Feasibility for Solid Waste Power Generation at Phu Quoc Island, Vietnam*

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Abstract - ***Solid waste treatment, improving economic feasibility and improving the environment are urgent issues in Vietnam. Phu Quoc Island, the largest island in Vietnam, is expected to become a national center for ecotourism, recreation and entertainment, however the problem of solid wastes causing environmental pollution is very problematic and will have need the attention of society. The objective of this article is to study the feasibility of a solid waste generation solution for Phu Quoc, to demonstrate the economic and technical feasibility, based on the use of planning data generated for Phu Quoc in the period 2020-2030, environmental data in Vietnam, the application of the world's technology... The research results show that the potential for electricity generation from solid waste at Phu Quoc varies from 4.7-7.0 MW, the corresponding production cost from 6.4 to 5.3 cents/kWh. The project's NPV can reach $5.1 million at a rate of 7%; The IRR project is 10.5%; The payback time of the capital is 13.01 years. The net profit margin and the return on investment were respectively 18.9% and 14.9% ... With this result, we can conclude that the project for the production of electricity from solid waste at Phu Quoc is a high feasibility should be applied in practice.***

Keywords: ***urban solid waste; possibility of electricity generation***

I. INTRODUCTION

Vietnam is in the process of industrialization and modernization of the country. This has accelerated the increase in the number and scale of production lines and the increasing demand for commodities and raw materials that have stimulated socio-economic development. However, this development leads to the release of large amounts of waste into the environment, especially solid wastes *("chất thải rắn"*, CTR in vietnamese) such as domestic wastes, industrial waste, medical waste, hazardous waste. According to statistics, the amount of solid waste generated in urban areas in Vietnam is about 38,000 tons per day [1] with an average increase of 12% per year, thus the treatment of environmental pollution solid waste is becoming an urgent need.

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In particular, Phu Quoc is the largest island district in Vietnam, located far from the mainland, Phu Quoc is planned to develop sustainably and harmoniously between economic development in association with environmental protection. To step by step build Phu Quoc into an island sea city, a center of tourism and high-class services, and a center of national and regional science and technology. However, Phu Quoc currently has two large landfill sites and they have existed for more than a decade with more than 140 tons of waste generated each day, causing environmental pollution. Therefore, the problem of waste treatment to bring Phu Quoc green development is more urgent than ever. This will not only help to improve the environment, but also contribute to the energy supply in a reliable and environmentally responsible way. It is time to step up research and increase scientific methods to treat waste in Phu Quoc safely, minimizing the amount of waste generated. For the above reasons, it can be seen that it is urgent to study the potential of electricity generation from urban waste in Phu Quoc to contribute to reducing environmental pollution and promoting sustainable socio-economic development.

The content of this article consists of several following parts, such as: overview of Phu Quoc, overview of solid waste in urban area, renewable energy solutions from solid waste, policy of the government of Vietnam on renewable energy solutions from solid waste, possibility of electricity generation from solid wastes at Phu Quoc. Some numerical results of this research are considered in order to discuss about the technical potential and the economic potential of the project. The concluding remarks are presented in the last section.

II. OVERVIEW OF PHU QUOC



Figure 1. *Maps of Phu Quoc and Vietnam*

Phu Quoc is also known as Dao Ngoc, the largest island in a population of 22 islands located in the Gulf of Thailand. Phu Quoc island has a total area of 574 square kilometres. Phu Quoc Island and other islands constitute the Phu Quoc District of Kien Giang Province. Phu Quoc is far 120 km from Rach Gia and 45 km from Ha Tien town (Figure 2). Before 1975, the population was just over 5,000. After 1975, population on the island increased rapidly, by 2015 the population on the island is 101,407 people, the average density is 172 people/km^2. In 2006, the Kien Giang coastal and ocean biosphere reserve, including Phu Quoc, was recognized as a world biosphere reserve by UNESCO.

