Feasibility Study of Floating Photovoltaic (FPV) around East Nusa Tenggara Coastal Area

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Abstract. To provide electricity for the Maluku, Papua, and Nusa Tenggara regions, the government plans to utilize 232 MW of solar energy in 2021-2030. An alternative solar power plant using floating photovoltaic (FPV) can be used especially around East Nusa Tenggara (NTT). This research presents a feasibility study of FPV development around the coast of NTT which aims to identify effective location for FPV structure for generating solar energy using analysis methods benefit-cost ratio (BCR). Eleven variations of energy requirements were evaluated between 20-70 MW with 5 MW interval for 2x2 FPV layout design. The current result shows that the effective location for FPV is at -10.237679 south latitude and 123.483909 east longitude which is around coastal area of Kupang City. The location was chosen due to its optimal 30 MW energy requirement value with 17,266.60 m^2 areas, investment cost of $4,719,000, and economically feasible BCR of 1,116 (BCR > 1).

Keywords: Benefit cost ratio, Feasibility study, Floating offshore solar power plant, Floating photovoltaic, Solar irradiance.

1 Introduction

According to NASA [1] , the area of Indonesia with the maximum solar irradiance is in the coastal area of East Nusa Tenggara (NTT) at 7.03 to 8.01 kW/m^2/day. The potential for Solar Power Plants in this area is 7,272 MW, with an installed capacity of 4 MW. This is feasible given that solar power plants (PLTS) need a larger area if they're going to generate more electricity.

To address these issues, the floating photovoltaic (FPV) solar power plant is being introduced as an alternative to ground-mounted or rooftop Solar Power Plants. The water that exists surrounding the FPV provides a cooling effect on the panels installed, making them more efficient [2], it can be put on a bigger scale, and it can help lower evaporation rates and algae growth [3]. Another benefit seen solely in offshore FPVs is the ability to prevent abrasion from sea water and sea wave height [4]. While the operational risks might have an impact on the aquatic ecosystem [5]. The undersea bathymetry/contour can change due to FPV offshore, needing rechecking as required [6].

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In spite of the huge potential for solar irradiation, the benefits, and drawbacks of FPV, as well as the prevailing geographical circumstances by the ocean, offshore FPV is not adopted in Indonesia. On this premise, a preliminary study is required for offshore in East Nusa Tenggara seas in order to undertake a feasibility evaluation of FPV construction. The benefit-cost ratio (BCR), which is the basis for the analysis, is used to determine if the plan would be profitable or not. It is expected that the findings of this study would be useful to governments and investors interested in expanding offshore in NTT. In this study, there was no review of environmental factors and no planning for the mooring and anchoring system.

2.1 FPV Infrastructure

The floating photovoltaic (FPV) solar power plant is presented as an innovation to address the issue of limited land. Solar panels/PV modules, floating structures/pontoons, mooring and anchoring, wires, inverters, and transmitters comprise FPV [7]. The PV module converts solar irradiance into an electric field [8], [9]. The buoyant floating structure serves as a location to anchor the PV modules and inverters [7]. Mooring and anchoring are used to keep the floating structure's location and height stable [10], [11].

2.2 Energy Estimation

Solar irradiance (GHI) is a measurement of the density of sunlight or the overall power of a radiation source that strikes a specific region [12]. As shown in equation (1), the solar radiation received by the earth consists of direct normal irradiance (DNI), which does not depart from it, and diffuse horizontal irradiance (DHI); which does deviate since it travels through air particles [12],

$$G_{HI} = D_{NI} + D_{HI} \tag{1}$$

The amount of energy (E) produced is determined by the solar irradiance (GHI) along with the PV module's characteristics [13] which include the performance-to-energy-loss ratio (PR), the efficiency of the PV module (ηPV), and the area of the PV module (APV), he amount varying depending on the brand used. E is determined by equation (2). Another factor influencing energy estimation is the duration of solar radiation (LPM) the amount of which relies on how long the sun shines at that place [14]. Whereas the annual energy output is calculated as the sum of all the energy generated over a given year, as shown in equation (3). The energy loss is calculated using [15] as shown in Table 1.

