International Journal on Advanced Science Engineering Information Technology

Vol.10 (2020) No. 5
ISSN: 2088-5334

Wind Energy Feasibility Study of Seven Potential Locations in Indonesia

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***Abstract*— This study evaluated seven potential locations for wind energy in Indonesia. This study applied economic analysis using static analysis and the Monte Carlo simulation. The later was used to measure the financial indicators and then to analyze the sensitivity of economic uncertainties. The result findings show that in term of annual energy production volume among the seven selected locations, Jeneponto location has the highest value of 4,339,003.2 MWh with a capacity factor of 25.22% and Bantul location has the lowest value of 526,476 MWh with a capacity factor of 16.51%. According to economic uncertainty analysis, the highest NPV and attractive IRR values with high deviation standard values will be interesting to the risk-taking investors. Otherwise, the lowest NPV and IRR values fit the risk of avoiding-type investors due to its low deviation standard values. Based on sensitivity analysis, the increase of average NPV and IRR values of all seven locations are influenced positively by first 5-year of the selling price, which contributes approximately 30% and 50% of NPV and IRR's percentage change. By contrast, the decrease in average NPV values of all seven locations is influenced by the discount rate, which contributes approximately 15% of NPV's percentage change. Meanwhile, the decrease in average IRR is influenced by capital investment cost, which contributes approximately 20% of IRR's percentage change. Policymakers can further consider the parameters mentioned above.**

***Keywords*— annual energy production; capacity factor; monte Carlo simulation; economic uncertainties; wind energy.**

I. INTRODUCTION

In Indonesia, fossil energy still constitutes the primary energy source [1]. And its unstable price and a limited reserve have contributed to the uncertain economic environment in the country. This situation has encouraged the Indonesian government to develop alternative energy from other potential sources such as renewable sources. Indonesia, as an archipelago country, has a high-potential alternative energy source such as solar, wind, bio, sea-wave, and geothermal energies. According to the National Power Plant Company (PLN)'s projection, the country's population growth has also increased the demand for electricity from 219 TWh in 2015 to become 464 TWh in 2024. It has forced the government to set the ambitious target in 2025 by achieving the electrification ratio up to 95% and scaling up the contribution of renewable energy to become primary mixed energy up to 23% [2].

Wind, as a remarkable endowment from Indonesia's topography and geography, is a very potential alternative energy source to release its dependence on fossil energy. However, wind energy utilization in the country is still low, only around 1.6 MW, which has been used for the non-commercial sector [3]. This lack of utilization has pushed the government to fund some studies, from technical to economic, on potential wind farms. Based on those studies, the government has attracted the private sector investment to build power plants by issuing a suitable minimum tariff policy to accelerate the utilization [4].

The development and implementation of wind energy in Indonesia have encountered a typical problem due to the unavailability of detailed data and information on wind energy potentials and the limited availability of wind turbine technology in the local market. The above-mentioned problem has become the barrier toward the development and utilization of wind energy technology solution in the country. Therefore, this study aims to conduct a feasibility study of seven potential wind energy locations in Indonesia. The seven locations are Baron, Special Region of Yogyakarta Province; Lebak, Banten Province; Bantul, Special Region of Yogyakarta Province; Sukabumi, West Java; Garut, West Java; Sidrap, South Sulawesi; and Jeneponto, South Sulawesi. Those locations were chosen because of their potentialities and accessibilities.

II. MATERIALS AND METHOD

Indonesia has several potential locations to generate wind power lying from western to eastern parts of the country like Aceh, Southern part of Java, East Nusa Tenggara, South and North Sulawesi, Islands of Eastern part of Indonesia until Papua. Since this potentiality is very diverse, it needs to be explored and mapped so that it can be more cost-effectively developed to become wind power. The first step to take in the development of wind power is wind mapping. Up to now, Indonesia has not had a comprehensive wind map due to its very expensive cost. There have been 166 potential wind energy locations recorded [5]. It shows 35 potential locations with the annual average rate of wind velocity above 6 m/s and 34 potential locations with the annual average rate of wind velocity between 4 – 5 m/s [6].

Fig. 1 shows that the wind energy potentials in Indonesia at 50 meters above sea level [7]. The potential locations inland areas are highlighted with light brown color. It shows that the wind energy sources are in several areas in the southern coast of the island of Java, south-eastern Islands (Nusa Tenggara Timur and Maluku) and southern part of Sulawesi Island. Other than those mentioned-above areas, the islands of Sumatera, Kalimantan and Papua also have potential wind energy sources. The result of wind speed study conducted in several potential locations in Indonesia at 50 meters above sea level is shown in Table 1 [6].

Table 1 shows that the most potential location is Jeneponto, South Sulawesi, with 491 W/m^2 of wind energy density, and less potential one is Bantul, Special Region of Yogyakarta Province with 91 W/m^2 of wind power density. The Eq. 1 [8] below shows the calculation of the capacity factor.

$$CF = \frac{e^{\left[-\left(\frac{V_c}{c}\right)^k\right]} - e^{\left[-\left(\frac{V_R}{c}\right)^k\right]}}{\left(\frac{V_R}{c}\right)^k - \left(\frac{V_c}{c}\right)^k} - e^{\left[-\left(\frac{V_f}{c}\right)^k\right]} \qquad (1)$$

Where, V_c : cut in wind velocity; V_R : rated wind velocity; V_f : furling wind velocity; k : Weibull shape value; and c : Weibull scale value. c and k are Weibull parameters [9]. The Eq. 2 [10] below shows the calculation of the average power of a turbine.

