Tampere University of Applied Sciences

Environmental Impacts Assessment and Economic Efficiency of Phong Phu 2 Solar Power Plant in Vietnam

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ABSTRACT

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Renewable energy is a new trend in energy industry, especially in a developing country as Vietnam. In order to meet the country's high energy demand, the government of Vietnam has approved the project of Phong Phu 2 solar power plant in Binh Thuan Province, Vietnam.

In this thesis, two sustainability aspects are determined: environmental impacts and economic efficiency. In order to assess the environmental impacts, a group of specialists has come to the project location and monitored environmental condition as well as construction activities of the power plant. The capital asset pricing model was applied to calculated economic factors (net present value and benefit – cost ratio) and analyzed to see if the project is profitable or not.

In conclusion, Phong Phu 2 solar power plant does not show any disadvantages to the environment. Possibility of soil erosion and water pollution can be prevented by regular monitoring and maintenance. The project is sustainable through three aspects: environment, society and economy.

Key words: renewable energy, solar power, energy in Vietnam

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GLOSSARY

B/C	Benefit – cost ratio
dB	Decibel
CAPM	Capital asset pricing model
CERs	Certified Emissions Reductions
DC	Direct current
EPA	Environmental Protection Agency
ha	Hectare
$kWh/m^2/yr$	Kilowatt hours per square metre per year
kV	Kilovolt
kWp	Kilowattpeak
IC	Invested capital
MVA	Mega-volt-ampere
MW	Megawatt
MWh	Megawatt hours
µg	Microgram
NPV	Net present value
O_3	Ozone
PV	Photovoltaic
PM	Particulate matter
ppb	Parts per billion
ppm	Parts per million
STC	Standard test conditions
TWh	Terawatt hours
USD	United States Dollar
VND	Vietnamese Dong
W	Watt
WACC	Weighted average cost of capital
W/m^2K	Watts per square metre per degree Kelvin

1 INTRODUCTION

Nowadays, since traditional energy sources such as coal and fuel are running out, human is changing direction to use renewable energy instead, especially solar energy. Every year, the sun provides a huge amount of energy to our planet. Theoretically, solar radiation that hits the earth in an hour can meet the global energy demand in a year (Marsh 2019). Solar energy would generate zero-pollution, including greenhouse emission and air pollution (EIA 2018).

Vietnam is a South – East Asian country with a rapid economy growth as well as fast rate of industrialization, therefore this country's energy demand is increasing from 86 TWh (Terawatt hours) in 2010 to approximately 632 TWh in 2030. According to Vietnam Briefing (2019), total installed capacity of Vietnam in 2018 was nearly 48 MW, which means the country needs 6000 – 7000 MW installed capacity more per year to meet the demand.

Currently, the main energy sources of Vietnam are coal-fired and hydropower, which accounted for 71.9% in total power source. They are followed in order by gas fired power (17.8%), diesel with renewables (5.8%) and oil fired power (3.3%). Therefore, the government planned to develop renewable energy in order to increase the amount of power output and decrease harmful environmental impacts generated by other non-renewable sources, such as coal and fuel (Vietnam Briefing 2019). Figure 1 below shows the potential capacity with actual installed capacity of renewable sources in Vietnam in 2018.

The actual installed amount of solar energy is smaller comparing to other sources, although Vietnam has a potential of developing solar energy as most parts of it belong to tropical climatic zone. Especially, the south part of Vietnam has an abundance of solar radiation, which varies from 1607 to 2045 kWh/m^2 on horizontal surface and from 1241 to 1534 kWh/m^2 direct normal irradiation per year (The World Bank n.d.). Hence, Phong Phu 2 solar power plant was built to contribute to high energy demand of the country and decrease environmental pollution.