$$E = PR\ \eta_{PV}\ A_{PV}\, G_{HI} \tag{2}$$

$$AEP = T \cdot E \tag{3}$$

Table 1. Energy Loss Parameters in FPV

Parameter	Quantity (%)	Description
Temperature	0,4 – 05	/°C above *Standard Test Condition* (STC), 25°C
Inverter efficiency	2,5 – 5	
Dirt on the PV module's surface	0,5 – 70	Influenced by the

Parameter	Quantity (%)	Description
		installation angle of the PV module
AC *wiring*	1 – 3	
DC *wiring*	1 – 3	
Mismatch	1 – 3	
System availability	1 – 3	
Connector	1 – 3	

2.3 FPV Components Requirement

There are various processes involved in determining the component requirements for FPV, including the items listed below [16]:

2.3.1 Number of PV module (NPV)

Impacted by the location's energy demand (E) and the maximum energy capacity of a single PV module (R), based on the nominal capacity of the PV module (φ_o) and the duration of the day's worth of solar irradiance (t_s) Depending on the kind and brand of PV module used, the nominal capacity may vary. Designed as equation (4) and (5),

$$N_{PV} = \frac{E}{R} \tag{4}$$

$$R = \varphi_o t_s \tag{5}$$

2.3.2 Number of section (Ns)

The number of sections required will be determined by the FPV's configuration/design. If the FPV layout is square, with each sector divided by a walking zone (walking area, WZ) that is one meter wide. Table 2 shows the number of sections for various sections.

Table 2. The number of sections in the layout configuration

Layout	N_s
2 x 2	4
3 x 3	9
4 x 4	16
5 x 5	25

2.3.3 Number of PV module for each section (NA)

NA is a division between number of PV modul (NPV) and number of section Formulated as the following equation,

$$N_A = \frac{N_{PV}}{N_s} \tag{6}$$

The structure adopted is based on earlier research [17], and it comprises of three pieces that are joined by bolts. This structure's requirements are as follows [17]:

Table 3. FPV structure specifications

Material	*Fiber Reinforced Polymer* (FRP)
Length (N_f)	12,6 M
Width (W_i)	11,5 M
Number of Modules on the First Row	11
Number of Modules in the First Column	3
Maximum Number Of Modules in a Single Structure (N_D)	33
Weight (W_u)	1,148 Kg
Unit Cost (P_u)	0,044 USD/Kg

2.3.4 Number of structure (NC)

Number of structure is a division between Number of PV modulefor each section (NA) and maximum number of modules in a single structure (ND) from Table 3. Identified with following equation (7)

$$N_c = \frac{N_A}{N_D} \tag{7}$$

2.3.5 Number of PV modules in the first row and column of section (NE)

Considering that the FPV layout is square and that the number of initial row/column modules is the same, NE is determined using equation (8). With illustration shown in **Figure 1**.

$$N_E = \sqrt{N_C} \tag{8}$$

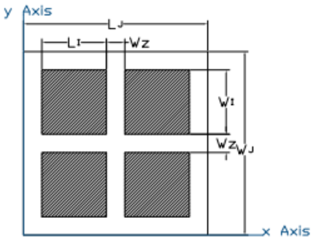

Fig. 1. Configuration sketch of FPV FPV 2x2

2.3.6 Section Length (LI)

Section length (LI) is a division between number of PV modules in the first row and column for each section (NE) and length of the structure (NF). Formulated as equation (9)

$$L_I = \frac{N_E}{N_F} \tag{9}$$

2.3.7 Section Width (WI)

Section width (WI) is a division between number of PV modules in the first row and column (NE) and width of the structure (WN). Formulated as equation (10)