$$P_{ave} = P_R(CF) = \eta_o \, {}^1\!/_2 \, \rho A V_R{}^3 (CF) \qquad (2)$$

The Eq. 3 [10] below shows the calculation of normalized average power.

$$P_N = \frac{\eta_o \, {}^1\!/_2 \, \rho A V_R{}^3 (CF)}{\eta_o \, {}^1\!/_2 \, \rho A c^3} = \left(\frac{V_R}{c}\right)^3 (CF) \qquad (3)$$

The annual production of energy is expressed in the following Eq. 4.

$$E = h_y P_N A(CF) \qquad (4)$$

NPV and IRR analysis describe the investment profitability indicated by the cash flow benefit and rate of return during wind turbine utilization. Various assumptions of future uncertainties such as the wind turbine's annual energy production, energy price, and recent fluctuated interest rate level are considered in calculations. On behalf of that reason, sensitivity analysis is used to consider the investment opportunity and risk. The Eq. 5 [3], [11] shows the calculation of NPV.

$$NPV = C_{i0} - C_{o0} + \frac{C_{i1} - C_{o1}}{(i+1)} + \frac{C_{i2} - C_{o2}}{(i+1)^2} + \ldots + \frac{C_{it} - C_{ot}}{(i+1)^P} + \frac{S}{(i+1)^P} \qquad (5)$$

Where S is salvage value, IRR is discount rate value when NPV equals to zero. After NPV and IRR are calculated, the cost structure and revenue streams are analyzed. The cost structure consists of capital costs and expenses. There are three categories in capital cost used here covering costs of a wind turbine, grid connection, and civil infrastructure. Expenses constitute operating and maintenance costs. Technical parameters comprise wind velocity, capacity factor, and wind power density. Economic parameters cover durability, residual value, price, inflation, and interest rate.

The wind turbine cost varies between $814/kW and $1035/kW, cost of electrical grid connection is from $66/kW to $162/kW, and civil infrastructure cost is from $14/kW to $154.57/kW. Detail of mentioned-above capital costs is respectively shown in Table 2-4. The operating and maintenance costs are ranging from $9/MWh to $22/MWh, as shown in Table 5.

TABLE I
DATA SUMMARY OF WIND ENERGY POTENTIAL LOCATIONS AT 50 METERS ABOVE SEA LEVEL

Location description	**V_{ave} (m/s)**	**Weibull Data**		**Wind Energy Density (W/m^2)**
		c (m/s)	**k**	
Baron, Special Region of Yogyakarta Province	6.13	6.29	2.24	254
Lebak, Banten Province	5.58	6.3	2.06	198
Bantul, Special Region of Yogyakarta Province	4.00	4.7	1.87	91
Sukabumi, West Java Province	6.27	7.1	2.08	272
Garut, West Java Province	6.57	7.4	2.89	268
Sidrap, South Sulawesi Province	6.43	7.3	2.05	320
Jeneponto, South Sulawesi Province	7.96	9	2.51	491