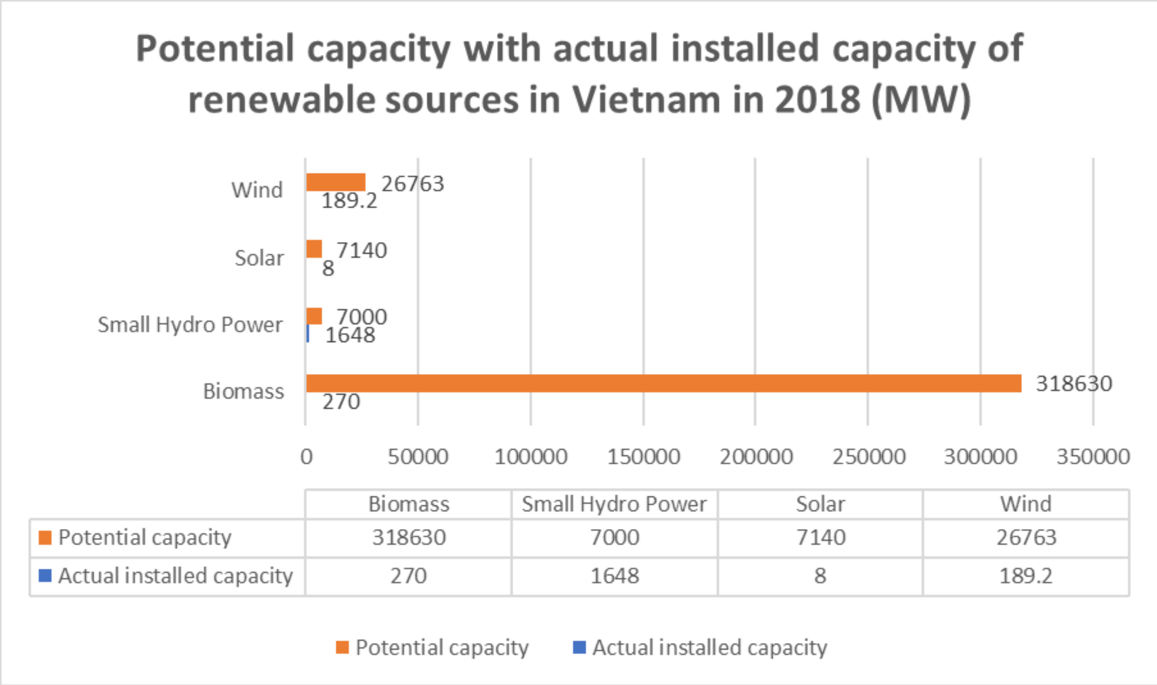


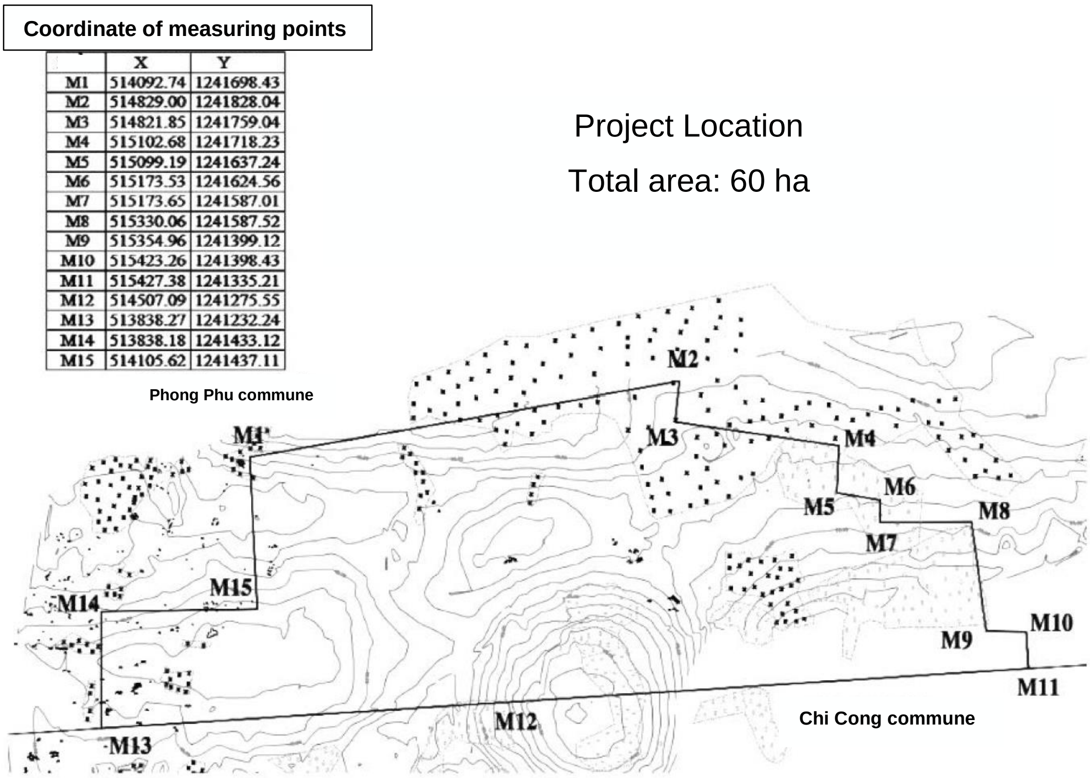
FIGURE 1. Potential capacity with actual installed capacity of renewable sources in Vietnam in 2018 (Vietnam Investment Review 2018)

1.1 Project overview: Phong Phu 2 solar power plant

Phong Phu 2 solar power plant, which belongs to SOLARCOM Company, has an installed capacity of 42 MWp. The plant is located in Phong Phu Commune, Tuy Phong District, Binh Thuan Province, Vietnam. This project costs approximately 51.664 million USD (about 1164.666 billion VND) and will start to operate in June 2019 (IEE 2017).

Binh Thuan Province located between three big economical areas of Vietnam, with potential of natural resources as dynamics of oil and gas industry, titan mining and energy industry. The government has approved a project of making Binh Thuan become an energy centre of the country in 2015 (IEE 2017).

The project located in a 60 ha area land in the south of Phong Phu commune. Flat terrain with gentle slope is suitable for building a solar plant. It can be seen through the common height of measuring points in figure 2. There were only a small amount of industrial crops (Acacia and Cashew), as well as grass and shrubs (see figure 3). These industrial crops were low efficient, therefore removal of those does not cause much damage to local economy.



Coordinate of measuring points

	X	Y
M1	514092.74	1241698.43
M2	514829.00	1241828.04
M3	514821.85	1241759.04
M4	515102.68	1241718.23
M5	515099.19	1241637.24
M6	515173.53	1241624.56
M7	515173.65	1241587.01
M8	515330.06	1241587.52
M9	515354.96	1241399.12
M10	515423.26	1241398.43
M11	515427.38	1241335.21
M12	514507.09	1241275.55
M13	513838.27	1241232.24
M14	513838.18	1241433.12
M15	514105.62	1241437.11

FIGURE 2. Coordinate of measuring points in project location (IEE 2017, reprinted by permission)

FIGURE 3. Landscape of project area (IEE 2017, reprinted by permission)

Based on the data taken from NASA Prediction of Worldwide Energy Resource, the difference between the highest temperature (27.5 ^{0}C) and the lowest temperature (23.5 ^{0}C) in a year at the project location is quite small (figure 4). The solar irradiation is quite high, which varies from 8.5 to over 10 kWh/m^{2} in recent years (figure 5). The climate condition at project location is suitable for the operation of solar energy.

