,1)+\Delta^{-1}(m,3)+\Delta^{-1}(vl,1)+\Delta^{-1}(h,4)+\Delta^{-1}(n,0)+\Delta^{-1}(vh,5)+\Delta^{-1}(h,4)+\Delta^{-1}(a,6)+\Delta^{-1}(h,4)\right)\right)$$

$$P^-_{L_{12}} = \Delta\left(\frac{1}{10}(2+1+3+1+4+0+5+4+6+4)\right)$$

$$P^-_{L_{12}} = \Delta(3.00)$$

$$P^-_{L_{12}} = (m,.00)$$

Optimistic preference.

$$P^+_{L_{12}} = \Delta\left(\frac{1}{10}\left(\Delta^{-1}(a,6)+\Delta^{-1}(l,2)+\Delta^{-1}(h,4)+\Delta^{-1}(m,3)+\Delta^{-1}(h,4)+\Delta^{-1}(l,2)+\Delta^{-1}(a,6)+\Delta^{-1}(\text{vh},5)+\Delta^{-1}(a,6)+\Delta^{-1}(h,4)\right)\right)$$

$$P^+_{L_{12}} = \Delta\left(\frac{1}{10}(6+2+4+3+4+2+6+5+6+4)\right)$$

$$P^+_{L_{12}} = \Delta(4.20)$$

$$P^+_{L_{12}} = (\text{h},.20)$$

Table 4.8 Pessimistic and optimistic preference in district level

Level 1	LC		PinR		RF		PR		SR		TR		TCI	
	P	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**	**O**
LC	-	-	3.0	4.2	3.2	4.0	2.7	4.0	1.9	4.2	2.6	4.2	1.4	2.4
PinR	1.8	3.0	-	-	3.4	4.4	3.0	3.6	3.7	4.6	3.0	4.1	2.4	2.7
RF	2.0	2.8	1.6	2.6	-	-	2.1	3.2	2.0	4.3	1.6	3.5	1.0	1.4
PR	2.1	2.8	2.4	3.0	2.8	3.9	-	-	3.5	4.0	4.7	5.1	1.2	2.2
SR	1.8	4.1	1.5	2.3	1.7	4.0	2.0	2.5	-	-	3.0	4.0	1.3	2.0
TR	1.9	3.4	1.9	3.0	2.5	4.4	0.9	1.3	2.0	3.0	-	-	1.3	1.6
TCI	3.6	4.6	3.3	3.5	4.6	5.0	3.8	4.8	4.0	4.5	4.4	4.7	-	-

The next step is looking for the linguistic intervals. The linguistic intervals are calculated by using the average of pessimistic and optimistic values. For example, using in one criterion as land cost (LC) as follows:

$$\left(\frac{1}{6}\left(\sum_{1}^{6} P^-_{L_{12}}, \sum_{1}^{6} P^+_{L_{12}}\right)\right)$$

$$\left(\Delta\left(\frac{1}{6}(3.00+3.20+2.70+1.90+2.60+1.40)\right), \Delta\left(\frac{1}{6}(4.20+4.00+4.00+4.20+4.20+2.40)\right)\right)$$

$$\left(\Delta(2.467), \Delta(3.833)\right)$$

$$\left((l,.467),(h,-.167)\right)$$

The linguistic intervals are converted to interval utilities as known as the value to get the midpoint by the average between pessimistic and optimistic values. The weight value is obtained by normalizes the midpoint.

$$Weights = \frac{3.150}{3.150 + 3.308 + 2.342 + 3.142 + 2.517 + 2.267 + 4.233}$$
$$Weights = 0.150$$

The linguistic interval, interval utilities, midpoint and weights of all seven criteria in district level are given in Table 4.9.

Table 4.9 The linguistic interval, interval utilities, midpoint and weights

Criteria	**Linguistic intervals**		**interval utilities**		**Midpoints**	**Weights**
	P	**O**	**P**	**O**		
LC	l,.467	h,-.167	2.467	3.833	3.150	0.150
PinR	m,-.117	h,-.267	2.883	3.733	3.308	0.158
RF	l,-.283	m,-.033	1.717	2.967	2.342	0.112
PR	m,-.217	h,-.500	2.783	3.500	3.142	0.150
SR	l,-.117	m,.150	1.883	3.150	2.517	0.120
TR	l,-.250	m,-.217	1.750	2.783	2.267	0.108
TCI	h,-.050	vh,-.483	3.950	4.517	4.233	0.202

After getting the weight ratio for every criterion in district level. We need to look for the efficiency by using the ratio as constraint of criteria. Table 4.8. is ratio relation of criteria in for province level is given in Table 4.10.

Table 4.10 Pessimistic and optimistic preference in province level

Level 2	**WV**		**PinP**		**TA**		**EC**		**LL**		**LF**		**LE**		**LVE**	
	P	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**	**O**
WV	-	-	5.1	5.5	4.3	5.4	3.2	5	4.5	5	4.2	4.7	3.5	4.7	3.1	5.3
PinP	0.7	0.9	-	-	3	3.9	2.5	3.5	3	4.2	3.4	4.5	3.5	4.8	3.1	4
TA	0.6	1.7	2.1	3	-	-	2.5	3.1	2.7	4	1.4	3.4	2.2	4	2.1	3.8
EC	1	2.8	2.5	3.5	2.9	3.5	-	-	2.8	4.3	2.7	4.1	3.1	4.6	3.5	4.5
LL	1	1.5	1.8	3	2	3.4	1.8	3.2	-	-	3.8	3.9	2.4	3.3	3.1	3.5
LF	1.3	1.8	1.5	2.6	2.5	4.6	1.9	3.2	1.9	2.2	-	-	2.7	2.9	2.7	3.4
LE	1.3	2.5	1.2	2.5	1.8	3.5	1.4	2.9	2.7	3.9	3.1	3.3	-	-	3.2	4
LVE	0.7	2.9	2	2.9	1.9	3.7	1.5	2.5	2.5	2.9	2.6	3.3	2	2.8	-	-

Pairwise comparison matrix is performed based on the fuzzy aggregation in Table 4.8 for district level and Table 4.10 for province level. The constraints show the lower bound and upper bound values as pessimistic and optimistic priorities in fuzzy matrix, for showing the example of the priority range in district level as Step 9 in Sub-Section 3.2.3. The constraints of the priorities for each criterion are given in Table 4.11 for district level and Table 4.12 for province level. Due to the space constraints in here just for showing one example of the constraints for district level as Palembang district. South Sumatra as representing for province level. The same procedure is applied for each region in district and province level to get location efficiency.

Table 4.11 The constraint of the priorities for district level

	LC		**PinR**		**RF**		**PR**		**SR**		**TR**		**TCI**	
	P	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**	**O**
LC	-	-	0.19	0.26	0.52	0.65	0.41	0.60	0.18	0.40	0.35	0.57	0.23	0.39
PinR	0.41	0.69	-	-	0.56	0.72	0.45	0.54	0.35	0.43	0.41	0.56	0.39	0.44
RF	0.46	0.64	0.10	0.16	-	-	0.32	0.48	0.19	0.41	0.22	0.48	0.16	0.23
PR	0.48	0.64	0.15	0.19	0.46	0.64	-	-	0.33	0.38	0.64	0.69	0.20	0.36
SR	0.41	0.94	0.09	0.14	0.28	0.65	0.30	0.38	-	-	0.41	0.54	0.21	0.33
TR	0.43	0.78	0.12	0.19	0.41	0.72	0.14	0.20	0.19	0.28	-	-	0.21	0.26
TCI	0.82	1.05	0.21	0.22	0.75	0.82	0.57	0.72	0.38	0.42	0.60	0.64	-	-

Table 4.12 The constraint of the priorities for province level

	WV		**PinP**		**TA**		**EC**		**LL**		**LF**		**LE**	
	P	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**	**O**
WV	-	-	0.00	0.00	0.00	0.00	0.56	0.88	0.79	0.88	0.96	1.07	0.86	1.15
PinP	0.12	0.16	-	-	0.00	0.00	0.44	0.61	0.53	0.74	0.78	1.03	0.86	1.18
TA	0.11	0.30	0.00	0.00	-	-	0.44	0.54	0.47	0.70	0.32	0.78	0.54	0.98
EC	0.18	0.49	0.00	0.00	0.00	0.00	-	-	0.49	0.75	0.62	0.93	0.76	1.13
LL	0.18	0.26	0.00	0.00	0.00	0.00	0.32	0.56	-	-	0.87	0.89	0.59	0.81

	WV		PinP		TA		EC		LL		LF		LE	
	P	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**	**O**
LF	0.23	0.32	0.00	0.00	0.00	0.00	0.33	0.56	0.33	0.39	-	-	0.66	0.71
LE	0.23	0.44	0.00	0.00	0.00	0.00	0.25	0.51	0.47	0.68	0.71	0.75	-	-

Hierarchical DEA is run to evaluate the total score between district and province level for wind turbine site selection after getting ratio of weight by HFLTS as seen in Table 4.13, the result shows that, considering expert judgement on the importance of significant criteria, South Sumatra as the most appropriate location for establishing wind turbine power plant, following by west Papua, Papua, Maluku, and East of Nusa Tenggara, respectively.