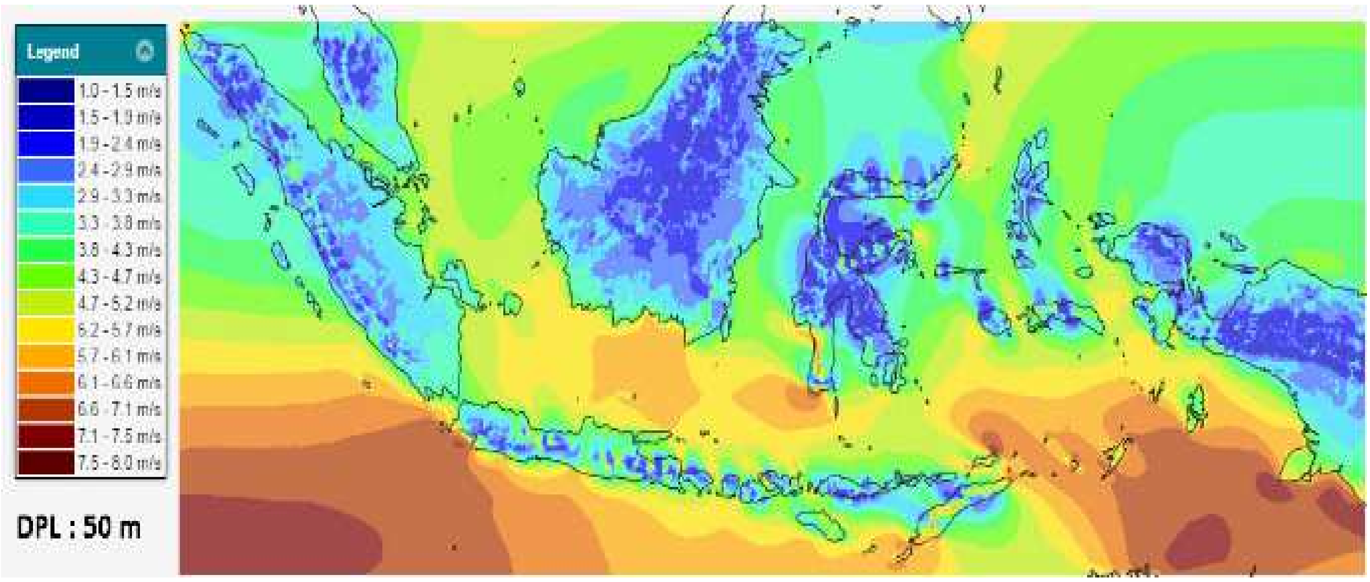

Fig. 1 Wind energy potential in Indonesia at 50 meters above sea level

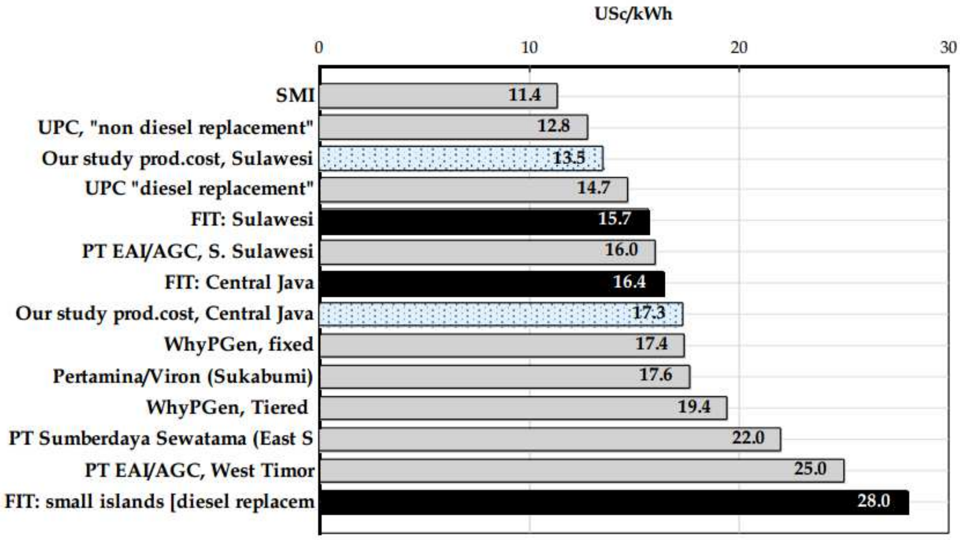

Fig. 2 Pricelist of wind power as proposed by developers [2]

TABLE II
WIND TURBINE COSTS

Review cost (per kW)	Chosen value* (per kW)
$1035 [12]	$1035
$937 [13]	$937
€928 [14]	$1010.17
65-70% of capital cost [15]	$855
70-80% of capital cost [16]	$814

*Converted from EURO to USD as of October 21st, 2016

TABLE III
GRID CONNECTION COSTS

Review cost (per kW)	Chosen value* (per kW)
€109 [14]	$118.65
€90-121.5 (average 106) [17]	$115.39
€115.24 [18]	$125.44
10-15% of investment cost [15]	$162
4-8% of investment cost [16]	$66

* Converted from EURO to USD as of October 21st, 2016

TABLE IV
CIVIL INFRASTRUCTURE COSTS

Review cost (per kW)	Chosen value* (per kW)
€142 [14]	$154.57
€70-94.5 (average 82.3) [17]	$89.59
$23 [19]	$23
$14 [20]	$14
5-15% of investment cost [15]	$114
5-12% of investment cost [16]	$95

* Converted from EURO to USD as of October 21st, 2016

TABLE V
OPERATING AND MAINTENANCE COSTS

Review cost (per MWh)	Chosen value* (per MWh)
$22 [21]	$22
$17.5 [22]	$17.5
$13.76 [20]	$13.76
$10 [23]	$10
$9 [24]	$9
€12 to 15 (average 13.5) [14]	$14.7

* Converted from EURO to USD as of October 21st, 2016

Wind velocity, Weibull parameter, capacity factor and wind power density which are classified as technical parameters have been completely explained in the previous discussion about wind energy potential in Indonesia. The common economic lifetime is 20 years according to some literatures [14], [18], [19], [25], [26]. The salvage value refers to IEA [21], which is assumed at 20% of capital cost. The selling price is ranging from $0.114/kW to $0.28/kWh, as indicated by Fig. 2.

The inflation rate refers to Indonesia inflation rate issued by Badan Pusat Statistik [27]. The Inflation data is ranging from 2.64 to 15.3, as shown in Fig. 3. The prevailing corporate tax rate is at 25 % according to Direktorat Pajak in 2010 until 2015 [28]. The discount rate refers to Bank Indonesia [29]. The discount rate is ranging from 5.79% to 12.08%, as shown in Fig. 4. Values and assumptions for input data are shown in Table 6.

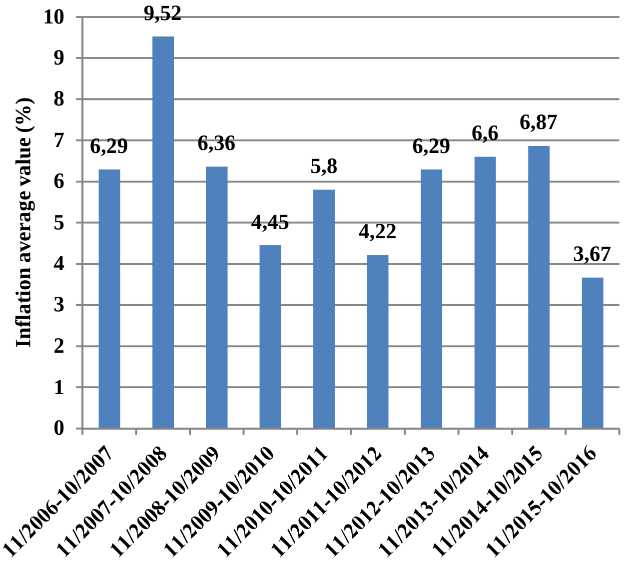

Fig. 3 Indonesia inflation rate from Badan Pusat Statistik [27]