$$W_I = \frac{N_E}{W_N} \tag{10}$$

2.3.8 FPV Length (LJ)

Refers to the total of section length (LI), walking area (WZ) and total walking area (n), with NY being the number of sections in the y direction. This is formulated in the equation (11)

$$L_J = L_I N_Y + nW_Z \tag{11}$$

2.3.9 FPV Width (WJ)

Refers to the total of section width (WI), walking area (WZ) and total walking area (n), with NX being the number of sections in the x direction. This is formulated in the equation (12)

$$W_J = W_I N_X + nW_Z \tag{12}$$

2.3.10 FPV Area (APV)

FPV area is a multiplication of section length (LJ) and section width (WJ). Formulated in the equation (13)

$$A_{PV} = L_J W_J \tag{13}$$

2.3.11 Number of inverter (IN)

The number of inverters required is determined on the capacity of the inverter. The optimal inverter's flow to capacity ratio typically ranges from 1.15 to 1.25 and should not exceed 1.55.

2.4 Economic Analysis

2.4.1 Investment Cost

The Solar Energy Research Institute of Singapore (SERIS), suppliers, contractors, and developers' expertise and studies serve as the basis for the cost assumptions for FPV components and other expenses linked to the construction process [18]. Furthermore, more exact prices will, of course, be determined by the plan's design as well as its location. The anticipated assumptions are provided in Table 4 below [18].

Table 4. FPV investment cost components

Component	**Cost ($/Wp)**	**Description**
PV Module	0,25	*polycrystalline silicon* material
Inverter	0,06	
Pontoon, *Mooring* and *Anchoring* System	0,14 – 0,22	*pontoon* HDPE material
Cable, *Combiner Box, Switchboard,* Transformator	0,14	
Design, Installation, Construction, *Testing, Commisioning*	0,14	
Grid Interconnection	0	A system for electricity is assumed to exist.

2.4.2 Benefit Cost Ratio (BCR)

Displays the relationship between the present value of benefits (present value of benefits, Bt) of the specified investment project and the present value of costs (present value of costs, Ct) which includes investment costs for year t (It), operating expenses and maintenance costs for year t (Mt) and corporate tax year t (Tt) [19]. If the BCR is more than one, the investment project is deemed to be profitable and practicable [20]. The BCR is calculated using the equation (15), [19], where r is the interest rate. The equations that show Bt (income in one year), Tt and Mt are listed in equation (16), (17), dan (18). The amount of investment cost (It) varies from year to year. The proportion of loans provided for investment purposes is denoted by rcap, while the interest rate on loans made is marked by ri hich is valid for the loan period (tre). There are no additional investing charges after the loan settles. The planned investment cost is expressed as an equation (19). Table 5 shows the assumptions on economic parameters.

$$BCR = \frac{\sum_{t=0}^{T} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{I_t + M_t + T_t}{(1+r)^t}} \tag{14}$$

$$B_{t(t)} = \begin{cases} 0, t \le t_{con} \\ pAEP\left(1 - r_{mPV}(t - t_{con})\right), t_{con} < t \le t_{op} \end{cases} \tag{15}$$

$$Tt = B_t r_{tax} \tag{16}$$

$$M_{t(t)} = \begin{cases} 0, t \le t_{con} \\ I_i r_{mPV}\left(1 + r_{inf}\right)^t, t_{con} < t \le t_{op} \end{cases} \tag{17}$$

$$I_t(t) = \begin{cases} \frac{I_i}{t_{con}}\left(1 - r_{cap}\right), t \le t_{con} \\ \frac{I_{ir_{cap}}}{t_{re}}\left(r_{i(t_{re}+t_{con}-t-1)}\right), t_{con} < t \le t_{re} \\ 0, t_{re} < t \le t_{op} \end{cases} \tag{18}$$