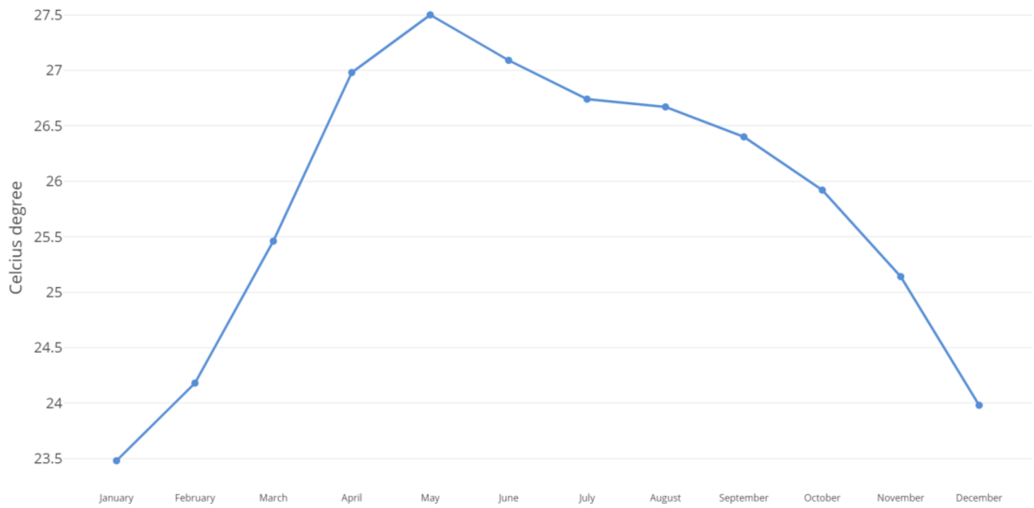


FIGURE 4. Average temperature at project location from 2007 to 2017 (These data were obtained from the NASA Langley Research Center (LaRC) POWER Project funded through the NASA Earth Science/Applied Science Program)

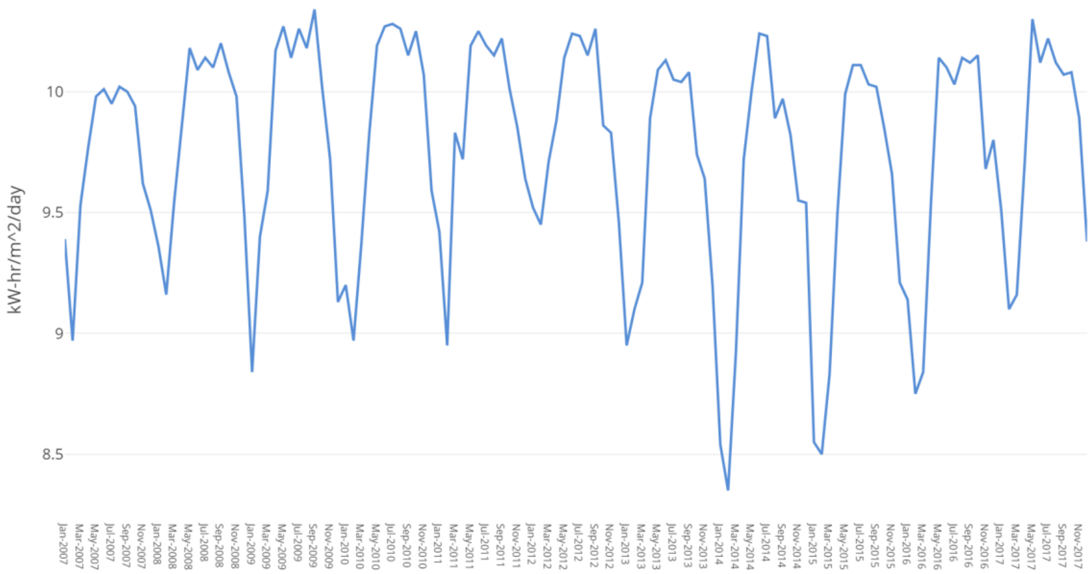


FIGURE 5. Thermal infrared (longwave) radiative flux at project location from 2007 to 2017 (These data were obtained from the NASA Langley Research Center (LaRC) POWER Project funded through the NASA Earth Science/Applied Science Program)

By using Meteonorm software, the sun's orbit at the project location is shown in figure 6 below.

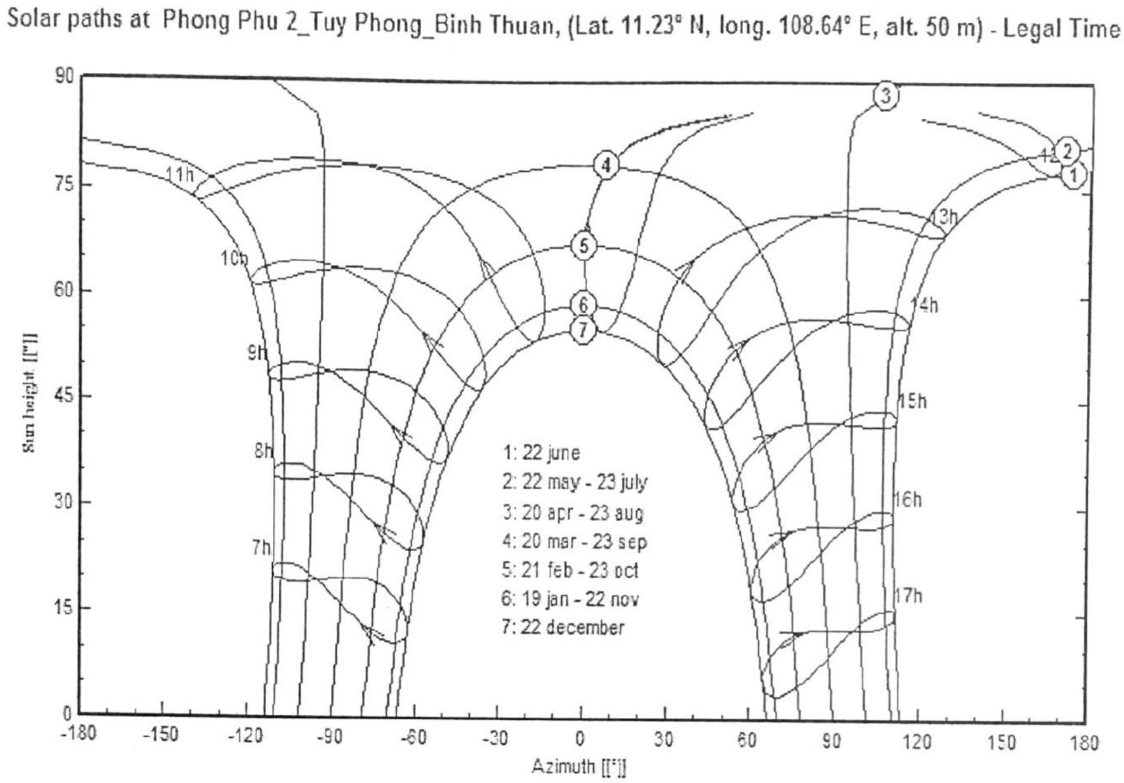


FIGURE 6. Solar paths at Phong Phu 2 solar project location (IEE 2017, reprinted by permission)

Absorption surface of solar panels faces to the South, with an angle of 12^0 in order to get the highest solar radiation. There were no objects in project area that can block solar panels from sunlight.