According to Decision No. 633/QĐ-TTg dated May 11, 2010 of the Prime Minister approving the adjustment of construction of Phu Quoc island, Kien Giang province to 2030, Phu Quoc will be a special economic-administrative zone; the national and international center of eco-tourism, convalescence and entertainment; the regional financial center is an important hub for international and regional transport and is a center for specialized scientific and technological research, a center for forest biodiversity conservation and sea of the country and the region. It has a special position on the national security and defense. Up to July 2011, Phu Quoc has 74 projects granted investment certificates, with a total investment capital of 48,087 billion.

It is forecasted 2020, the population of Phu Quoc will be around 340,000-380,000, of which the urban population will be about 200,000-230,000, the rural population will be around 80,000-90,000 and the exchanging population from the tourists will be around 50,000-65,000 people. By 2030, the population of Phu Quoc will be about 500,000-550,000, of which the urban population will be about 320,000-370,000, the rural population will be around 90,000-100,000 and the exchanging population from the tourists will be around 80,000-85,000. According to the above decision, it is forecasted that by 2020 there will be 2-3 million tourism visitors per year, of which 35-40% will be foreigners and there will be 5-7 million visitors per year in 2030, of which 45-50% will be foreigners.

With the current population, Phu Quoc has more than 1,600 operating enterprises, including hundreds of manufacturing establishments and many tourism service enterprises. However, most of these enterprises do not have the wastewater treatment system meeting the standards, leading to untreated waste water being discharged directly into the natural environment.

At the moment, Phu Quoc exists two large landfill sites over a dozen years, located in An Thoi Town and Cua Duong Commune with more than 140 tons of waste generated each day. However, they are close to the main road causing environmental pollution. At public beaches or estuaries in Phu Quoc residential area, it is easy to see the scene of waste is rampant...

TABLE 1. POWER DEMAND OF PHU QUOC (2018-2025) (KW) [2]

2018	2019	2020	2021	2022	2023	2024	2025
64.5	87.0	117.4	128.6	140.9	154.5	169.3	185.5



Figure 2. *An Thoi's landfills*

Phu Quoc was supplied electricity from the national grid via the 110 kV line of Ha Tien - Phu Quoc from February 2014 with a length of 64 km and the Phu Quoc 110 kV transformation station with a capacity of 2x40 MVA. When Phu Quoc diesel power plant has stopped working, it is only used as a backup source. It can only carry loads about 76% [3]. In case of incident of Phu Quoc underground cable, it will be difficult to ensure energy security.

According to statistics from Kien Giang Power Company, the situation of using power registration in Phu Quoc district in the period 2017-2018 is as follows:

- The projects put into operation by the end of 2017, a total of 46.9MW, including Vinpearl Casino: 12 MW; Vinpearl Phu Quoc 3 & 4: 17.8 MW; An Thoi Group: 11.8 MW; Sung Chi Hon: 1.2 MW; BIM Kien Giang Company: 4.1 MW.
- In 2018, additional loads will be added, a total of 36.6 MW, including MIK Group Vietnam (Movempic Project): 7 MW; An Phuong Group: 12.45 MW; Sung Hong Hon: 5.3 MW; Pulman Resort: 3.2 MW; Novotel: 5 MW; Public transformer substation load: 3.66 MW (about 10% increase).

III. RESEARCH METHODS

Schematic of feasibility of producing electricity from urban waste is shown in Figure 3.

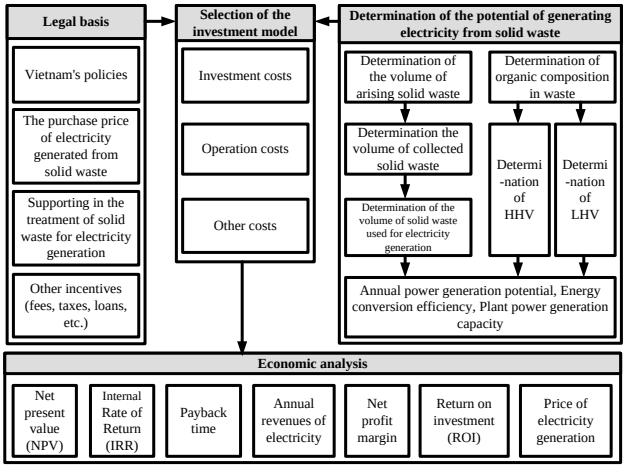


Figure 3. Schematic of feasibility of producing electricity from urban waste

A. Policy of the government of Vietnam on renewable energy solutions from solid waste

To solve the "wasting energy" problem, Vietnam has promulgated many policies and regulations in order to encourage the waste-to-energy incineration industry including tax rates, waste treatment subsidies, tax incentives, financial support, etc. Some details will be presented as follow.