Table 5. Economic Parameters

Parameter	**Value**	**Description**
Discount rate, r_d	4%	Bank Indonesia

Parameter	Value	Description
Loan interest rate, r_i	5%	Bank Indonesia
Inflation rate, r_{inf}	3%	Bank Indonesia
Corporate tax, r_{tax}	22%	Directorate General of Taxation
Loan portion, r_{cap}	80%	From the initial investment cost
Service period, t_{op}	20 years	Offshore NRE average lifespan
Construction period, t_{con}	2 years	
Loan repayment period, t_{re}	10 years	
Efficiency drop rate, r_{deg}	1,6%	Depends on the PV module used
Operation and Maintenance Level (OM), r_{OM}	2%	From the initial investment cost
Electricity cost, p	1500 Rupiah/kWh 0,15 \$/kWh	Average from PLN

3 Data and Research Method

3.1 Data

This study's input data included ocean depth data from *Badan Informasi Geospasial* (BIG) *Indonesia*, solar irradiance data from The NASA Prediction of Worldwide Energy Resources (POWER), temperature data from The NASA Prediction of Worldwide Energy Resources (POWER), PV module technical data from LONGi (PV modular producent), structure technical data [17], and inverter technical data from Energetech Solar, ABB (inverter producent).

3.2 Research Method

The study was carried out by examining the data in the research area, which had coordinates of South Latitude -7.75 to -11.25 and East Longitude 118.25 to 124.75. The area is then divided into numerous cells, with diameters of 0.1 or equivalent to 11.1 Km in the vertical direction and 65 cells in the horizontal direction. Later in the cell, an FPV system will be designed based on energy needs through the use of assumptions for economic parameters and energy parameters in selecting BCR.

4 Result and Discussion

Bathymetry maps were placed on top of solar irradiance data in the research area. An ideal area for FPV development is 50 meters of water depth. This figure is based on earlier study suggestions [17] that are based on labor economics. The GHI distribution in the study area varies from 7,03 to 8,01 kWph/m^2/day.

Energy demand is estimated to vary between 20 MW and 70 MW with 5 MW intervals according to energy needs and energy potential. According to BPS statistics, the lowest value of the LPM from 2019 to 2021 is 8.55 hours, and the LPM is set at 6 hours with careful consideration. Temperature, which is utilized at an average temperature of 36,8°C, is another factor that influences energy consumption [21].

Aside from energy needs, technical data from PV modules, structural units, and inverters are included in determining the demand for components in the FPV system. The PV module used is LONGi brand with Hi-MO 5m LR5-72HPH 550M types, the structural unit used is based on previous studies [17], and the inverter used is Energetech Solar brand ETS-400kW-380V-SDP, ABB brand type PVS800-57-0630KW-B, PVS800-57-0875KW-B, and PVS800-57-1000KW-C, and The inverter type and the number of inverter units employed in the FPV were changed to meet the energy requirements along with the FPV configuration.

The number and kind of inverters required will be determined by the energy requirements and the FPV arrangement employed. The selection is based on the array-to-inverter ratio, which should be 1.15 to 1.25 in ideal conditions to keep planning costs low [22]. Table 6 shows that increasing the amount of E increased the inverter capacity need in addition to the number of inverters (In) used.

Table 6. Combination of Energy Demand for FPV Configuration and Inverter Type

E (MW)	**Inverter Type**	***Output* Inverter *(kW)***	***Array-to-Inverter* Ratio**	**Number of Inverter (unit)**
20	HPSP0800-CC-350	840	1,22	1
25	ETS-400kW-380V-SDP	500	1,17	2
30	PVS800-57-1000KW-C	1200	1,29	1
35	PVS800-57-0630KW-B	700	1,24	2
40	HPSP0800-CC-350	840	1,17	2
45	HPSP0800-CC-350	840	1,3	2
50	PVS800-57-0865KW-B	1050	1,15	2
55	PVS800-57-0865KW-B	1200	1,28	2
60	PVS800-57-1000KW-C	1200	1,22	2
65	PVS800-57-0500KW-B	600	1,33	4
70	PVS800-57-0630KW-B	700	1,25	4

The NE value is the same for all coordinates in the review area and all E values to be identified. This is based on the need for a PV module (NPV) with the same value at each site and a GHI value that does not change considerably. The NE value obtained is decimal, however the structural unit employed only has three structural sub-units, hence the NE value must be corrected to an integer or decimal value of 0.33 or 0.67.