1.2 PV technologies

There are many types of photovoltaic modules on the market, however, this work focused on three widely-used modules: monocrystalline silicon (c-Si), polycrystalline silicon (poly-Si) and thin-film.

Monocrystalline silicon solar cell is one of the first solar modules was made in renewable energy industry. It is made from pure silicon crystal, which does not absorb the sunlight so well, therefore c-Si modules need to be thick and hard in order to capture the light. However, monocrystalline silicon modules have an efficiency range from 15% to 25%, which is higher than many other solar module (Dirjish 2012).

Polycrystalline silicon cells were made by melting raw silicon and formed it into square-shape (Energy Informative n.d.). This type of modules has an efficiency varies from 13% to 16%. The reason is each poly-Si cell has many crystals inside, which prevents electrons from moving fast. However, a study has shown 100 micron-thicked poly-Si can absorb sunlight as well as a monocrystalline silicon that is three times thicker. Poly-Si is quite durable as its lifespan is more than 25 years (Neville 1995; PennState n.d.).

Thin-film solar cells can be made from different materials: amorphous silicon, cadmium telluride, copper indium gallium selenide or organic photovoltaic cells. Thin-film cells include micron-thickness crystalline layers, which makes them lighter than other solar cells. However, the efficiency of thin-film solar cells is quite low, which varies from 7% to 13%. That means, in order to get a certain amount of power, thin-film modules require more installed space as well as more equipment (Tonkin 2018; Energy Informative n.d.).

Solar modules which is used in Phong Phu 2 solar power plant will be chosen in these three types of solar cell. Table 1 below shows the advantages and disadvantages of monocrystalline silicon, polycrystalline silicon and thin-film.

TABLE 1. Solar modules comparison

Solar panel types	Advantages	Disadvantages
Monocrystalline silicon (c-Si)	• Highest efficiency rates, which varies from 15% to 25% • Requires less area than others • Longest lifespan	• Most expensive type • Easily broken: if a part of a c-Si module is covered by dust or shadow, it can be broken • Most of it cannot be recycled • Cannot perform well in cold temperature
Polycrystalline silicon (poly-Si)	• Simple manufacturing process • The amount of waste is less than c-Si (many parts can be recycled)	• Performs worse in high temperature than c-Si • Low efficiency: 13% - 16% • Requires large space to install
Thin-film	• Light and easy to install • More flexible • Does not strongly affected by high temperature and shadow or dust	• Lowest efficiency • Short lifespan • Requires so much space to install, due to its low efficiency • High cost of PV equipment

1.3 Environmental impact assessment (EIA)

Environmental impact assessment (EIA) is a process used to predict influences of a project on the environment during planning and decision making process, as well as identify suitable methods to reduce harmful impacts on the environment (Raj 2018). Based on the EIA results, competent authorities can give construction permit for the project. In Vietnam, environmental impact assessment requirement has been set in the Law of Environmental Protection in 2005.

In an EIA process, there are four basic steps: screening, scoping, reviewing and completion. Based on different projects, more activities can be added to EIA process, however, they are all used to achieve the same goals: determining environmental impacts and alternatives for a project (Komínková 2008). Figure 7 below illustrates the structure of an EIA process:

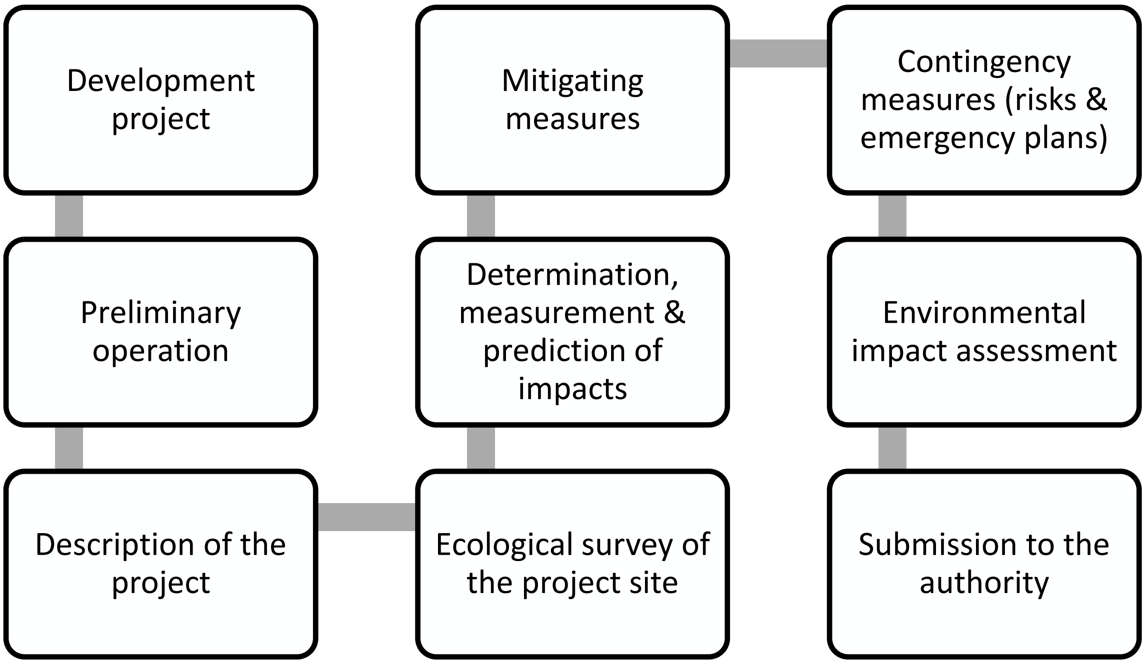


FIGURE 7. General structure of an EIA process

In this thesis, a short environmental impact assessment of Phong Phu 2 solar power plant was given, including environmental consequences and project alternatives, which will be considered by the authorities of Vietnam in decision making stage.