Table 4.13 Hierarchical Score for HFLTS

No	Province	Eff	District	Eff Dist	Step 1	Step 2	Step 3	Hierarchical Score
1	South Sumatra	0.725	Palembang	0.6076	4.9965	3.6238	13.1317	2.626
			Pagar Alam	0.0000	0.0001	0.0001	0.0000	
			Lubuk Linggau	0.0001	0.0010	0.0007	0.0000	
			Prabumulih	0.0001	0.0010	0.0008	0.0000	
			Lahat	0.0002	0.0013	0.0010	0.0000	
2	West Papua	0.729	Manokwari	0.1218	0.7429	0.5414	0.2931	1.979
			Sorong	0.0001	0.0004	0.0003	0.0000	
			Fakfak	0.0005	0.0032	0.0024	0.0000	
			Sorong City	0.6972	4.2520	3.0989	9.6031	
			Bintuni	0.0002	0.0015	0.0011	0.0000	
3	Papua	0.885	Jayapura	0.0017	2.9959	2.6500	7.0227	1.695
			Merauke	0.0002	0.3528	0.3121	0.0974	
			Biak Numfor	0.0000	0.0487	0.0431	0.0019	
			Nabire	0.0002	0.3285	0.2906	0.0844	
			Mimika	0.0007	1.2740	1.1269	1.2700	
4	Maluku	0.908	Ambon	0.6807	1.5134	1.3738	1.8874	1.388
			Seram	0.0002	0.0004	0.0003	0.0000	
			Tual	0.7079	1.5738	1.4287	2.0413	
			Aru	0.8598	1.9117	1.7355	3.0118	
			Buru	0.0003	0.0008	0.0007	0.0000	

No	Province	Eff	District	Eff Dist	Step 1	Step 2	Step 3	Hierarchical Score
5	East Nusa Tenggara	0.639	Kupang	0.0030	3.2750	2.0918	4.3758	0.938
			Alor	0.0003	0.3644	0.2327	0.0542	
			Belu	0.0003	0.3631	0.2320	0.0538	
			Ngada	0.0005	0.5607	0.3581	0.1283	
			Southwest Sumba	0.0004	0.4368	0.2790	0.0779	

4.4 Principle Component Analysis Results

Based on the scree plot in Fig. 3.17., will be extracted for total three eigen values consisting of two eigen values which have values greater than 1 and one eigen value close to 1 from the analysis that's why have to do it in two steps to analyze again in dimension reduction. Choosing analyze with correlation matrix due to the variable are measured in different units, this implies normalizing all variables using division by their standard deviation.

Correlation Matrix[a]

		Primary	Secondary	Tertiary	Tot_Cost_Inf	Land_Cost	Population	Ratio_of_Free_Space
Correlation	Primary	1.000	.795	.685	.685	-.148	-.101	.091
	Secondary	.795	1.000	.715	.715	-.134	-.074	.077
	Tertiary	.685	.715	1.000	1.000	-.230	-.177	.152
	Tot_Cost_Inf	.685	.715	1.000	1.000	-.230	-.177	.152
	Land_Cost	-.148	-.134	-.230	-.230	1.000	.643	-.189
	Population	-.101	-.074	-.177	-.177	.643	1.000	-.243
	Ratio_of_Free_Space	.091	.077	.152	.152	-.189	-.243	1.000

a. This matrix is not positive definite.

Fig.4.2 Correlation matrix on district level

Looking at the correlation on Fig 4.2 between Primary and Secondary road have positive correlation 0.795 they seem to hang together when the primary road is needed in wind turbine site criteria, Secondary can also necessary. But there is also some negative correlation such as Land cost and population which are different in usual but cannot expect too much such a thing as slightly not significant. We can see a lot of positive correlation mostly on Primary, Secondary, Tertiary and Total Cost of Infrastructure that very consistent, Overall have a lot positive correlation but there are also have some negative correlation that's not going to be real straight forward one component extraction effects on the scree-plot. That true as three component extraction.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.695
Bartlett's Test of Sphericity	Approx. Chi-Square	397.289
	df	15
	Sig.	.000

Fig.4.3 KMO and Bartlett's Test on district level

The Bartlett's test of sphrericity will be non-significant because see on Fig. 4.3. in this case is statistically significant basically telling that at least one statistically significant correlation matrix. On the Kaiser-Meyer-Olkin measure of Sampling Adequacy is also more effect size measure is determining whether use principal component analysis or not. 0.695 or up to 0.70 or higher is great the lower point is on less than 0.40 this is the rule time that generally used. Overall on the correlation matrix, KMO that are over than 0.40 and The Bartlett's test is statistically significant this will make confidence to perform the component analysis on district level.

Communalities

	Initial	Extraction
Primary	1.000	.756
Secondary	1.000	.793
Tertiary	1.000	.886
Tot_Cost_Inf	1.000	.886
Land_Cost	1.000	.826
Population	1.000	.821
Ratio_of_Free_Space	1.000	.996

Extraction Method: Principal Component Analysis.

Fig.4.4 Communalities on level 1

The Communalities is output from SPSS that shows the extraction based on three components being extracted as shown on Fig. 4.4. Communalities represent variance that have been counted from Component analysis. We can see that ratio of free usage area have the largest amount of variance that being explained by component analysis solutions as 99.6% of the significant criteria on wind turbine site selection, following with total cost infrastructure and tertiary road, respectively. Overall the communalities are good due to more than 50 % for each criterion.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	3.458	49.403	49.403	3.458	49.403	49.403	3.375
2	1.625	23.217	72.620	1.625	23.217	72.620	1.835
3	.880	12.575	85.195	.880	12.575	85.195	1.158
4	.482	6.884	92.079				
5	.352	5.025	97.104				
6	.203	2.896	100.000				
7	3.001E-16	4.287E-15	100.000				

Extraction Method: Principal Component Analysis.

a. When components are correlated, sums of squared loadings cannot be added to obtain a total variance.

Fig.4.5 Total variance on district level

The real important thing that should be interpret on column extraction sums of squared loadings that have been extracted from the three components factor solutions as given in total variance on Fig. 4.5. These are the eigenvalues 3.375 for the first component, 1.835 for the second component, and following by the third component is 1.158. Overall the extraction sums of squared loadings have more than 1. The cumulative percentage of variance and these are the rotated component solution eigenvalues. SPSS technically calls rotations sums of squared loading as the eigenvalues in the rotated component solutions which is oblique on scree plot that we used for the first step of the analysis.

Component Matrix[a]

	Component		
	1	2	3
Tot_Cost_Inf	.933	.126	.008
Tertiary	.933	.126	.008
Secondary	.851	.261	-.031
Primary	.838	.229	-.027
Population	-.315	.827	.195
Land_Cost	-.372	.777	.289
Ratio_of_Free_Space	.233	-.429	.870

Extraction Method: Principal Component Analysis.
a. 3 components extracted.

Fig.4.6 Component matrix of district level

The component matrix on Fig. 4.6 of component loadings is basically the extraction method based on the unrotated solution just for showing the initial value and we don't need to interpret it.

Pattern Matrix[a]

	Component		
	1	2	3
Tot_Cost_Inf	.922	-.058	.042
Tertiary	.922	-.058	.042
Secondary	.903	.060	-.038
Primary	.878	.035	-.027
Land_Cost	-.040	.912	.052
Population	.037	.899	-.050
Ratio_of_Free_Space	.006	.006	.998

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.
a. Rotation converged in 3 iterations.