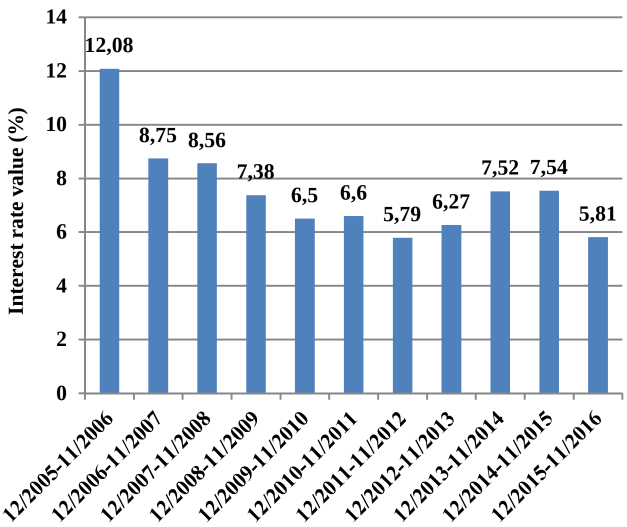

Fig. 4 Indonesia discount rate from Bank Indonesia [29]

TABLE VI
ASSUMPTIONS AND VALUES TO BE USED AS INPUT DATA

Item Descriptions	Value	Assumptions
Wind turbine cost	930.23/kW	Value is ranging from $814/kW until $1035/kW
Operation and maintenance cost	$14.49/MWh	Value is ranging from $9/MWh until $22/MWh
Grid connection cost	$117.5/kW	Value is ranging from $66/kW until $162/kW
Civil infrastructure cost	$81.69/kW	Value is ranging from $14/kW until $154.57/kW
Price	$0.1766/kWh	Value is ranging from $0.114/kW until $0.28/kWh
Discount rate	7.53%	Value is ranging from 5.79% until 12.08%
Salvage value	20%	Assumed at 20 % of original capital cost [21]
Lifetime	20 years	The common lifetime [14], [18], [19], [25], [26]
Inflation	7.24	Value is ranging from 2.64 until 15.3
Tax rate	25%	Corporate tax rate in Indonesia is 25 % [28]
Depreciation period	20 years	Equal to the economic lifetime

III. RESULTS AND DISCUSSION

A cut-in wind speed of 0.5 V_R has resulted from the loss in the gearbox and generator at cut-in. Meanwhile, the furling speed of 2 V_R means that the turbine control system is able to maintain a constant power output [10]. The plot of Power Normalization (PN) is indicated by Fig. 5 for Weibull shape parameter k and cut-in wind speed c.

Fig. 5 shows that locations with lesser k values are superior to those with greater k values. Locations with lesser V_R values tend to have lesser k values than those of locations with greater V_R. The lesser V_R will usually reduce the average power instead of increasing it due to lesser values of k. In Fig. 5 we see that the greatest normalized powers occur when values of k = 1.87 at V_R/c = 1.85; k = 2.05 at V_R/c = 1.71; k = 2.06 at V_R/c = 1.70; k = 2.08 at V_R/c = 1.69; k = 2.24 at V_R/c = 1.6; k = 2.51 at V_R/c = 1.48; and k = 2.89 at V_R/c = 1.36. Generally, minimum area required as wind farm is about 4 km^2 [30]–[33].

Capacity factor is very important to determine the energy production volume, which is, in turn, it will influence the sales. Table 7 shows capacity factors each location where the highest and lowest values are located in Garut at 30.06% and in Bantul at 16.51%, respectively. Meanwhile, the finding shows differently for the annual energy production volume. The highest and the lowest values are located in Jeneponto at 4,339,003.2 MWh and in Bantul at 526,476 MWh, respectively. The difference is due to large wind distribution values like in Jeneponto so that it produces a larger annual energy production volume.

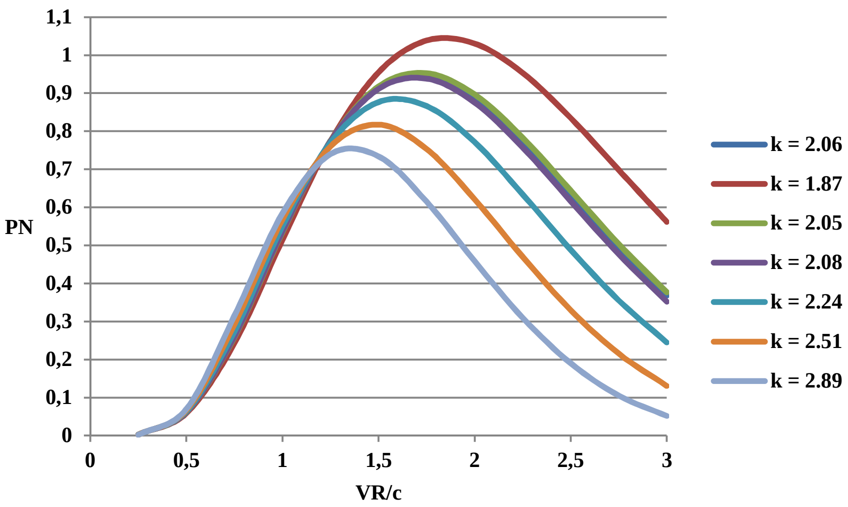

Fig. 5 Normalized power versus normalized rated speed for $V_c = 0.5\ V_R$, $V_f = 2\ V_R$