The area required of the PV module is reduced as a consequence of the NE to NER correction procedure. This is possible since rounding down reduces the number of PV modules, which adds to the area of the PV modules and the quantity of electrical energy generated. This procedure makes FPV more cost-effective, yet it also adds to a loss in energy output. Table 7 shows the NPV and NE values before and after adjustment for each E value. As it can be observed, increasing the E value raises the demand for the FPV's technical component.

Table 7. Tabulation of PV module component requirements for each value of E

E	NPV	NE	NE_R	NPV_R
20MW	2.569,76	4,41	4,33	2.464,00
25MW	3.212,20	4,93	4,67	2.816,00
30MW	3.854,64	5,40	5,33	3.740,00
35MW	4.497,08	5,84	5,67	4.180,00
40MW	5.139,52	6,24	6,00	4.752,00
45MW	5.781,96	6,62	6,33	5.280,00
50MW	6.424,40	6,98	6,67	5.808,00
55MW	7.066,83	7,32	7,00	6.468,00
60MW	7.709,27	7,64	7,33	7.084,00
65MW	8.351,71	7,95	7,67	7.700,00
70MW	8.994,15	8,25	8,00	8.448,00

After determining the requirements for FPV components, the costs are calculated. The process of determining expenses necessary in the purchase of FPV relates to the construction, planning, and maintenance investment costs. The corrected PV system size (PR) serves as the foundation for the cost analysis procedure, which is carried out using Table 7.

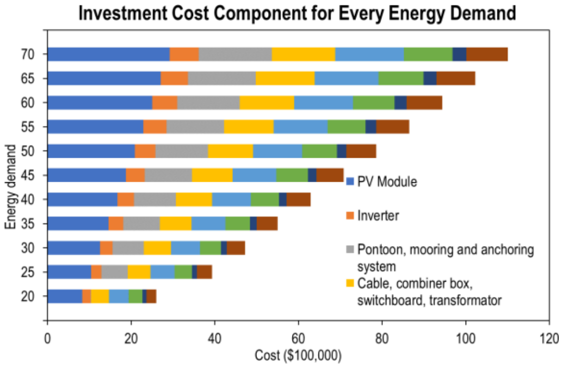

Fig. 2. Investment Cost Component for each Energy Demand

From **Figure 2**, it can be observed that increasing the value of E leads in a rise in the total costs that must be expended. Different quantities of E result in varying amounts of investment expenses per component. This demonstrates that the costs incurred are solely dependent on and directly proportionate to variations in energy requirements.

BCR analysis is conducted for all coordinate points in the review area and each value of energy demand (E) using the equations in sub-sections 4.2. Total earnings, total investment expenses, total FPV maintenance costs, and total corporate taxes imposed on FPV are reviewed to determine the BCR value. In each review, a uniform value is established for all points in all versions of E. This is due to the major reference in the analytical process is energy requirements, therefore the GHI value will impact how large the PV module area is required while having no effect on the value.