Fig.4.7 Pattern matrix on district level

When we have oblique rotated component solution, we really want to use the pattern matrix are given in Fig. 4.7. The pattern matrix is to help to identify the nature of the components and what have here in the first component is total cost of infrastructure is 92.2%, tertiary road is 92.2%, secondary road is 90.3%, and primary road is 87.8% all loading nicely on this first component so wind turbine site selection criteria seem to hang together to trade together as significant criteria. But that's not always exactly true because these factor loadings are not on all 0.95 but they are high enough to suggest a pretty strong pattern. These the rest of the listed criteria as land cost and ratio of free space don't seem to load very strong only the exception would be ratio of free space what do you use as a statistically significant component loading.

The second component has two major loadings that are land cost is 91.2% and population 89.9% then it has negative component loading and if look at total cost of infrastructure and tertiary road. its component loading to the first component and the second component its one's positive and one's negative either one is very high positive in first component. Mostly we choose positive value for both components and have a significant decision or both have difference value on less of negativity.

The third component has one major loading that is ratio of free space area as highly positive 99.8%. It is totally hanged to trade as significant criteria. So, we can conclude that majority the percentage of significant criteria have more that 87% as in the first component is total cost of infrastructure, tertiary, secondary and primary road, for the second component is land cost and population, and the last component is ratio of free usage area.

Structure Matrix

	Component		
	1	2	3
Tot_Cost_Inf	.938	-.239	.166
Tertiary	.938	-.239	.166
Secondary	.887	-.098	.055
Primary	.868	-.121	.069
Land_Cost	-.203	.907	-.174
Population	-.135	.904	-.264
Ratio_of_Free_Space	.124	-.237	.998

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

Fig.4.8 Structure matrix on level 1

The last table is the structured matrix which is actually the correlation between each variable in the analysis and that sequence of respective component from the most significant criteria to less significant criteria as given in Fig. 4.8.

On the District level we can conclude that have seven significant criteria which influence on wind turbine site selection in Indonesia such as total cost infrastructure, tertiary road, secondary road, primary road, population and land cost and we reduce ratio of free space based on analysis of principal component analysis.

Due to same steps to do analysis using principal component. In province level we can interpret the results directly.

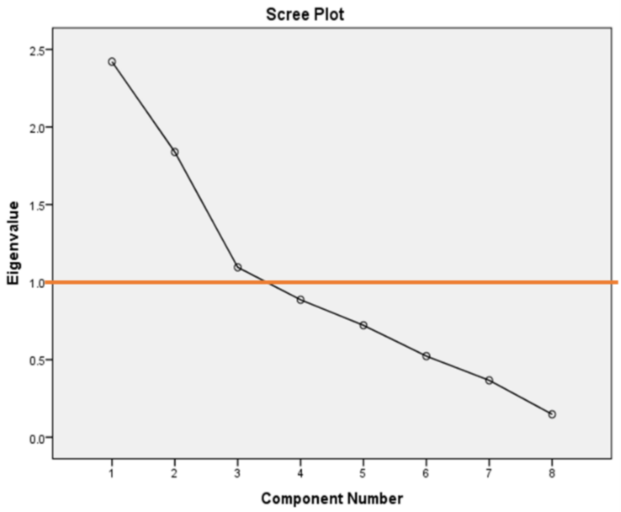

Fig.4.9 Scree plot for level 2

Based on the scree plot which have been shown on Fig. 4.9, we can see on the oblique shows on the first three component which have eigenvalue more than 1. Due to that 3 components look like have meaning components and we can use it on extraction analysis.

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.660
Bartlett's Test of Sphericity	Approx. Chi-Square	75.613
	df	28
	Sig.	.000

Fig.4.10 KMO and Bartlett’s Test for Level 2

The KMO and Bartlett's results test is given in Fig. 4.10 show that for KMO measure of sampling adequacy is 0.660 is good enough to determine using principal component analysis. The Bartlett's test of sphrericity will be non-significant because in this case is statistically significant basically telling that at least one statistically significant correlation matrix. Overall on the correlation matrix, KMO that are over than 0.40 and The Bartlett's test is statistically significant this will make confidence to perform the component analysis on province level.

Correlation Matrix

		Wind_Velocity	Population	Total_Area	Elec_Consumption	Landslide	FLood	Earthquake	Vol_Eruption
Correlation	Wind_Velocity	1.000	.419	-.169	.412	.068	-.230	.129	.042
	Population	.419	1.000	-.232	.830	.211	-.292	.535	.130
	Total_Area	-.169	-.232	1.000	-.255	-.111	.083	.049	-.066
	Elec_Consumption	.412	.830	-.255	1.000	.038	-.350	.398	.055
	Landslide	.068	.211	-.111	.038	1.000	.153	.278	.562
	FLood	-.230	-.292	.083	-.350	.153	1.000	-.127	.223
	Earthquake	.129	.535	.049	.398	.278	-.127	1.000	.283
	Vol_Eruption	.042	.130	-.066	.055	.562	.223	.283	1.000

Fig.4.11 Correlation matrix on level 2

Fig. 4.11 shows the correlation matrix on province level. Looking at wind velocity column we can see that majority have positive correlation such as wind velocity with population, electricity consumption, earthquake, volcanic eruption and landslide, but have some negative correlation with total area and flood. Correlation between wind velocity and population have positive 0.419 as dominant. Also looking at other column, we can say as generally, overall have a lot positive correlation but there are also have some negative correlation. It is meaning that more than one component has extraction effects on the scree plot. We use three components for extraction analysis.

Communalities

	Initial	Extraction
Wind_Velocity	1.000	.423
Population	1.000	.842
Total_Area	1.000	.813
Elec_Consumption	1.000	.796
Landslide	1.000	.706
FLood	1.000	.500
Earthquake	1.000	.737
Vol_Eruption	1.000	.729

Extraction Method: Principal Component Analysis.

Fig.4.12 Communalities on level 2

The results of variance being showed in the communalities table is given on Fig. 4.12 We can see that majority have good value of extraction. Population have the highest amount of variance as 84.2% and wind velocity even have less amount still more than 10 % for saying as a statistical criterion on 42.3%.

Total Variance Explained

Component	Initial Eigenvalues Total	Initial Eigenvalues % of Variance	Initial Eigenvalues Cumulative %	Extraction Sums of Squared Loadings Total	Extraction Sums of Squared Loadings % of Variance	Extraction Sums of Squared Loadings Cumulative %	Rotation Sums of Squared Loadings[a] Total
1	2.745	34.316	34.316	2.745	34.316	34.316	2.666
2	1.743	21.792	56.108	1.743	21.792	56.108	1.837
3	1.055	13.193	69.301	1.055	13.193	69.301	1.118
4	.753	9.407	78.708				
5	.681	8.514	87.222				
6	.444	5.552	92.774				
7	.438	5.480	98.254				
8	.140	1.746	100.000				

Extraction Method: Principal Component Analysis.

a. When components are correlated, sums of squared loadings cannot be added to obtain a total variance.

Fig.4.13 Total variance on level 2

The rotation sums of squared loadings are the most important thing to interpret as the extraction results from three components factor solutions which are given in Fig. 4.13. These are the result 2.666 for the first component, 1.837 for second component and the last as 1.118 for third component. These results show the position of component after rotated component as scree plot on the early analysis.

Component Matrix[a]

	Component 1	Component 2	Component 3
Population	.910	-.080	.083
Elec_Consumption	.857	-.247	.021
Earthquake	.634	.272	.511
Wind_Velocity	.571	-.207	-.231
Vol_Eruption	.279	.804	-.068
Landslide	.328	.765	-.119
FLood	-.397	.570	-.130
Total_Area	-.334	.054	.836

Extraction Method: Principal Component Analysis.

a. 3 components extracted.

Fig.4.14 Component matrix on level 2

The component matrix shows the initial component as unrotated solution as given in Fig. 4.14. In here just show the early step before being rotated.