According to the Prime Minister's Decision N°. 31/2014/QĐ-TTg of May 05, 2014 of the on mechanism to support the development of solid waste power generation projects in Vietnam. Accordingly, the price of electricity generated by solid waste generators is 10.05 UScents/KWh.

The Ministry of Industry and Trade has issued Circular N°. 32/2015/TT-BCT of October 8, 2015 requiring Electricity of Vietnam EVN to purchase all electricity generated from grid-connected solid waste generation projects with the use of direct burning technology costs 2,114 VND/kWh, equivalent to 10.05 UScents/kWh (excluding VAT).

The Ministry of Construction issued Decision No. 322/QĐ-BXD of 06/4/2012 on disclosure of construction investment and the cost of treatment of domestic solid waste for individuals and organizations referring to the process of investing and operating solid waste disposal facilities, the waste treatment fee in the technology of generating electricity is equivalent to 19.23 USD/ton of waste.

Other preferences and supports: The Government of Vietnam has issued a number of fiinancial policies to encourage investment. As such, research and development of solid waste generation projects is a good way to utilize solid waste fuel. It not only contributes to increasing electricity but also minimizes environmental pollution.

B. Potential of generating electricity from solid waste

The characteristics and composition of urban solid waste depend on many factors, such as socio-economic characteristics, climatic conditions, recycling levels, etc. The level of urbanization is rapidly increasing, This leads to increasingly urban solid waste and increasingly complex components. It is estimated that the average amount of urban solid waste in Vietnam in 2015, 2020, 2025 is respectively about 1.2, 1.4, 1.6 kg/person/day [1].

The composition of solid wastes leading to landfills, which can be used as raw materials for organic fertilizer production, accounts for 54-77.1%; plastic 8-16%; metal 2%; Hazardous waste is discharged into household waste about 1%. [1]

$$C + H + O + N + S + A + W = 100\% \quad (1)$$

where *C*, *H*, *O*, *N*, *S*, *A* and *W*, respectively, are the percentages by weight of the elements carbon, hydrogen, oxygen, nitrogen, sulfur, ash and humidity.

Renewable energy solutions from solid waste: Depending on the composition and humidity content of the solid waste, the energy in organic matter of recovered solid waste can be generated for the production of electricity and heat by the two most common methods today: biochemical methods and methods thermochemistry. Each method is associated with many different technologies (see Figure 4).

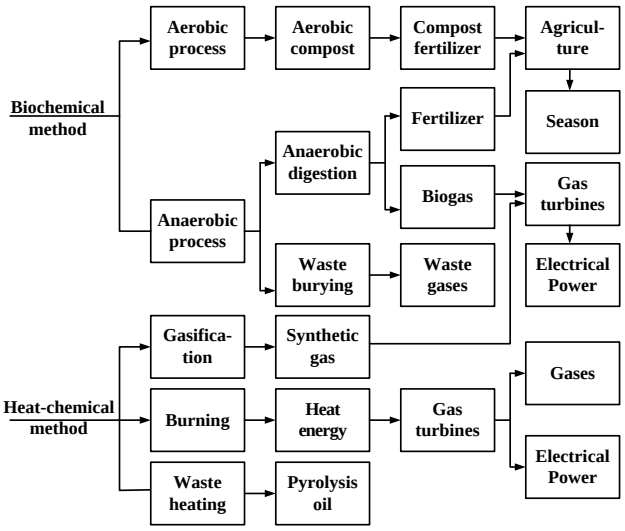


Figure 4. *Renewable energy solutions from solid waste [4]*

Humidity of solid waste - Humidity of solid waste is determined by two methods:

- Humidity is calculated based on the wet weight of the solid waste as a percentage of water content in 100 kg wet solid waste. Humidity by wet mass method is determined [5]:

$$a = (w - d)\,\mathrm{x}100 / \mathrm{w} \quad (2)$$

where *a* is humidity (% mass); *w* is the initial sample weight (kg); *d* is the sample weight after drying at temperature 105°C (kg).