1.4 Economic efficiency

Economic efficiency presents a state of economic aspect of a project or a company, in which the input value is minimised, while the profit of the project is maximised. Economic efficiency can be analysed by different factors, such as employment rates, financial internal rate of return (FIRR) or interest rates (Investopia 2018).

In this thesis, net present value (NPV) and benefit – cost ratio (B/C) are used to study the economic efficiency of Phong Phu 2 solar power plant. Net present value can be get by subtracting the cash outflow from the cash inflow in a period of time. If NPV is positive, the project is profitable and if NPV is lower than 0, the project may get a net loss (Investopia 2019a). In order to see the relationship between the benefits and cost of a project, a benefit – cost ratio is calculated. If B/C of a project is greater than 1, which means the benefit is bigger than the cost, the project is expected to get positive net present value. On the other hand, when B/C is smaller than 1, the relative cost is more than the benefit, which means the project will not bring back any profit (Investopia 2019b).

Besides, a weighted average cost of capital (WACC) is also used to estimate the economic efficiency of Phong Phu 2 solar power plant, particularly the cost of capital. This factor presents the interest a company earns for each dollar it spends. Therefore, WACC can be seen as an indicator to see if the project is worth invested or not (Investopia 2019c). WACC is calculated by using capital asset pricing model (CAPM). CAPM is the most-widely used model in finance to link the systematic risk to the expected return of investment (Investopia 2019d).

2 AIMS

In order to make Phong Phu 2 solar power plant project become sustainable, three following aspects need to be considered: environment, society and economy. This thesis focuses on environmental impacts and economic efficiency of the power plant.

Through this work, the Government of Vietnam can see the potential of this solar project in minimizing environmental pollution and enhancing the country's economy.

3 MATERIALS AND METHODS

3.1 Environmental Impacts Assessment

The environmental impacts of Phong Phu 2 solar power plant are assessed during construction and operation phases. Available mitigation measures are also suggested in this part.

Monitoring has been made by a group of environmental specialists, which lasted for 5 days. Air, water, and soil quality, as well as other environmental aspects were spectated during this field trip. Furthermore, construction activities of the power plant was monitored and compared to national standards.

Meteonorm software was used to design and calculate the total amount of solar radiation on horizontal surface. Data was collected from NASA Prediction of Worldwide Energy Resource, Photovoltaic Geographical Information System (PVGIS) and local centres for hydro – meteorological forecasting.

3.2 Economic Efficiency

3.2.1 Materials' advantages and energy output of Phong Phu 2 solar power plant assessment

In order to assess the economic efficiency of this power plant, the advantages of chosen materials were determined by using Photovoltaic Geographical Information System. Through this, different factors that might affect the power output of Phong Phu 2 solar power plant were evaluated.

The average energy in output of PV is calculated by using the following formula:

$$E = A \cdot r \cdot H \cdot PR \tag{1}$$

In which:

E - energy in output (kWh)

A - total absorption area of PV modules (m^2)

r - PV module's efficiency (%)
H - total solar radiation on horizontal surface (kWh/m^2)
PR - performance ratio, coefficient for losses = 0,84229
(Photovoltaic software n.d.)

The number of PV modules needed was calculated by dividing the expected total energy system output by the PV module's power:

$$Number\ of\ PV\ modules = \frac{Total\ energy\ output\ (W)}{PV\ module's\ power\ (W)} \qquad (2)$$

3.2.2 Economic analysis

In order to analyse the economic efficiency of this solar power plant project, two following factors were assessed: net present value (NPV) and benefit – cost ratio (B/C). Besides, in order to estimate the cost of capital in this project, a weighted average cost of capital (WACC) was calculated by using formula (3):

$$WACC = g \cdot r_d + (1 - g) \cdot r_e \qquad (3)$$

In which:
r_d - the cost of debt
r_e - the cost of equity
g - the proportion of finance that equals to debt/(debt + equity)

By applying CAPM model, the cost of equity (r_e) is calculated by using formula (4):

$$r_e = r_f + \beta \cdot (r_m - r_f) \qquad (4)$$

In which:
r_f - the risk-free rate
β - the measure of relative risk of the company
r_m - the expected return on the market
(Frontier Economics 2005)

Table 2 below shows related information of Phong Phu 2 solar power plant which was used to analyse the economic efficiency of the project.

TABLE 2. Input data for economic efficiency analysing

Input data	**Value**
Construction time	1 year
Lifespan	25 years
IC	1164,666 billion VND (51,994 million USD)
Proportion of debt/(debt + equity)	70%
Debt interest	Foreign loan: 4%/year Domestic loan: 9%/year
Installed capacity	42 MWp
Energy output	1^{st} year: 69,233 MWh, lost coefficient: 0,5% per year
Operation and maintenance fee	2% of equipment fee
Certified Emissions Reductions (CERs)	0,5 USD/tCO_2
Enterprise income tax	First 4-year: 0% Next 9-year: 5% Next 2-year: 10% Others: 20%

NPV of this project is expected to be positive; if not, it means the project does not bring any profit and should be stopped. NPV can be calculated by formula (5) below:

$$NPV = \frac{Future\ value - outflow}{(1 + WACC)^t} \quad (5)$$

In which,

Future value - net cash in a particular period

t - number of time period

(Investopia 2019e)

To find out the suitable price of electricity output, a factor called break-even point is determined. At this point, total cost equals to total revenue. Or it can be seen through the following formula (6):

$$Break - even\ quantity = \frac{Fixed\ costs}{Sales\ price\ per\ unit - Variable\ cost\ per\ unit} \quad (6)$$

(CFI n.d.)

4 RESULTS AND DISCUSSION

4.1 Environmental Impacts

According to EIA (2018), there would be no air pollution, greenhouse gas or water pollution produced by solar energy power plant. Potential hazards are leaking hazardous fluids and materials (which are used in converting sunlight to electricity) to the environment and ray of sunlight created by the solar cells can kill birds or insects. Construction area may affect nearby plants and animals habitat.