Pattern Matrix[a]

	Component		
	1	2	3
Population	.896	.147	-.004
Elec_Consumption	.883	-.019	-.078
Earthquake	.620	.352	.482
FLood	-.567	.463	-.037
Wind_Velocity	.551	-.018	-.301
Vol_Eruption	.012	.853	-.010
Landslide	.060	.836	-.069
Total_Area	-.159	-.154	.867

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.
a. Rotation converged in 6 iterations.

Fig.4.15 Pattern matrix on level 2

The pattern matrix helps to identify oblique rotated component solution is given on Fig. 4.15. In first component we can see the positive loadings is population, electricity consumption, earthquake, wind velocity, land slide and volcanic eruption. The second component have 5 major loadings as volcanic eruption, landslide, flood, earthquake and population. Wind velocity and electricity consumption have decreased on few negativities and have not impact on changes. On third components just have two loadings positive as Total area and earthquake but majority on negativity neither one is very high. Overall, we can conclude that each criterion has positive loadings even in just one component and have an impact on solution as the group of components. Due to that, we can conclude that all of criteria have statistically significant and we do not need to reduce the criterion.

Structure Matrix

	Component		
	1	2	3
Population	.906	.201	-.074
Elec_Consumption	.888	.031	-.156
Earthquake	.600	.419	.450
Wind_Velocity	.576	-.003	-.350
FLood	-.536	.426	.040
Vol_Eruption	.066	.854	.040
Landslide	.117	.835	-.024
Total_Area	-.244	-.111	.872

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

Fig.4.16 Structure matrix on level 2

As we have discussed the function of structure matrix on Fig. 4.16 to show the sequence of influence criteria. Looking at last criterion on total area, even on first and two components give negative loadings but have a great trend on last component as 87% its look like increasing trend and have been impacted by rotated component solution.

Component Correlation Matrix

Component	1	2	3
1	1.000	.061	-.087
2	.061	1.000	.060
3	-.087	.060	1.000

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

Fig.4.17 Component correlation matrix on level 2

Component correlation matrix is correlation between each component based on rotated component solutions is given in Fig. 4.17. Looking at component 1 shows that have correlation with component 2. Due to negativity on component 3 so component 1 have not correlation with it. Differently at component 2 have positive correlation for component 1 and component 3. It is showing the good relation from rotated component solution.

We can conclude that population, electric consumption, earthquake, wind velocity, flood, volcanic eruption, landslide, and total area as the significant criteria which are influencing on province level of wind turbine site selection in Indonesia. Following results of significance criterion, multivariable ranking method namely Principal component Analysis (PCA) is used for verifying a hierarchical DEA result. The PCA ranking result is given in Table 4.14.

Table 4.14 Principal Component Analysis Results

Province	Prov Eff	District	Dist Eff	Step 1	Step 2	Step 3	Hierarchical Score
South Sumatra	0.949	Palembang	1.000	2.325	2.208	4.874	1.340
		Pagar Alam	0.136	0.316	0.300	0.090	
		Lubuk Linggau	0.338	0.786	0.747	0.557	
		Prabumulih	0.256	0.595	0.565	0.319	
		Lahat	0.420	0.978	0.928	0.862	
West Papua	1.000	Manokwari	0.301	0.483	0.483	0.233	1.339
		Sorong	0.110	0.176	0.176	0.031	
		Fakfak	1.000	1.605	1.605	2.576	
		Sorong City	0.705	1.131	1.131	1.280	
		Bintuni	1.000	1.605	1.605	2.576	
Papua	1.000	Jayapura	0.358	1.049	1.049	1.100	1.166
		Merauke	0.243	0.713	0.713	0.508	
		Biak Numfor	0.260	0.760	0.760	0.578	
		Nabire	0.240	0.703	0.703	0.495	
		Mimika	0.606	1.775	1.775	3.150	
Maluku	1.000	Ambon	0.687	1.041	1.041	1.083	1.105
		Seram	0.348	0.527	0.527	0.278	
		Tual	0.719	1.089	1.089	1.187	
		Aru	1.000	1.514	1.514	2.293	
		Buru	0.547	0.828	0.828	0.686	
East Nusa Tenggara	1.000	Kupang	0.201	0.653	0.653	0.427	1.101
		Alor	0.251	0.818	0.818	0.669	
		Belu	0.467	1.519	1.519	2.308	
		Ngada	0.248	0.805	0.805	0.649	
		Southwest Sumba	0.370	1.204	1.204	1.450	

4.5 Comparison of Three Methods Result

The top five are chosen based on the three methods which are discussed. Hierarchical data envelopment analysis (DEA) is one of multi-variable approach which can measure efficiency score, in here the result represents the total score of the province combine with district level. Hesitant fuzzy linguistic term set is used for measuring uncertainty criteria which can influence in site selection, in this study the judgement, expertise and advisement by the expert needed to evaluate the importance of the criterion. After getting the hesitant criteria which have been proven, validation is needed to validate the significance criteria. The top five suitable locations for establishing wind turbine power plant in Indonesia are South Sumatra, Papua, West Papua, Maluku and East Nusa Tenggara provinces, respectively as shown in Fig. 4.18 as geographically location.

Table 4.15 Comparison of three methods result.

Province	**DEA**	**Rank**	**Fuzzy DEA**	**Rank**	**PCA**	**Rank**
South Sumatra	1.340	1	2.626	1	1.340	1
West Papua	1.339	2	1.979	2	1.339	2
Papua	1.166	3	1.695	3	1.166	3
Maluku	1.105	4	1.388	4	1.105	4
East Nusa Tenggara	1.101	5	0.938	5	1.101	5

The Table 4.15 shows that although using three methods differently still giving the same priority ranking. Expert judgement can help with multi complex decision and uncertainty condition. The fuzzy DEA results based on the expert advice giving the same priority as South Sumatra have the highest priority to build a wind farm. It shows that the importance criteria relation with specific bound weight are optimal used. The significance criteria which are obtained based on principal component analysis shows that the ratio of free usage area and total cost of infrastructure are highly influence to the results in district level. The ratio of free usage area in South Sumatra is high. It shows that more space area in one region is advantages. The availability of the infrastructure of primary road and secondary road in each region have improved in South Sumatra as primary concern. In this region do not need to build some additional infrastructure in tertiary road. It can be decreasing the total cost of infrastructure. The minimize total cost of infrastructure is preferable to influence the efficiency score. In the province level some criteria such as population, electricity consumption and less of natural disaster are the most influence to the total efficiency score. The availability human resources in South Sumatra shows that higher spreading population is in Palembang district. It can decrease the resources management for the transportation and accommodation cost of labors. Electricity consumption as the demand in South

Sumatra is high are needed to show the amount of electricity distribution to the center area. The establishment of wind farm in South Sumatra can help as the alternative energy resources to fulfill the electricity demand. The third influence criteria in South Sumatra is less of natural disaster. The South Sumatra as geographically located in the Sumatra Island based on the occurrence of the disaster shows that in this region have less of landslide, earthquake and volcanic eruption. Due to the reasons that South Sumatra can be decided as the most suitable location to build a wind farm power plant.