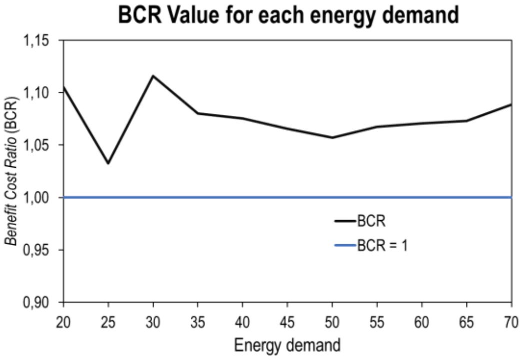

Fig. 3. BCR value for each energy demand

Figure 3. shows that the value of BCR fluctuates in response to an increase in the value of energy demand (E). The fluctuation is caused by the correction operation, which involves rounding down the value of NE. Since NE for certain E has a reasonably minor difference to the control limit (0.00; 0.33 or 0.67), the demand for structural units in the section is quite considerable when repairs are performed. NER is created as a new number, with consequences for the amount of energy and profit. NER will create a high AEP and profit at a high value. A reduction in the value of AEP results in a lower profit for E with a certain NE. Meanwhile, investment costs will continue to rise as long as E increases. These factors cause a decrease in BCR, as shown in Figure 4.6 (e) for E values of 25 MW, 35 MW, 40 MW, 45 MW, and 50 MW, indicating that the NE has been corrected. in that range caused a lower AEP The rise in BCR as in E is 30 MW, 55 MW, 60 MW, 65 MW, and 70 MW, indicating that the corrected NE creates a rather significant AEP, as shown by an increase in BCR.

In general, all plans with existing energy demands are feasible to execute since they generate a BCR larger than one, with ideal energy demands identified by the maximum BCR at E worth 30 MW, with a BCR of 1.116.

Based on the homogeneity of the BCR value throughout the research sites, this value has little significance in determining the best location for FPV construction in NTT coastal area. The position is now determined only by the GHI value and the potential of the area, with the depth of the water serving as a control. GHI has few consequences in the analytical process since energy demand is an independent variable that influences other factors, hence GHI cannot be used to pick the most suitable site.

In FPV planning, the optimal site is centered on the coordinates SL -10.237679 and EL 123.483909. This is based on the comparatively high GHI value of 7.58 kWph/m^2/day, the closest distance from the grid of 640 m, and the considerable potential for regional development. The existence of a plan for the development of the salt, sugar, and mining industries [23], [24] the relatively more diverse mining potential [25], the development of industrial areas, and the potential for energy export from Australia to Singapore to be missed all indicate that the electrical energy required at that location is not available [26]. Furthermore, if the energy export plan is achieved and the NTT government's criteria for a 50% share of energy exports are reached, this can be a good step for the NTT government in using the potential of electrical energy from solar irradiance [26]. Table 8 shows the FPV planning data for these sites.

Table 8. FPV planning data and economic data at optimal locations

Parameter	**Value**
South Latitude, SL	-10,237679
East Longitude, EL	123,483909
Number of *Section*, NS	4 *section*
Length *Section*, LI	67,2 m/*section*
Width *Section*, WI	61,33 m/*section*
Length FPV, LJ	137,4 m/*section*
Width FPV, WJ	125,67 m
Area of FPV, APV	17.266,6 m^2
Number of PV, NPV	3.740 modul
Inverter Types	PVS800-57-1000KW-C
Number of inverter	1 unit
Profit, Et	$5.970.188,13
Initial Investment Cost, Ii	$4.719.000
Total Investment Cost, It	$1.623.336,00
Total Maintenance Cost, Mt	$2.414.767,58
Total tax, Tt	$1.313.441,39
Benefit cost ratio, BCR	1,116
Array-to-inverter Ratio, RoI	1,29

5 Conclusion

FPV planning is at coordinates -10.237679 South Latitude and 123.483909 East Longitude, with an energy consumption of 30 MW and an FPV area of 17,266.60 m^2 based on GHI, water depth, area potential, and distance of points to the grid. The investment cost $4,719,000, the BCR value was 1,116, and the project considered feasible.

This study uses energy demand as an independent variable, resulting in various levels of homogeneity of values such as AEP, total costs, profits, and investment costs. Based on this, more studies may examine the consequences of the demand for PV module area as an independent variable and conduct BCR analysis while taking into account the energy requirements of each location to generate value variations.

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