- Humidity is calculated based on the dry matter content of the solid waste as a percentage of water content in 100 kg of dry solid waste.

Calorific value of solid waste**:** Calorific value is the amount of heat generated by a complete combustion of a unit of solid waste (kcal/kg), the heat of solid fuel is approximated by the Mendeleep formula [5], as follow:

$$Q = 81 \times C + 300 \times H - 26 \times (O - S) - 6 \times (9 \times A + W) \quad (3)$$

The calorific value of dry solid waste treatment is calculated from the calorific value of wet solid waste according to the following formula [5]:

$$Q_{dry} = Q_{wet} \times 100 / (100 - \%\mathrm{W}) \quad (4)$$

Technical potential of the project - The potential energy of urban solid waste is based on the volume and composition of solid waste. In this case, the volume of daily-life solid waste generated in a day M_T (tons/day) is calculated according to the following formula [4]:

$$M_T = P \times wc \quad (5)$$

where *wc* is the indicator of solid waste per capita (kg/person/day); *P* is the calculated urban population (person).

In reality, the rate of urban solid waste collection and treatment is only about 85% of the total waste delivered to the landfill every day [4]:

$$M_F = M_T \times 0.85 \quad (6)$$

At present, the composition of plastic, metal, glass, ceramics of the collection and treatment of solid waste are classified for recycling. Therefore, we have only the organic fraction of solid waste which is used for energy recovery. The total amount of waste that can be recovered by burning for electricity generation [4]:

$$M_{F(i)(day)} = M_F \times f_{(i)} \quad (7)$$

where $f(i)$ is the percentage of organic components in the waste used for the treatment of combustion, with $f(i)$ =54-77% [4].

Accordingly, the volume of solid waste treated for electricity generation in one year is determined by the formula [4]:

$$M_{F(i)(year)} = M_F \times f_{(i)} \times 365 \quad (8)$$

The low heat value (HHV) and the high value (LHV) of solid waste (MJ/kg) can be determined by (9) [6] and (10) [7], as follows:

$$LHV = HHV - (9 \times \%H + \%H_2O) \times 2.44 \quad (9)$$

$$HHV = 0.3491 \times C + 1.1783 \times H + 0.1005 \times S - 0.1034 \times O - 0,015N - 0.0211 \times A \quad (10)$$

where HHV, LHV are measured by MJ/Kg; C, H, O, N, S, and A represent masses of carbon, hydrogen, oxygen, nitrogen, sulfur and ash.

The total heat used to rotate the steam turbine of the boiler is based on the equilibrium equation of energy and mass [8, 9]. The useful heat (Btu/h) needed to rotate the steam turbine is calculated by the following formula [4]:

$$Q_{inc} = b \times HHV \times (100 - e)/100 \quad (11)$$

where: e is the total heat loss; b is the dry mass of the input (lb/h), b = *23.583* lb/h; HHV: high heat value.The total energy loss e is calculated by the following formula [4]:

$$e = e_{dfgl} + e_{mfl} + e_{lhl} + e_{ufl} + e_{ml} \quad (12)$$

where e_{dfgl} is dry exhaust gas emissions, exhaust gas through the chimney; e_{mfl} is loss of humidity in fuel (waste); e_{lhl} is hidden heat loss; e_{ufl} is loss of fuel (waste); e_{ml} is other losses.

The dry exhaust gas emissions e_{dfgl} is calculated by [4]:

$$e_{dfgl} = 24 \times (T_{FG} - T_A) \times n \quad (13)$$

where T_{FG} is the temperature of the exhaust gas in the stack (0F); T_A is ambient temperature (0F); n is the mass flow of the dry gas emission (lb/Btu). With the actual combustion technology, the exhaust gas temperature is 3900F, T_{FG}=*3900F* and T_A=*800F*.