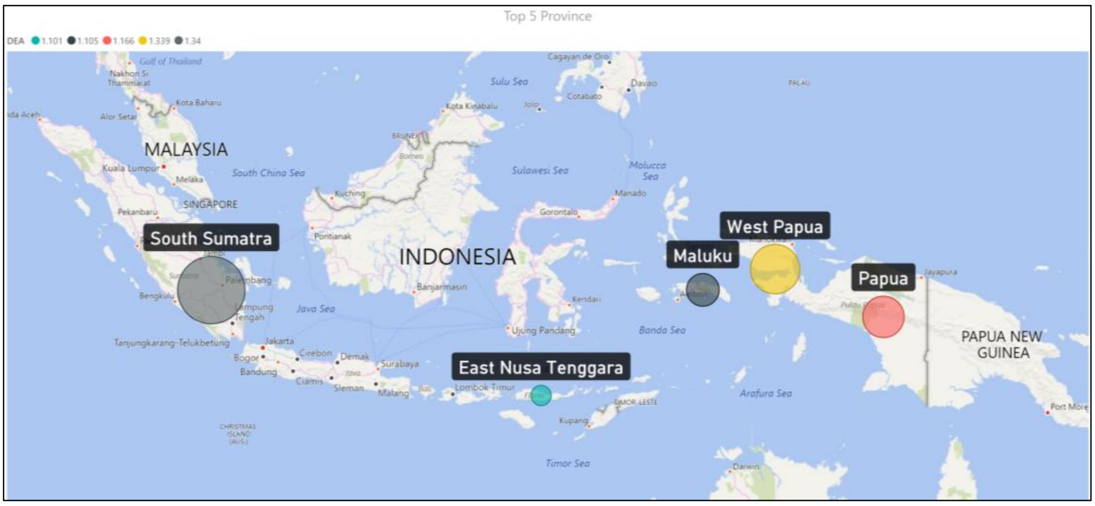

Fig.4.18. Top five Provinces in Indonesia

Chapter 5
Conclusions and Recommendations

5.1 Conclusion

Wind energy as natural energy resources is a renewable, freely available and environmentally compared with other sources of fossil fuel, such as coal, and oil. In this study, three methods are proposed to decide the most suitable location based on the multi criteria approach. The hierarchical DDEA to determine the integrated efficiency scores of DMUs between the district level and the province level. The Fuzzy Data Envelopment Analysis is used for measuring the bound weight ratio for specific DMUs based on the expert judgement, advice and expertise. The validation based on principal component analysis to know the significance of criteria which are influences to the wind turbine site selection in Indonesia. The possible factors used in the districts level as defined by land cost, population in region, ratio of free usage area, primary road, secondary road, tertiary road, and total cost of infrastructure. In the provinces level as defined by wind velocity, population in province, total area, electricity consumption, less of land slide, flood, earthquake and volcanic eruption. This method was applied to 33 provinces and 165 districts of Indonesia. The final result shows that the South Sumatra province has the highest efficiency score which is the most economical location for constructing a wind farm as given in Fig. 5.1. The most significant criteria which influence on wind turbine site selection based on principal component analysis in district level is ratio of free usage area, following by total cost of infrastructure, and tertiary road. Population, electricity consumption and total area influence in province level. This study is a milestone for policy makers, government and private stakeholders in decision making for selecting the most suitable sites for wind power plant construction in Indonesia. The hierarch DEA results can be used to assist decision maker on selecting the most suitable wind farm site. The proposed approach can be considered as an alternative solution, and an early study for policy makers.

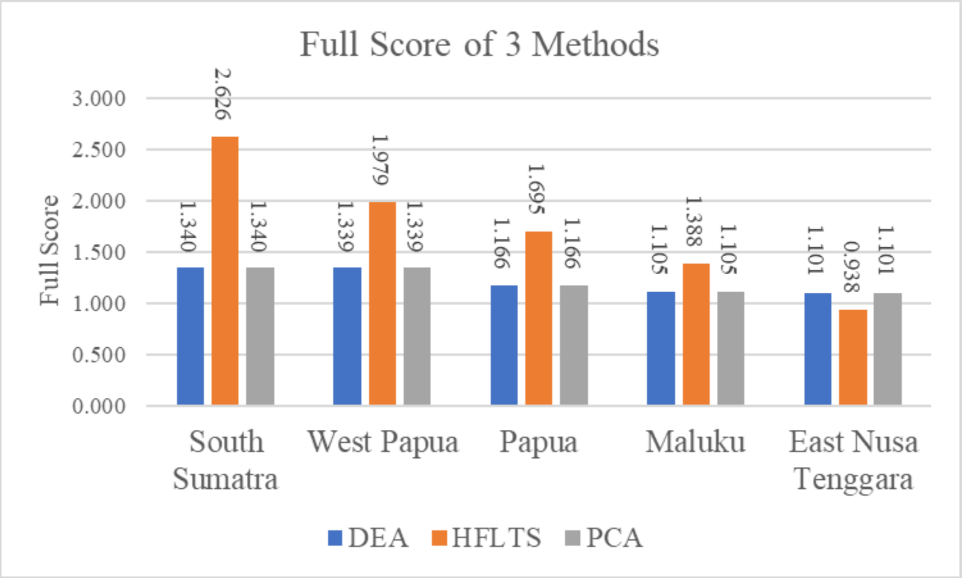

Fig.5.1. Full Score of Three Methods

5.2. Recommendations

Further improvement could be on criterion specification, which includes social, environmental, economic, and technical aspects. The final site selection will be more practical, if opinions from experts, policy makers, government, and private stakeholders are also considered in the analysis. Collecting more specific data is better approach to improve the advance analysis in wind turbine site selection.