TABLE VII
CALCULATED CAPACITY FACTORS AND ANNUAL ENERGY PRODUCTION VOLUMES OF WIND ENERGY LOCATIONS

Location description	**V_R/c (from Fig. 2)**	**Capacity Factor (%)**	**Annual Production of Energy (MWh)**
Baron, Yogyakarta	1.60	21.61	1,923,345.6
Lebak, Banten	1.70	19.33	1,341,068.4
Bantul, Yogyakarta	1.85	16.51	526,476
Sukabumi, West Java	1.69	19.50	1,858,521.6
Garut, West Java	1.36	30.06	2,822,822.4
Sidrap, South Sulawesi	1.71	19.07	2,138,316
Jeneponto, South Sulawesi	1.48	25.22	4,339,003.2

TABLE VIII
THE MAIN OUTPUTS

Location description	**Annual energy production volume (1000) (MWh)**	**Annual revenue (1st year) (USD1000)**	**Capital cost (USD1000)**	**Operation and maintenance cost (1st year) (USD1000)**	**Depreciation cost (1st year) (USD1000)**	**Taxable income (1st year) (USD1000)**	**Tax to be paid (1st year) (USD1000)**	**Net income (1st year) (USD1000)**
Baron, Yogyakarta	1,923.3	339,662.8	1,147,503.3	27,869.3	45,900.1	265,893.4	66,473.4	245,320.2
Lebak, Banten	1,341.1	236,832.7	894,479.6	19,432.1	35,779.2	181,621.4	45,405.4	171,995.3
Bantul, Yogyakarta	526.5	92,975.7	411,133.5	7,628.6	16,445.3	68,901.7	17,225.4	68,121.6
Sukabumi, West Java	1,858.5	328,214.9	1,228,809	26,930	49,152.4	252,132.6	63,033.2	238,251.8
Garut, West Java	2,822.8	498,510.4	1,210,726.2	40,902.7	48,429.1	409,178.7	102,294.7	355,313.1
Sidrap, South Sulawesi	2,138.3	377,626.6	1,445,681.3	30,984.2	57,827.3	288,815.2	72,203.8	274,438.6
Jeneponto, South Sulawesi	4,339	766,268	2,218,177.3	62,872.2	88,727.1	614,668.7	153,667.2	549,728.6

TABLE IX
CASH FLOW (IN USD 1000)

Location description	0	1	5	10	15	20
Baron, Yogyakarta	-1,147,503.3	245,320.2	238,577.3	227,012	210,608.4	416,842.9
Lebak, Banten	-894,479.6	171,995.3	167,293.7	159,229.7	147,792.2	310,465.6
Bantul, Yogyakarta	-411,133.5	68,121.6	66,275.9	63,110.1	58,620	134,478.1
Sukabumi, West Java	-1,228,809	238,252	231,736.2	220,650.7	204,709.9	427,989.7
Garut, West Java	-1,210,726.2	355,313.1	345,416.8	328,442.9	304,367.9	512,366.3
Sidrap, South Sulawesi	-1,445,681.3	274,438.6	266,942.1	254,084.2	235,847.1	499,166.8
Jeneponto, South Sulawesi	-2,218,177.3	549,728.6	534,516.9	508,426	471,418	862,567.8

TABLE X
NPV AND IRR IN AVERAGE

Location description	Annual production of energy (1000) (MWh)	Capital cost (USD1000)	NPV (USD1000)	IRR (%)
Baron, Yogyakarta	1923.3	1,147,503.3	947,801.1	20.16
Lebak, Banten	1341.1	894,479.6	578,098.3	17.89
Bantul, Yogyakarta	526.5	411,133.5	174,349	15.03
Sukabumi, West Java	1858.5	1,228,809	810,635.8	18.06
Garut, West Java	2822.8	1,210,726.2	1,806,233.4	28.4
Sidrap, South Sulawesi	2138.3	1,445,681.3	904,717	17.63
Jeneponto, South Sulawesi	4339	2,218,177.3	2,463,173.9	23.71

TABLE XI
THE ASSUMPTIONS ARE DATA TO RISK FACTOR

Item	Value	Distribution	Min	Max	Most Likely
Wind turbine cost ($/kW)	*	Uniform	814	1035	
Grid connection cost ($/kW)	*	Uniform	66	162	
Civil infrastructure cost ($/kW)	*	Uniform	14	154.47	
O & M cost ($/MWh)	*	Uniform	9	22	
Capacity factor (%)	*	Uniform	16.51	30.06	
Salvage value (%)	*	Triangular	5	20	20
Depreciation period (years)	20	Fixed			
Lifetimes (years)	20	Fixed			
Tax rate (%)	25	Fixed			
Inflation (%)	*	Uniform	2.64	15.3	
Price ($/kWh)	*	Tringular	0.114	0.28	0.1766
Interest rate	*	Uniform	5.79	12.08	

* Value varies based on the simulation result

The main output for 7 locations, the cash flow, and the average of NPV and IRR are irrespectively indicated by Table 8, Table 9, Table 10. The calculations show that the NPV average of each location has a positive value, which is the best value, located in Jeneponto and the worst is in Bantul. For IRR, the best and the worst are Garut and Bantul, respectively. To support the economic calculation and analysis, the analysis of uncertainty is added using the Monte Carlo simulation method wherein deterministic and stochastic variables are used as shown in Table 11.