4.1.1 Air pollution

During the construction phase, dust can be generated from ground filling, excavation activity, and movement of vehicles through pathways. Emissions such as carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxides (NOx), carbon monoxide (CO) and particulate matter (PM) can come from construction equipment and vehicles. In operation phase, the solar power plant will not affect the air quality as mentioned above. Table 3 below shows the measured pollutants in the air at construction site:

TABLE 3. Concentration of air pollutants at the construction site

Pollutants	**Concentrations (µg/m³)**
$PM_{2.5}$	28
PM_{10}	39
O_3	47
NO_2	5
CO	196
SO_2	2

Concentration of $PM_{2.5}$ is lower than the limitation (which is 65 µg/m^3), as well as the PM_{10} concentration (of which standard is 150 µg/m^3). The concentration of O_3, NO_2, CO and SO_2 also does not exceed the limitations set by the United States Environmental Protection Agency.

In order to minimize the dust, vehicles should run under a speed limitation and be used as less as possible. Trucks which are used to transport soft yielding materials (e.g. sand and soil) should be covered in order to prevent dust blowing. Sprinkling can be applied to reduce the dust.

4.1.2 Noise pollution

During the construction phase, there would be noise generated from ground filling, excavation activity, concrete foundation installation and transportation. The construction site is far away from the residential area, therefore only workers are affected by the noise.

The major noise sources on construction site include background noise, material handling, earth moving and other construction equipment such as compressed air blower, power saw and electric drill. According to LHSFNA (2014), earth moving equipment such as front end loader, back hoe or truck has an operation sound level range from 79 dB to 103dB, which contributes the greatest number of noise hazards on construction worksites. Besides, pile driver, pneumatic breaker and hydraulic breaker create bigger noise, which varies between 82 dB and 111 dB. In operation phase, noise which comes from inverters, transformers, substation and transmission lines is under the standards, which is 90 dB at workers ear and 65 dB at property line (LHSFNA 2014). Furthermore, noise generated by transformers can be heard only in a range between 1 and 2 meters. Besides, the power plant does not cause any noise at night.

All equipment and machines should be maintained frequently and minimized their uses in order to prevent noise pollution. Workers must be equipped with hearing protection devices. According to eLCOSH (N.d.), highest noise-reductions equipment in the world is earmuffs, and the second one is foam earplugs. Workers should not work more than 8 hours in the construction site with the noise of construction equipment.

4.1.3 Soil erosion and contamination

Overall, construction activities do not cause much damage to the soil. However, during the excavation, ground filling, and other earth moving activities, soil erosion can occur. Furthermore, wastes from construction materials or oil spilling are considered as dangerous factors as may cause soil pollution and degradation. In operation phase, there will be no oil spilling or other hazardous wastes that might affect the soil, so that the soil will not be degraded or polluted.

In order to control erosion at Phong Phu 2 solar power plant, the company decided to build French drains around the construction site. It is an underground piping system which included a pierced pipe put under a gravel bed with a geotextile fabric. Excess ground water goes through the gravel layer to the pipe and travels through the discharge point.

The company has to have an action plan and necessary equipment if there are any spill accidents happen. For example, if there are any oil spills on soil, managers and workers should have suitable treatment, such as bio piles – mixing contaminated soil with soil amendment into compost piles (CPEO N.d.). Soil contaminants can be separated and washed by using heat (thermal treatment) or water (soil washing) (Enva N.d.).

4.1.4 Water usage and pollution

The biggest concern about water aspect is the huge amount of water that solar power plant required for cooling purpose. Almost solar power plants need nearly 76 litters per MWh for cleaning, and it is equals to 0.1% the amount of water used by a typical family per year (SEIA n.d.). According to Polywater (n.d.), cleaning in the early morning as well as the evening helps reducing the amount of water, because without sunlight, evaporation occurs more slowly than other time of day.

Leak of harmful substances during construction as well as operation phase and waste treatment phase may lead to water pollution. Rainwater can wash cadmium out of broken solar modules and take it to the ground, which is a threat of soil and water pollution, especially after natural disasters as tornadoes, storms or earthquakes (Forbes 2018). If wastewater of the plant is not treated well, it would bring hazardous chemicals to surrounded water bodies (e.g. nearby lake and stream) and cause harmful effects to plants, animals and human. There is a case in China: a solar plant of Jinko Solar Holding Co. diffused hydrofluoric acid into the nearby river and killed many animals living there. Pigs which were raised in the local farms also died because farmers had used contaminated water taken from that river to clean their livestock (Mulvaney 2014). In order to prevent risks, the power plant should have proper wastewater treatment plan.

4.1.5 Loss of biodiversity

In the area of Phong Phu 2 solar power plant, there were only few trees were affected. This area was an empty land, only some shrubs and few weeds used to live there. Hence, this project does not cause much damage to vegetation. After construction phase, in order to diversify the grassland, it is recommended to use sheep grazing at low stocking density instead of chemical to prevent soil and water pollution (Montag, Parker & Clarkson 2016).

Some bird species living around the construction area such as White-rumped Shama (Copsychus malabaricus), Swift (Apodidae) and Sparrow (Passeridae) might be affected by construction and operation activities. Birds might see solar panels as large water bodies and results in a faint or death after hitting those panels. Furthermore, birds can die because of overheating when they fly to standby focal points or central receiver. Glare disturbance caused by reflection of panels' surface. Insects are easily attracted by the light coming from the power plant, as well as the birds which hunt those insects (Smit n.d.). According to a study researched by McCrary et al. (1984), about 6 birds die yearly and hundreds of insects die hourly because of solar power plant.

According to Turney and Fthenakis (2011), in comparison to coal mining, solar power plant requires less soil removal, which is easier to recover the soil and ecosystem. Fortunately, the power plant does not locate in any birds' migration routes, which helps minimizing bird death potential. In order to reduce the birds' death, solar modules are equipped with antireflection coats (ARC), which not only help increasing the efficiency of the cells, but also minimize the visual effects (Swatowska et al. 2011).

4.1.6 Human health and well-being

Due to a reduction in pollutants comparing to traditional thermal power plants in Vietnam, Phong Phu 2 solar power plant brings good impacts to human health. People are less exposed to mercury, cadmium, particulates and other hazardous chemicals than traditional power generation sources in Vietnam.