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Appendices

Appendix A

Data Resources

A.1 Districts Level Data

					Input					Output	
	Province		District	Port	Primary	Secondary	Tertiary	Total Cost of Insfr	Land Cost (m^2) (IDR)	Population	Ratio of Free U
1	Aceh	1	Lhokseumawe	International Samudera Pasee Port	15.3	2.6	0	0	700000	188221	0.000961954
		2	Banda Aceh	Ulee Lheue Port	6	1.2	0	0	900000	235305	0.000260768
		3	Langsa	Kuala Langsa Port	7.9	0.5	0	0	700000	178334	0.001471452
		4	Subulussalam	Tapak Tuan Port	102	25.2	41.8	6270000000	600000	78801	0.01765206
		5	Sabang	Sabang Port	1.3	0.2	0	0	700000	38077	0.004018174
2	North Sumatra	6	Medan	Belawan International Port	18.8	8.8	0	0	7900000	2465469	0.000107485
		7	Tebing Tinggi	Kuala Tanjung Port	19.3	20.5	3	450000000	1000000	169786	0.000182583
		8	Tanjung Balai	Tanjung Tiram Port	13.2	34.3	12.2	1830000000	900000	165763	0.000650507
		9	Pematangsiantar	Tanjung Tiram Port	33	33.5	6.3	945000000	900000	278055	0.000200176
		10	Padang Sidempuan	Angin Sibolga Port	42.8	34.4	10.9	1635000000	700000	225544	0.000508371
3	West Sumatra	11	Padang	Indonesian Port II	6.7	2.1	0	0	2000000	872271	0.000795235
		12	Bukit Tinggi	Indonesian Port II	28.8	63.4	8.2	1230000000	1000000	113326	0.00022272
		13	Payakumbuh	Indonesian Port II	80.1	33.5	14.7	2205000000	350000	125608	0.00067846
		14	Pariaman	Indonesian Port II	28.7	20.1	11.3	1695000000	400000	85485	0.000773586
		15	Solok	Indonesian Port II	34.8	16.6	8.2	1230000000	350000	63672	0.001119644
4	Riau	16	Pekanbaru	Duku Port	4.5	2.4	0	0	12500000	855221	0.000739306
		17	Dumai	Dumai Port	3.5	3.3	0	0	7000000	264084	0.006147211
		18	Kampar	Roro sei Paknik Port	112	125	43.1	6465000000	4000000	722328	0.015205654
		19	Rokan Hilir	Bandar Seribu Kubah Port	52.1	23.7	14.1	2115000000	700000	625642	0.014195962
		20	Siak	Tanjung Buton Port	33.7	14.6	17.4	2610000000	400000	407093	0.020327493
5	Jambi	21	Jambi	Pelita Jambi Port	6	7.4	0	0	5000000	602187	0.00017194
		22	Sungaipenuh	Indonesian Port II	98.4	113	35.5	5325000000	300000	101325	0.003863805
		23	Merangin	Indonesian Port II	157	120	83.6	12540000000	900000	329077	0.023334964
		24	Sarolangun	Pelita Jambi Port	88.3	72.4	32.4	4860000000	900000	309621	0.019972805
		25	Tebo	Pelita Jambi Port	66.1	75.1	67.6	10140000000	700000	323554	0.019968846
6	South Sumatra	26	Palembang	Indonesian Port II	1.3	0	0	0	2000000	1548064	0.000238504
		27	Pagar Alam	Indonesian Port II	142	78.6	59.1	8865000000	500000	136244	0.00465092
		28	Lubuk Linggau	Indonesian Port II	72.9	91.1	28.3	4245000000	300000	208225	0.001928203
		29	Prabumulih	Indonesian Port II	33.6	35.7	23.7	3555000000	400000	188082	0.001339522
		30	Lahat	Indonesian Port II	87.7	91.8	41.1	6165000000	500000	418845	0.012681875
7	Bengkulu	31	Bengkulu	Bengkulu Pelindo Port	11.1	6.1	0	0	700000	360495	0.00042081
		32	Kaur	Linau Port	44.5	18.9	6.1	915000000	300000	123236	0.019223685
		33	Rejang Lebong	Bengkulu Pelindo Port	64.3	33.2	11.4	1710000000	200000	268569	0.006106364
		34	Seluma	Bengkulu Pelindo Port	31.8	38.1	19.4	2910000000	100000	204790	0.011721471
		35	Kepahiang	Bengkulu Pelindo Port	41.6	44.3	11.5	1725000000	100000	144418	0.004604689
8	Lampung	36	Bandar Lampung	Panjang Port	7.9	5.5	0	0	3500000	1166761	0.000253694
		37	Metro	Panjang Port	25.3	17.2	4.7	705000000	350000	161799	0.000381894
		38	Pesawaran	Panjang Port	22.1	25.6	10.1	1515000000	337000	542984	0.004131816
		39	Tanggamus	Piers Attorney Port	33.2	17.5	5.8	870000000	700000	634643	0.004759526
		40	Mesuji	Mesuji Port	37.8	31.6	8.4	1260000000	337000	302524	0.007219262
9	Bangka Belitung Islands	41	Pangkal Pinang	Balam Base port	3.4	1.2	0	0	1600000	202959	0.000440483
		42	Bangka	Balam Base port	26.8	13.5	6	900000000	700000	304944	0.009676137
		43	Belitung	Tanjung Pandan Port	13.9	7.6	3.2	480000000	800000	152250	0.015064762
		44	West Bangka	Muntok Port	38.9	16.2	5	750000000	600000	179711	0.015695255
		45	East Belitung	Belitung Port	11.1	25.5	13.8	2070000000	650000	109564	0.022880782
10	Riau Islands	46	Batam	Batam Port	8.3	7.3	0	0	5000000	1029808	0.000932455
		47	Bintan	Bintan Lagoon International Port	15.1	12.4	4.4	660000000	2500000	140169	0.009404433
		48	Tanjungpinang	Sri Bintan Putra Port	3	1.2	0	0	1000000	203008	0.00071209
		49	Lingga	Jagoh Port, Dabo Singkep	11.4	5.9	3.9	585000000	700000	87463	0.025916902
		50	Karimun	Tanjung Batu Port	13.2	5.5	2.4	360000000	1000000	237002	0.003851233
11	DKI Jakarta	51	South Jakarta	Tanjung Priok Port	16.1	15.5	0	0	24600000	2113411	7.30194E-05
		52	Central Jakarta	Tanjung Priok Port	6.8	10.5	0	0	21000000	1114581	4.69952E-05
		53	East Jakarta	Tanjung Priok Port	9.9	10.6	0	0	20000000	2852887	6.40404E-05
		54	West Jakarta	Tanjung Priok Port	12.9	8.4	0	0	22000000	2234397	5.56929E-05
		55	North Jakarta	Tanjung Priok Port	7.5	7.1	0	0	20000000	1647853	8.4953E-05
12	West Java	56	Bandung	Patimban port	59.4	44.6	0	0	11000000	2339463	7.16703E-05
		57	Bogor	Tanjung Priok Port	36.2	30.4	3	450000000	11000000	982469	0.000120614
		58	Sukabumi	Ratu Port	39.8	12.1	9.9	1485000000	1700000	2436729	0.001701338
		59	Tasikmalaya	Cirebon port	31.7	63.1	18.3	2745000000	1700000	1640647	0.00155499
		60	Cimahi	Tanjung Priok Port	84.3	37.7	24.6	3690000000	2000000	513176	7.65235E-05
13	Central Java	61	Semarang	Tanjung Mas Port	5.6	3.9	0	0	14800000	1621384	0.000230531
		62	Jepara	Kartini Port	2.7	2.6	0	0	1700000	1141236	0.00092816
		63	Pekalongan	Nusantara Port	3.1	2.6	0	0	2676000	911277	0.000918491
		64	Surakarta	Tanjung Mas Port	60.4	38.3	10.5	1575000000	5000000	552118	8.33336E-05
		65	Magelang	Tanjung Mas Port	39.2	29.5	10.2	1530000000	1700000	1261661	0.000874189
14	DI Yogyakarta	66	Yogyakarta	Tanjung Mas Port	65.6	59.9	4.6	690000000	21000000	407617	7.97317E-05
		67	Sleman	Tanjung Mas Port	57.4	53.1	10.5	1575000000	4500000	1062801	0.000540854
		68	Bantul	Tanjung Mas Port	60.2	80.4	7.7	1155000000	4500000	912937	0.000556588
		69	Kulon Progo	Tanjung Mas Port	84.5	25.2	28.6	4290000000	4000000	409568	0.001431459
		70	Gunung Kidul	Tanjung Mas Port	60.8	60.5	39.2	5880000000	700000	749155	0.001910713