Monte Carlo has made a simulation of 1000 iterations for each output variable of NPV and IRR. Fig. 6 shows that in term of NPV value, the highest potential location is Jeneponto as demonstrated by its average NPV compare to others six locations. Meanwhile, deviation standard of Jeneponto is also the highest among others which it means that for risk-avoiding investors would avoid investing except they are able to influence the significant variable (i.e. the first 5-year selling price) not to have fluctuated. But for risk-taking investors, this location is the best choice for investment. Interestingly, though Bantul is the lowest NPV value, its lowest variance is suitable for risk-avoiding investors. Fig. 7 shows that in term of IRR value, the highest potential location is Garut as shown by its average IRR compare to other six locations. Meanwhile, the deviation standard of Garut is also the highest among others which it means that for risk-avoiding investors would avoid investing except they are able to influence the significant variable (i.e. capital investment cost) not to be fluctuated. But for risk-taking investors, this location is the best choice for investment. Interestingly, the other 6 locations have nearly similar deviation standard values of around 4%.

Fig. 8 shows that the increase of average NPV values of all seven locations is influenced positively by the first 5-year of the selling price, contributing approx. 30% of NPV change percentage. By contrast, the decrease in average NPV values of all seven locations is influenced by the discount rate, contributing approx. 15% of NPV change percentage.

Fig. 9 shows that the increase of average IRR values of all seven locations is influenced positively by the first 5-year of the selling price, contributing approx. 50% of IRR change percentage. By contrast, the decrease in average IRR values of all seven locations is influenced by capital investment cost, contributing approx. 20% of the change percentage.