According to Turney and Fthenakis (2011), concentration of mercury (Hg) released by solar power is about 0,1g Hg GWh^{-1}, which is much more less than coal (15g Hg GWh^{-1}). Air pollutants such as NOx and SO_2 are also minimized, which helps decreasing diseases like asthma, pneumonitis and bronchial symptoms (WHO 2018).

Phong Phu 2 solar powerplant is expected to not create any bad visual effects for locals, because it is located quite far from residential areas.

4.1.7 Waste

In order to transfer sunlight to electricity, some hazardous chemicals such as cadmium telluride (CT) and copper indium selenide (CIS) are used. These substances can harm the environment, as well as human health if they are not controlled properly during the manufacturing and disposal process (Thoubboron 2018). However, cadmium is usually used in thin-film PV, not the polycrystalline silicon used in Phong Phu 2 solar power plant, therefore its impacts are minimized.

In manufacturing process, silicon tetrachloride is produced as a by-product, which can cause skin damages (burns), lung disease related to air pollution and hydrochloric acid (HCl) release (Thoubboron 2018). In order to prevent silica dust, air quality in the power plant area should be monitored frequently and workers should be equipped with personal protective equipment such as gas mask and gloves. By-products can be reused, recycled or led through pollution control methods (Prakash et al. 2015).

According to Professor Dustin Mulvaney (2015), approximately 90% of PV modules are made from a type of glass, which includes cadmium, antimony, lead and plastics. Therefore, it is impossible to recycle this glass as usual. In a crystalline PV module, there might be up to hundred grams of lead. These materials usually end up in landfills, in which lead (as well as cadmium) can contaminate the groundwater. A domestic recycling network should be developed in order to ensure safe recycling of PV modules.

Wastewater comes from cooling and cleaning activities for solar panels or from workers' daily activities is stored in septic tank and transported to nearby treatment plants.

4.2 Economic Efficiency

In this part, two main aspects were considered: efficiency of PV modules and benefit of the power plant. Efficiency of PV modules was determined through comparison with other types of module, as well as lifespan calculation. On the other hand, benefit of the project, which is shown by net present value and benefit – cost ratio, was analysed to see if it is possible when applying the price that is set by the Government of Vietnam.

4.2.1 PV modules comparison

In this work, crystalline silicon (c-Si), polycrystalline silicon (poly-Si) and thin-film were compared to pick the most suitable module which should be used in Phong Phu 2 solar power plant.

Table 4 below shows both gathered information about location of the power plant as well as PV modules. The output data was calculated by using PVGIS online tool and formula (1).

TABLE 4a. Input data of three types of module in Phong Phu 2 power plant conditions

Data	Unit	c-Si	poly-Si	Thin-film
Location		Phong Phu 2, Tuy Phong village, Binh Thuan Province, Vietnam		
Cordinate		11,227247^{0}N; 108,640775^{0}E		
Total solar radiation on horizontal surface	kWh/m^2/yr	1960		
Annual average atmosphere temperature	^{0}C	26,7		
Type of solar modules		NSP, Mono 280 Wp 60 cells	NSP, Poly 275 Wp 60 cells	First Solar FS-4120A-3
Azimuth	degree	12/-11	12/-11	12/-11
PV modules' power	W	280	275	120
PV modules' efficiency	%	17,2	16,9	16,7
Nominal Operating Cell Temperature	^{0}C	-40÷+85	-40÷+85	-40÷+85
Number of modules are connected in series	modules	23	23	10
Number of parallel series	series	6520	6640	25720
Power loss in PV system because of dust	%	2	2	2
Heat loss coefficient of PV modules	W/m^{2}K	20.0 W/m^{2}K	20.0 W/m^{2}K	20.0 W/m^{2}K
Temperature-power coefficient	%/^{0}C	-0,42	-0,42	-0,28
Loss coefficient of DC transmission line at STC	%	-1,1	-1,1	-1,1
Inverter power	kW	1000	1000	1000
Inverter average efficiency	%	98,5	98,5	98,5

TABLE 4b. Calculated data of three types of module in Phong Phu 2 power plant conditions

Data	Unit	c-Si	poly-Si	Thin-film
Total amount of modules	modules	149960	152720	357200
Radiation absorption area of PV modules	m^2	243967	248257	257184
Required land area	m^2	50000	50000	55000
Total PV power	kWp	41989	41998	41971
Total output power	kW	37621	37647	38957
Amount of inverter	inverters	40	40	40
Amount of transformer 0,4/22 kV 2,5 MVA	transformers	20	20	20
Amount of transformer 22/110 kV 25 MVA	transformers	2	2	2
Average energy in output of PV	MWh/yr	69,275	69,233	72,408
Net power production	MWh/yr	66,839	66,795	69,859
Energy yield	kWh/kWp.yr	1650	1648	1725
Power efficiency/ Performance	%	83,05	82,98	86,85

As can be seen in the table above, crystalline silicon (c-Si) would bring a better performance than polycrystalline silicon modules. However, it costs 0,03 $/Wp more when using c-Si than using poly-Si. While thin-film brings best performance (greater output energy, energy yield and power efficiency), it costs more money than other types due to increasing number of modules and required area. In addition, total area of designed power plant is 60 ha, so thin-film modules would take too much land area. Therefore, in this case, poly-Si must be the most suitable modules for Phong Phu 2 solar power plant.

4.2.2 PV performance estimation

According to Jordan and Kurtz (2012), most of PV modules lose approximately 0.5% efficiency of power output after each operating year. The histogram below shows the degradation rate of poly-Si technology.

The efficiency decreases 0,5% per year, that means after 20 years of operation, the performance of PV modules is approximately 90% of the original one. Besides, other effects such as partial shadowing, dust and dirt also affects the energy output (European Commission 2017).

According to calculation results in Table 1, average energy in output of poly-Si is 69,233 MWh. In the favourable climate condition of Phong Phu 2, loss coefficient is supposed to be 0,5%. Figure 8 below shows estimated energy output in the next 25 years.