					Input					Output	
	Province		District	Port	Primary	Secondary	Tertiary	Total Cost of Insfr	Land Cost (m^2) (IDR)	Population	Ratio of Free U
15	East Java	71	Surabaya	Tanjung Perak Port	5.1	1.8	0	0	21000000	2805906	0.000124929
		72	Pasuruan	Pasuruan Port	8.1	10.2	3.5	525000000	5000000	1553563	0.0009488
		73	Malang	Pasuruan Port	27.4	22.2	5.4	810000000	4000000	808945	0.000179592
		74	Kediri	Tanjung Perak Port	50.6	50.1	16.4	2460000000	3500000	1440425	0.000962251
		75	Probolinggo	Probolinggo Port	24.7	11.4	8	1200000000	1000000	1072101	0.001582136
16	Banten	76	Tangerang	Tanjung Priok Port	17.1	13.1	1.6	240000000	15900000	1566190	9.82831E-05
		77	Serang	Karangantu Port	10.7	11.1	3.1	465000000	1000000	1401036	0.001237855
		78	Lebak	Binuangeun Port	16.9	40.1	24.3	3645000000	700000	1133671	0.003022535
		79	Cilegon	Merak Port	8.9	3.2	0	0	1572000	387543	0.000452853
		80	Pandeglang	Labuan Port	17.9	16.3	5.1	765000000	700000	1139061	0.002411539
17	Bali	81	Denpasar	Indonesian, Benoa Port	4.6	4.9	0	0	15000000	632016	0.000202178
		82	Gianyar	Benoa Port	26.5	7.2	0	0	12000000	485377	0.000758174
		83	Buleleng	Buleleng Port	20.5	7.2	3.5	525000000	10000000	805883	0.001693459
		84	Bangli	Benoa Port	31.8	26.7	7.4	1110000000	5000000	261240	0.001878388
		85	Klungkung	Nusa Penida Port	4.5	5.6	2.8	420000000	5000000	211862	0.001486817
18	West Nusa Tenggara	86	Mataram	Lembar Port	11	10.4	2.5	375000000	2300000	408900	0.000149914
		87	Bima	Bima Port	15.4	16.6	17.1	2565000000	700000	519078	0.006560921
		88	Dompu	Bima Port	16.1	40.4	5.8	870000000	600000	211051	0.011331574
		89	East Lombok	Lembar Port	11.6	30.1	3.5	525000000	1500000	1279949	0.00096157
		90	Sumbawa	Badas Port	15.4	24	8.3	1245000000	600000	503978	0.013183075
19	East Nusa Tenggara	91	Kupang	Tenau Port	7.7	3.1	2.3	345000000	2500000	433970	6.03268E-05
		92	Alor	Feri Port	6.3	15	10	1500000000	700000	207283	0.013819754
		93	Belu	Atapupu port	7.7	11.2	10.6	1590000000	300000	218880	0.00587066
		94	Ngada	Aimere port	34.5	6.3	5.1	765000000	450000	162721	0.010114736
		95	Southwest Sumba	Waikelo Port	5.1	10	12.1	1815000000	700000	300671	0.004923854
20	West Kalimantan	96	Pontianak	Indonesian Port II	0.95	0	0	0	2500000	651139	0.000165556
		97	Singkawang	Sedau Port	6.2	2.1	1.4	210000000	1700000	230216	0.002189248
		98	Bengkayang	Teluk Suak Port	23.6	68.6	52.3	7845000000	700000	280168	0.018115845
		99	Landak	Dwikora Port	79.2	24.2	33.6	5040000000	600000	391767	0.022756128
		100	Kubu Raya	Dwikora Port	19.3	13.8	22	3300000000	800000	596421	0.011666625
21	Central Kalimantan	101	Palangka Raya	Sampit Port	93.3	84	41.5	6225000000	3000000	249429	0.009619972
		102	Seruyan	Sigintung Port	11.4	8.5	7.5	1125000000	700000	141334	0.11606549
		103	Gunung Mas	Sampit Port	96.6	95.8	72.2	10830000000	400000	135872	0.079523375
		104	South Barito	Sampit Port	138	108	35.1	5265000000	700000	121557	0.072640819
		105	Pulang Pisau	Sampit Port	96.1	42.4	58.8	8820000000	300000	122143	0.073659563
22	South Kalimantan	106	Banjarmasin	Trisakti Port	4	0	0.6	90000000	2500000	635688	0.000113263
		107	Banjarbaru	Trisakti Port	26.7	5.4	3.3	495000000	850000	216600	0.001712835
		108	Balangan	Trisakti Port	92.4	46.7	85.4	12810000000	600000	121429	0.015468298
		109	Barito Kuala	Trisakti Port	14.2	16.7	8.6	1290000000	300000	303193	0.009883012
		110	Tabalong	Semayang Port	120	78.1	29.2	4380000000	300000	230847	0.016318037
23	East Kalimantan	111	Balikpapan	Semayang Port	5.4	1.5	1.9	285000000	15000000	597625	0.000881824
		112	Samarinda	TPK Palaran Port	5.6	13.6	8.8	1320000000	10300000	752845	0.001040055
		113	Bontang	Tanjung Laut Port	1	0.21	0.39	58500000	1000000	161356	0.002520514
		114	Paser	Semayang Port	5	48.3	102	15300000000	900000	240043	0.03220623
		115	Tarakan	Malundung Port	3.3	1.9	0.7	105000000	800000	179079	0.000402057
24	North Sulawesi	116	Manado	ASDP Manado Port	0.7	1.8	0.3	45000000	16000000	461636	0.00034068
		117	Bitung	Bitung Port	1.4	5	3.5	525000000	1133000	218520	0.001386097
		118	Tomohon	ASDP Manado Port	4.1	22.1	0.4	60000000	700000	96411	0.001184512
		119	Minahasa	Amurang Port	11.9	17.4	15.3	2295000000	600000	331647	0.000337316
		120	Kotamobagu	Amurang Port	4.8	62.7	23.3	3495000000	600000	120597	0.000564359
25	Central Sulawesi	121	Palu	Pantoloan Port	3.2	18.1	1.8	270000000	3500000	359350	0.001099374
		122	Parigi Moutong	Tinombo Port	56.2	16.6	10.4	1560000000	700000	439799	0.011573264
		123	Donggala	Donggala Port	51.6	45.2	6.5	975000000	850000	288686	0.014808754
		124	Banggai	Luwuk Port	16.9	10.7	7.8	1170000000	600000	355415	0.027215227
		125	Poso	Laut Poso Port	1.3	1.2	1	150000000	600000	238400	0.029833263
26	South Sulawesi	126	Makasar	Soekarno Hatta Makasar Port	1.4	9.2	6.3	945000000	14070000	1651146	0.00012068
		127	Palopo	Tanjung Ringgit Port	1.2	1.9	0.6	90000000	300000	180130	0.001404486
		128	Sidrap	Awerange Port	29	51.1	0.4	60000000	450000	317691	0.005927867
		129	Parepare	Indonesian Port 4	0.8	0.8	0	0	500000	175040	0.00056747
		130	Maros	Soekarno Hatta Makasar Port	25.4	11.2	6.7	1005000000	300000	395081	0.004098198
27	Southeast Sulawesi	131	Kendari	Indonesian Port 4	6.8	4.1	0	0	9300000	331013	0.000908998
		132	Baubau	Murhum Port	2.2	0.6	0	0	300000	152143	0.001452581
		133	Muna	Nusantara Raha Port	9.8	15.2	12.6	1890000000	400000	223982	0.008581761
		134	Kolaka	Kolaka Port	7.3	1.3	2	300000000	300000	204044	0.016092558
		135	Wakatobi	Mola Port	6.4	1.5	1.5	225000000	350000	107898	0.005185824
28	Gorontalo	136	Gorontalo City	Indonesian Port 4	2.7	1.9	0	0	700000	191897	0.000414754
		137	North Gorontalo	Anggrek Port	2.7	5.5	0	0	300000	122124	0.013724984
		138	Bone Bolango	Indonesian Port 4	20.7	15.2	10.2	1530000000	250000	157215	0.012621633
		139	Pohuwato	Marisa Port	4.1	19.1	0.4	60000000	150000	136448	0.031105696
		140	Boalemo	Tilamuta Port	8.4	15.7	15.8	2370000000	150000	141796	0.010754041
29	West Sulawesi	141	Mamuju	Mamuju Port	2.8	15.9	2.7	405000000	700000	290672	0.017200453
		142	Majene	Palipi Port	49.3	5.9	3.2	480000000	300000	164107	0.005775744
		143	Polewali Mandar	Tanjung Silopo Port	34.9	6.2	3.3	495000000	250000	513180	0.003460092
		144	Mamasa	Tanjung Silopo Port	50.7	27.9	12.9	1935000000	150000	200977	0.014956338
		145	North Mamuju	Pasangkayu Port	55.7	8.8	12.6	1890000000	500000	205774	0.014791713
30	Maluku	146	Ambon	Ambon Port	5.9	0.8	0	0	700000	372249	0.000802178
		147	Seram	Kobi Sadar Port	45.8	31.2	12.2	1830000000	350000	125684	0.051159097
		148	Tual	Tual Port	1.7	0.4	0	0	150000	82955	0.003066602
		149	Aru	Dobo Port	1.8	3.5	0	0	150000	100766	0.080904472
		150	Buru	Namlea Port	66.2	6.8	6	900000000	200000	128720	0.03831821
31	North Maluku	151	Ternate	A Yani Port	1.9	1.4	0	0	5836000	213274	0.000522286
		152	Sula	Sanana Port	16.5	11	10.2	1530000000	700000	122726	0.026924368
		153	Morotai	Morotai Ferry Port	14.1	24.8	5.5	825000000	350000	63033	0.039281012
		154	Tidore	Trikora Tidore Port	3.3	5	0	0	700000	103171	0.015951479
		155	Halmahera	Tongute Port	8.8	8.9	5.9	885000000	600000	130137	0.01309543
32	West Papua	156	Manokwari	Manokwari Port	2.2	2.4	0	0	2000000	190337	0.016740203
		157	Sorong	Arar Port	15.5	17.2	9.4	1410000000	1700000	120956	0.05410422
		158	Fakfak	Fak Fak Port	2.6	2.4	2.5	375000000	700000	83072	0.132854391
		159	Sorong City	Sorong Port	2.5	0.6	0	0	500000	272349	0.002411024
		160	Bintuni	Bintuni Port	7	6.6	5	750000000	450000	75410	0.276366927
33	Papua	161	Jayapura	Indonesian Port 4	4.3	6.3	1.5	225000000	2000000	162199	0.068786799
		162	Merauke	Merauke Port	57.6	40.5	17.5	2625000000	1500000	219438	0.200835771
		163	Biak Numfor	Laut Biak Port	4.4	7.2	8	1200000000	500000	138401	0.018800442
		164	Nabire	Nabire Port	21.6	27.5	14	2100000000	700000	163390	0.068012791
		165	Mimika	LPMAK Port	3.8	26.6	6.7	1005000000	600000	303376	0.071307552