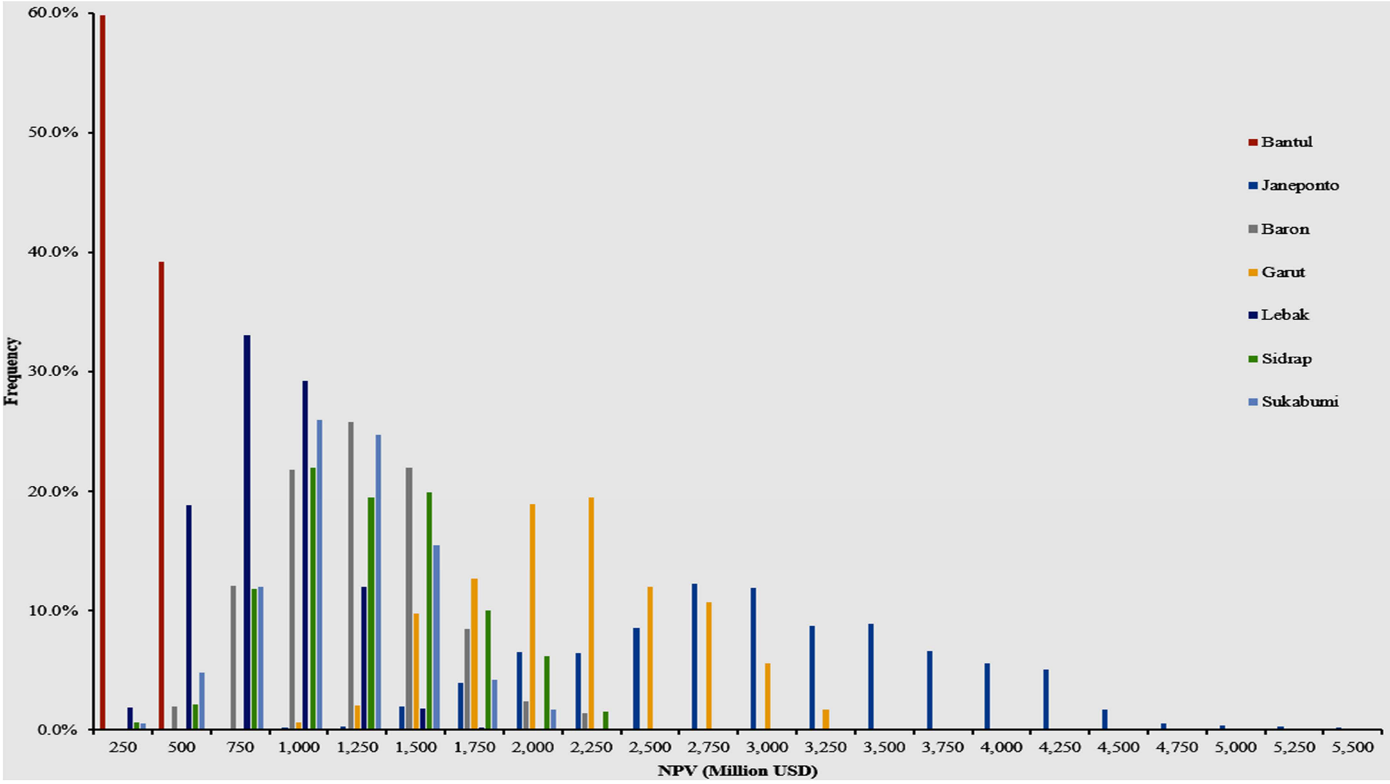

Fig. 6 The histogram NPV for risk analysis

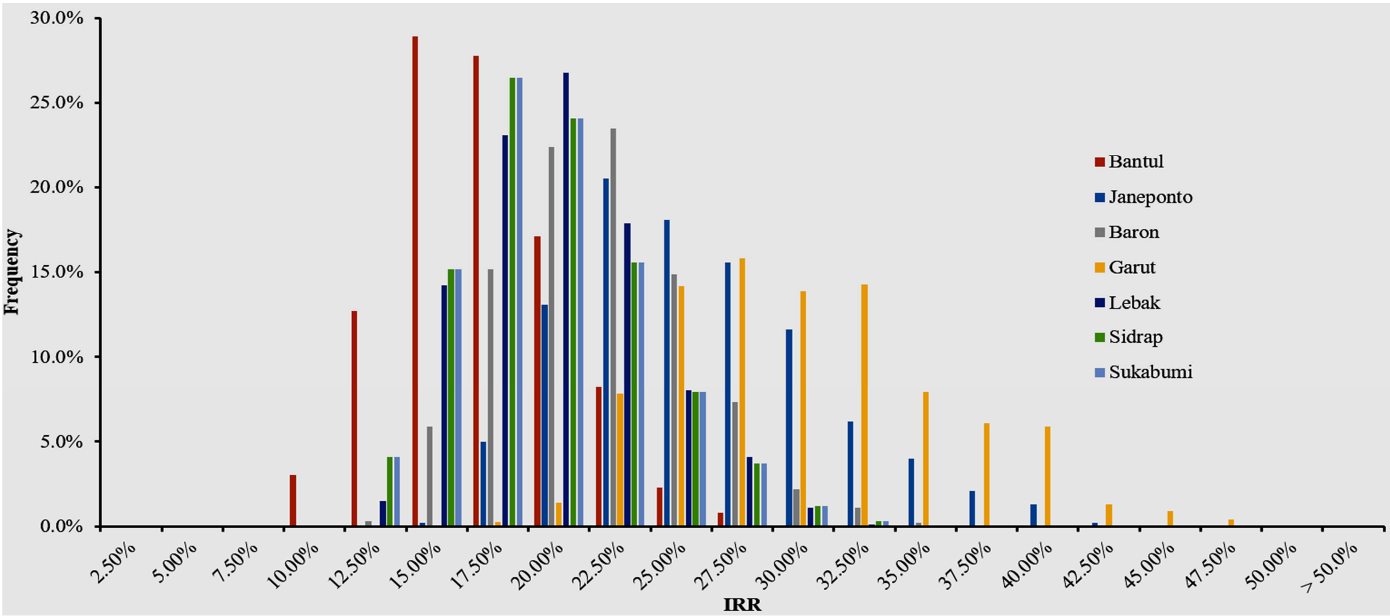

Fig. 7 The histogram IRR for risk analysis

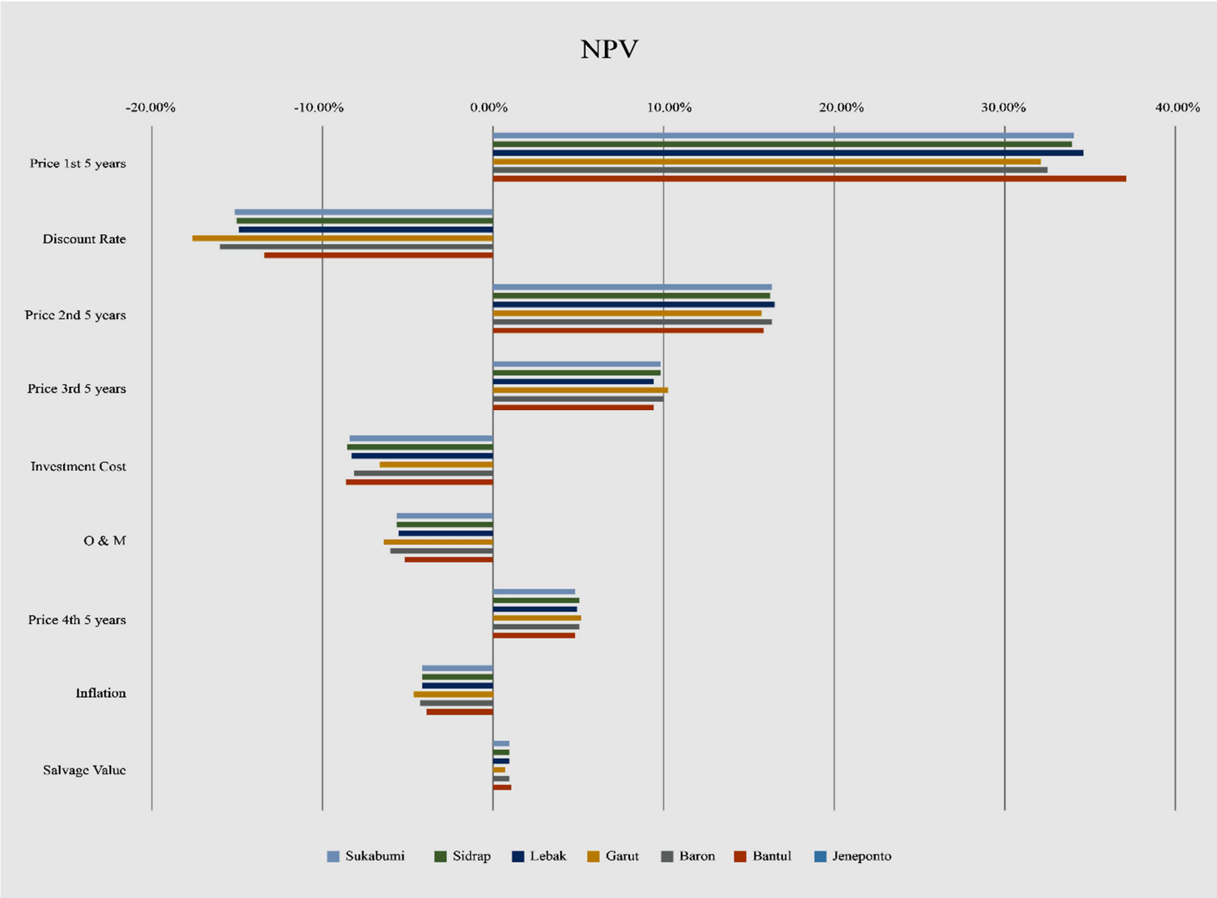

Fig. 8 Sensitivity analysis for averaged NPV

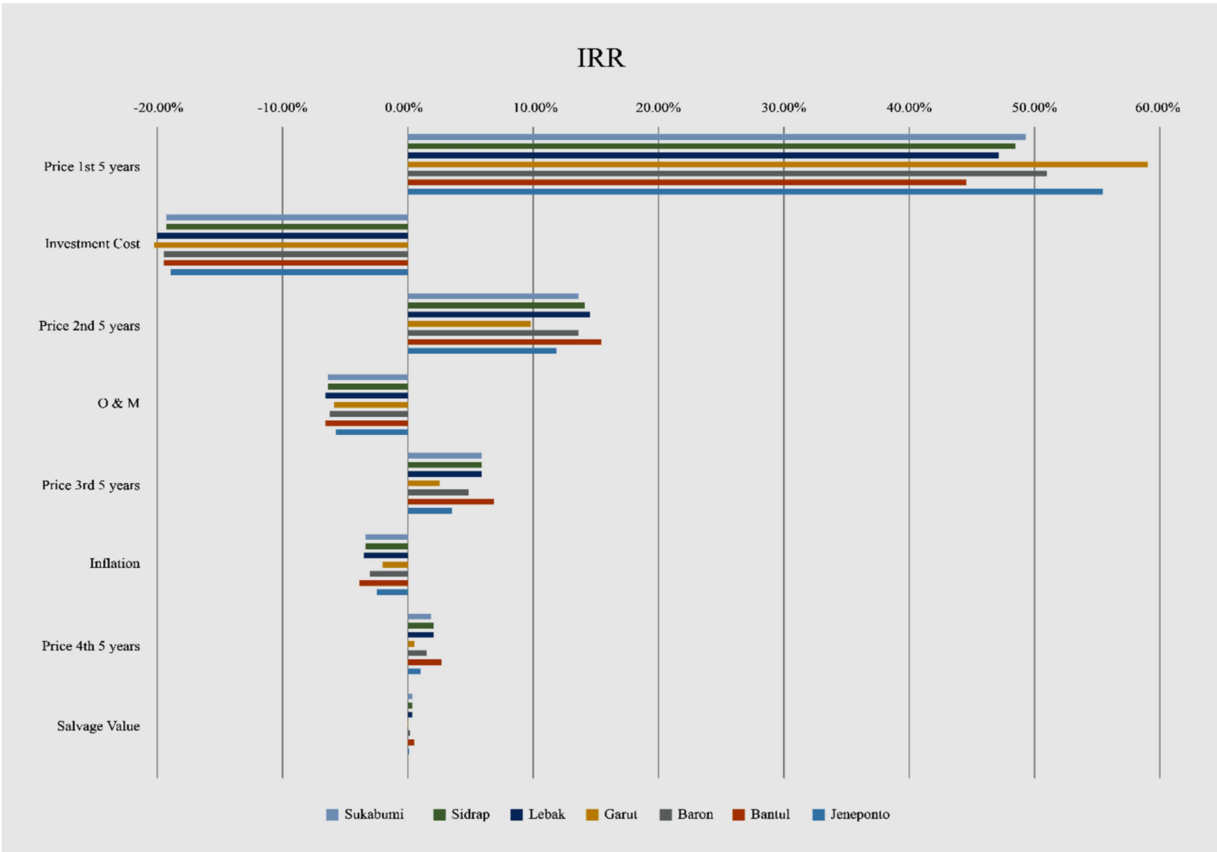

Fig. 9 Sensitivity analysis for averaged IRR

IV. Conclusions

Based on the result and discussion, it can be concluded that in term of annual energy production volumes of the seven selected locations, the highest value is in Jeneponto at 4,339,003.2 MWh with capacity factor 25.22%. The lowest value is in Bantul at 526,476 MWh with a capacity factor of 16.51%. According to the static economic analysis of NPV, all the seven selected locations have positive values in which the highest NPV value belongs to Jeneponto at USD 2.46B, and the lowest NPV belongs to Bantul at USD 0.174B. Calculations of IRR values showed that all seven selected locations have IRR values above-average loan interest rate of 11.89%. The highest IRR value belongs to Garut at 28.4%, and the lowest belongs to Bantul at 15.03%.

Based on economic uncertainty analysis, the highest NPV and attractive IRR values would fit more to the risk-taking investors due to their high deviation standard values. Otherwise, the lowest NPV and IRR values fit more to the risk-taking investors due to their low deviation standard values.

In the sensitivity analysis, the increase of average NPV and IRR values of all seven locations are influenced positively by first 5-year of the selling price, contributing approx. 30% and 50% of NPV and IRR percentage change, respectively. By contrast, the decrease in average NPV values of all seven locations is influenced by the discount rate, contributing approx. 15% of percentage change, whereas the decrease in average IRR is influenced by capital investment cost, contributing approx. 20% of the percentage change. The parameters mentioned above can be further considered by policymakers.

Acknowledgement

The authors are grateful to the Laboratory of Statistics and Optimisation of Industrial Engineering of Universitas Pancasila.

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