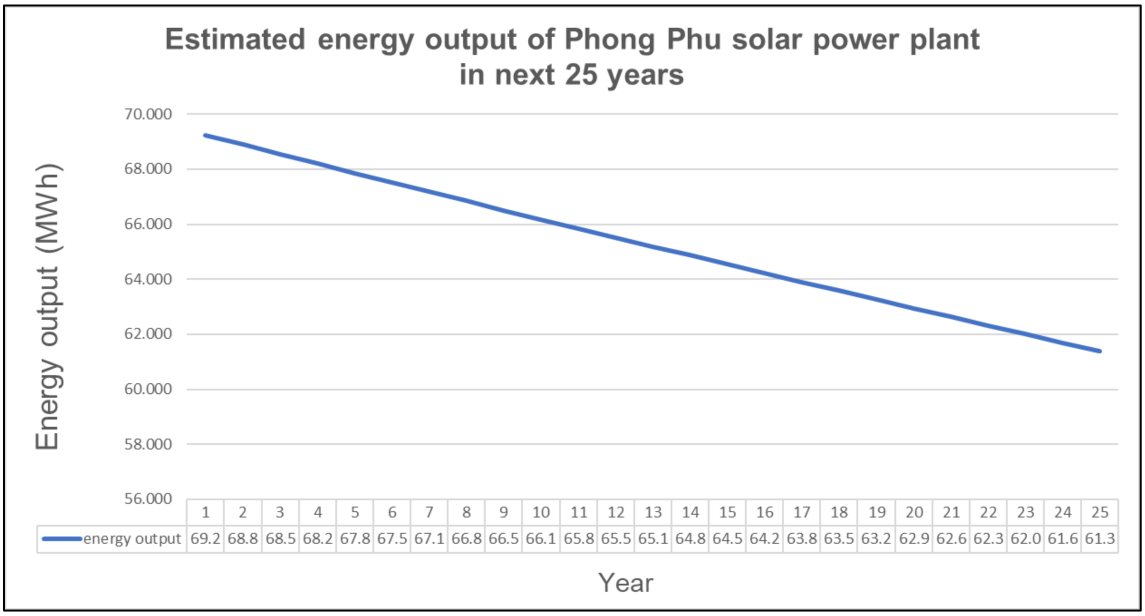


FIGURE 8. Estimated energy output of Phong Phu 2 solar power plant in next 25 years

As can be seen in the figure above, in 2044, the energy output of Phong Phu 2 solar power plant might be only 61,3 MWh. In order to extend the life of PV modules, physical damage such as scratches caused by trees and bushes has to be minimized. Besides, solar panels also need to be cleaned and maintained regularly to avoid dust or dirt.

4.2.3 Economic analysis

By using formula (3) and (4), WACC was calculated for both cases: foreign loan and domestic loan.

TABLE 5. WACC of Phong Phu 2 solar power plant project

	Foreign loan	Domestic loan
WACC	5,35%	8,24%

Break-even analysis was considered to get the fall-back price, which makes the company does not get profit nor loss. The price was calculated when CERs is applied or not.

TABLE 6. Fall-back price of electricity (US Cent/kWh)

	Foreign loan	Domestic loan
With CERs	6,770	8,960
Without CERs	6,795	8,986

To reach break-even point, sell price of electricity is 6,77 – 8,96 cent/kWh when CERs is applied, and 6,795 – 9,986 cent/kWh without CERs. That means when the electricity which generated by Phong Phu 2 solar power plant is sold with the calculated fall-back price, there would be no profit for the project.

The Government of Vietnam has set the tariff for solar projects, which is 9,35 US cents/kWh (Vietnam Briefing 2019). In both cases, with CERs and without CERs, net present value and benefit-cost ratio of this project were calculated by using formula (5):

TABLE 7. Financial factors in case 1: CERs applied

	Foreign loan	Domestic loan
NPV (million USD)	19,28	1,59
B/C	1,471	1,043

TABLE 8. Financial factors in case 2: no CERs

	Foreign loan	Domestic loan
NPV (million USD)	19,58	1,44
B/C	1,466	1,039

In both cases, B/C ratio is greater than 1, which means the project has the possibility to gain profit. For example, in case 1, when CERs is applied and loans come from foreign bank, B/C ratio is 1,471. The company can gain $1,5 benefits for each $1 spent. When the project gets foreign loan and applies CERs, it would get maximum benefit.

4.2.4 Other advantages

Phong Phu 2 solar power plant can provide energy for local area, which helps reducing money for electricity transmission. Furthermore, it helps decreasing environmental pollution, people do not have to pay for healthcare (with diseases caused by air pollution) and the government can save money from cleaning the environment.

Phong Phu 2 solar power plant would create jobs for local people. Similarly, social evils such as drug addiction and gambling are reduced. In addition, Phong Phu 2 solar power plant was built to meet the high demand of energy in Vietnam, especially in Binh Thuan Province. It plays an important role in development of economy and society.

5 CONCLUSION

Overall, as many other solar projects, Phong Phu 2 solar power plant does not generate any pollution during its operation phase. Construction phase of the plant may cause dust, noise and soil erosion because of excavation activity or transportation. Sprinkling and French drain might be applied to decrease the amount of dust and prevent soil erosion. Antireflection coats (ARC) was equipped on solar cells, which can minimize the birds and insects death due to solar modules.

Dangerous by-product (silicon tetrachloride) and other chemicals can cause pollution and disease when they are spread in the air, water bodies or soil. The company should monitor the air quality as well as other environmental index to ensure environmental quality meet the standards.

Polycrystalline silicon modules was chosen to be installed into Phong Phu 2 solar power plant because it brings back high energy output while requiring a reasonable area, as well as its low cost. According to estimation, the performance of Phong Phu 2 solar power plant is approximately 90% of the original one after 20 years of operation. Regular maintenance and proper cleaning methods can help extending the life of PV modules.

With the tariff of solar projects set by the government of Vietnam, which is 9,35 US cents/kWh, the project is profitable. Moreover, Phong Phu 2 solar power plant not only helps reducing environmental pollution, but also decreasing healthcare fee that people have to pay as a result. Therefore, this project is sustainable when considering on three aspects: environment, society and economy.

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