A.2 Provinces Level Data

	Output			Input				
Province	Wind Velocity (m/s)	Population	Area (sq.km)	Electricity Consumption (Gwh)	Landslide (times)	Flood (times)	Eartquake (times)	Volcanic eruption (times)
Aceh	5.3	4494410	57,956.00	2119	273	1 649	1 228	0
North Sumatra	2.7	12982204	72,981.23	8704	569	807	191	194
West Sumatra	2.4	4846909	42,012.89	3063	225	306	78	6
Riau	2.9	5538367	87,023.66	3586	24	512	0	0
Jambi	5.9	3092265	8,201.72	1083.79	58	518	40	0
South Sumatra	5.5	7450394	50,058.16	4783	145	745	2	0
Bengkulu	3.9	1715518	91,592.43	785.43	151	213	56	0
Lampung	4.0	7608405	16,424.06	3571.00	82	508	5	0
Bangka Belitung Islan	4.2	1223296	19,919.33	861.52	4	58	0	0
Riau Islands	5.7	1679163	34,623.80	2695	13	51	0	0
DKI Jakarta	6.9	9607787	664.01	41329	0	151	0	0
West Java	4.7	43053732	35,377.76	44071	1 578	1 193	412	5
Central Java	3.3	32382657	9,662.92	20408	1 222	1 273	129	1
DI Yogyakarta	10.2	3457491	32,800.69	2484	77	76	27	2
East Java	4.3	37476757	3,133.15	30825	665	1 218	207	43
Banten	13.3	10632166	47,799.75	8575	150	531	19	0
Bali	2.4	3890757	5,780.06	4594	150	58	0	0
West Nusa Tenggara	6.4	4500212	18,572.32	1402.30	46	286	68	0
East Nusa Tenggara	7.0	4683827	48,718.10	749.76	581	445	97	17
West Kalimantan	8.8	4395983	147,307.00	1989.63	65	616	0	0
Central Kalimantan	5.0	2212089	153,564.50	1048.64	23	534	0	0
South Kalimantan	3.0	3626616	38,744.23	2187.64	40	623	0	0
East Kalimantan	5.3	3553143	129,066.64	3007.30	55	409	4	0
North Sulawesi	4.1	2270596	13,851.64	1302.58	308	353	102	102
Central Sulawesi	5.3	2635009	11,257.07	948.78	205	731	158	0
South Sulawesi	3.9	8034776	61,841.29	4479.46	280	728	22	0
Southeast Sulawesi	4.0	2232586	46,717.48	703.59	123	702	175	0
Gorontalo	5.9	1040164	16,787.18	398.82	73	323	99	0
West Sulawesi	2.2	1158651	38,067.70	258.70	157	159	8	0
Maluku	4.5	1533506	46,914.03	509.51	122	233	43	0
North Maluku	5.0	1038087	31,982.50	329.44	52	285	143	63
West Papua	5.0	760422	319,036.05	455.58	54	88	160	0
Papua	8.5	2833381	99,671.63	763.32	251	308	341	0

Appendix B

General Optimization Model in IBM ILOG CPLEX

B.1 Model on Districts Level

Model:

```
/*********************************************
 * OPL 12.5.1.0 Model
 * Author: Galih Pambudi
 * Creation Date: Mar 17, 2018 at 11:23:37 AM
 *********************************************/

 //define indices
 int District=...; //the set of district name
 int ninputs= ...; //the set of input criteria
 int noutputs=...; //the set of output criteria

 range DMU=1..District; //range of decision making unit in districts
 range Input=1..ninputs; //number of input
 range Output=1..noutputs; //number of output

 //define parameter
 // Input
 float I[DMU][Input]=...;  // Data of inputs
 // Output
 float O[DMU][Output]=...; // Data of outputs

 int refDMU=...; // measurement of the DMU efficiency

 //assert refDMU in DMU;
 //decision variables
 dvar float+ teta; // variable of DMU efficiency
 dvar float+ lambda[DMU]; // variable of lambda value

 //objective function
 minimize teta; // minimize input

 subject to
 {

 forall(j in Input)
     ctInput:
         sum(i in DMU) (lambda[i]*I[i][j]) <= teta*I[refDMU][j]; //
 input constraint
 forall(j in Output)
     ctOutput:
         sum(i in DMU) (lambda[i]*O[i][j]) >= O[refDMU][j]; //
 output constraint

 }
  execute // shows report for DMU
 {
```

```
 writeln("",teta);
 if (teta==1) writeln("DMU Efficient");
 else writeln("DMU Not efficient");
 writeln("lambda=",lambda);
 writeln();
}

// Loop to measure efficiency for all DMU
main // To implement Flow Control
{
thisOplModel.generate(); //generating the current model instance

for(var dmu in thisOplModel.DMU)
{
   //writeln("District ",dmu);
   for(j in thisOplModel.Input)
 thisOplModel.ctInput[j].setCoef(thisOplModel.teta,-
 thisOplModel.I[dmu][j]);
   for(j in thisOplModel.Output)
 thisOplModel.ctOutput[j].LB=thisOplModel.O[dmu][j]; // modifying
 lower bound of output
    cplex.solve(); //one of CPLEX Optimizer's MP algorithms to solve
 the model
  thisOplModel.postProcess(); //to control and manipulatethe
 solutions
}
}
```

Data:

```
/*********************************************
 * OPL 12.5.1.0 Model
 * Author: Galih Pambudi
 * Creation Date: Mar 17, 2018 at 12:23:37 AM
 *********************************************/

District=165; //total of districts
refDMU=1; //DMU reference
ninputs=5; //total amount of input criteria
noutputs=2; //total amount of output criteria
SheetConnection sheetData("Theses Data.xlsx"); //data connection
with excel data
x from SheetRead(sheetData,"I"); //read input table
y from SheetRead(sheetData,"OPCA"); //read output table

//teta to SheetWrite(sheetData,SheetWriteConnectionString);
woutputs from SheetRead(sheetData,"wo");
winputs from SheetRead(sheetData,"wi");
```

B.2 Model on Provinces Level

Model:

```
/*********************************************
 * OPL 12.5.1.0 Model
 * Author: Galih Pambudi
 * Creation Date: Mar 17, 2018 at 18:23:37 AM
 *********************************************/

 //define indices
 int province=...; //the set of province name
 int ninputs= ...; //the set of input criteria
 int noutputs=...; //the set of output criteria

 range DMU=1..province; //range of decision making unit in provinces
 range Input=1..ninputs; //number of input
 range Output=1..noutputs; //number of output

  //define parameter
 // Input
 float X[DMU][Input]=...;  // Data of inputs
 // Output
 float Y[DMU][Output]=...; // Data of outputs

 int refDMU=...; // measurement of the DMU efficiency

 //assert refDMU in DMU;
 //decision variables
 dvar float+ teta; // variable of DMU efficiency
 dvar float+ lambda[DMU]; // variable of lambda value

 //objective function
 minimize teta; // minimize input

 subject to
 {

 forall(j in Input)
     ctInput:
         sum(i in DMU) (lambda[i]*X[i][j]) <= teta*X[refDMU][j]; //
 input constraint
 forall(j in Output)
     ctOutput:
         sum(i in DMU) (lambda[i]*Y[i][j]) >= Y[refDMU][j]; //
 output constraint

 }

 execute // shows report for DMU
 {
 writeln("",teta);
 if (teta==1) writeln("DMU Efficient");
 else writeln("DMU Not efficient");
 //writeln("lambda=",lambda);
writeln();
}
```

```
// Loop to measure efficiency for all DMU
main // To implement Flow Control
{
thisOplModel.generate(); //generating the current model instance

for(var dmu in thisOplModel.DMU)
{
   writeln("Province ",dmu);
   for(j in thisOplModel.Input)
 thisOplModel.ctInput[j].setCoef(thisOplModel.teta,-
 thisOplModel.X[dmu][j]);
   for(j in thisOplModel.Output)
 thisOplModel.ctOutput[j].LB=thisOplModel.Y[dmu][j]; // modifying
 lower bound of output
    cplex.solve(); //one of CPLEX Optimizer's MP algorithms to solve
 the model
  thisOplModel.postProcess(); //to control and manipulatethe
 solutions
}
}
```

Data:

```
/*********************************************
 * OPL 12.5.1.0 Model
 * Author: Galih Pambudi
 * Creation Date: Mar 17, 2018 at 19:23:37 AM
 *********************************************/

province=33; //total of provinces
refDMU=1; //DMU reference
ninputs=5; //total amount of input criteria
noutputs=3; //total amount of output criteria
SheetConnection sheetData("Theses Data.xlsx"); //data connection
with excel data
X from SheetRead(sheetData,"X"); //read input table
Y from SheetRead(sheetData,"Y"); //read output table

//teta to SheetWrite(sheetData,SheetWriteConnectionString);
```