The mass flow of the dry gas emission (lb/Btu) is determined as follow [4]:

$$n = \left(\left((12.7 \times C + 38.1 \times H)(1 + a/100)\right) - 0.5 \times O\right) / HHV \quad (14)$$

where *C*, *H* and *O* are the percentage by mass of carbon, hydrogen, oxygen in the fuel (waste), *a* is the percentage of excess air and high heat value (HHV) in Btu/lb which is determined by the formula [4]:

$$a = \%O_2 \times 100\% / (21 - \%O_2) \quad (15)$$

where $\%O_2$ is the amount of O_2 in the flue gas,% volume; 21 is the amount of O_2 gas in the air,% volume.

Loss of humidity in fuel - solide waste (e_{mfl})

Another loss that results in the high heat values (HHV) and the low heat values (LHV) is heat loss due to humidity in the fuel, which can be determined as follows [10]:

$$e_{mfl} = M_{db} \times (H_2 - H_1) / HHV \quad (16)$$

where M_{db} is % humidity (dry weight), H2 is the enthalpy of the stream leaving the chimney at the temperature of the exhaust gas; H1 is the Enthalpies of the water. These two values of enthapies can be calculated by [4]:

$$H_1 = \left(0.3958 \times 10^{-4} \times T_{FG} + 0.4329\right) \times T_{FG} + 1062.2 \quad (17)$$

$$H_2 = T_A - 32 \quad (18)$$

Hidden heat loss (e_{lhl})

Hidden heat loss (e_{lhl}) is one of the losses in the boiler and can be calculated by the formula [4]:

$$e_{lhl} = (100 \times H \times 8.94) \times \text{HHV} \times (H_2 - H_1) \quad (19)$$

where H is the volume of Hydrogen (dry mass), *HHV* in Btu/lb, *H2* and *H1* are enthapies of the vapor leaving the chimney at the exhaust gas temperature and the enthapies of the water.

Other losses (e_{ml}) are other losses that are difficult to assess and usually given a default value of 2.03% of the input fuel [11]. The annual electricity generation potential (kWh/year) is defined as follows [4]:

$$E_{P(INC)} = Q_{INC} \times \eta \times 8.760 / 3412.14 \quad (20)$$

where the value of 3412.14 is the conversion factor from Btu to kWh, η is the electric power of the steam turbine [12].

Power generation capacity of the plant

$$G_{P(INC)} = E_{P(INC)} / (8760 \times CF) \quad (21)$$

where *CF* is the power factor [12].

C. The economic potential of the project

Investment cost of the combustion plant [13]

$$C_{inv} = 4900 \times (M_F)^{0.8} \times Q \times R \times S \quad (22)$$

where *Q*, *R*, *S* are coefficients of cost adjustment. *Q* is the conversion factor from Euro to USD; *R* is consumer price index; *S* is exchange rate from Euro to USD [3].

Operating costs [13]

$$C_{O\&M} = 700 \times (M_F)^{-0.29} \times Q \times R \times S \quad (23)$$

where *Q*, *R*, *S* are the coefficients of cost adjustment. *Q* is the conversion factor from Euro to USD; *R* is the consumer price index; *S* is the exchange rate from Euro to USD [3].

Annual revenues from annual electricity sales is calculated as follow:

$$\mathrm{Re}v = E_p \times F_d \quad (24)$$

where *Ep* is electricity output (kWh/year); F_d is electricity price (USD/kWh)

Annual waste treatment allowance:

$$ADS = WS \times M_{F(i)(year)} \quad (25)$$

where WSl a waste treatment allowance (USD/ton); *MF(i)(year)* is the amount of waste that generates electricity annually (tons).

Generation costs LCOE [4]:

$$LCOE = LCC \times CRF / \mathrm{E_P} \quad (26)$$

where *LCC* is the life cycle cost of the project, *CRF* is the capital return factor. *LCC* and *CRF* can be determined by the following formulas (27) and (28) [4]:

$$LCC = C_{inv} + \sum_{i=1}^{N} C_{O\&M} / (1+d_n)^n \quad (27)$$

$$CRF = (d_n \times (1+d_n)^N) / ((1+d_n)^N - 1) \quad (28)$$

where *N* is the number of years of project implementation.

The payback period is calculated according to the following formula:

$$Pt = T - 1 + (|CNCF_T - 1|) / NCF_T \quad (29)$$

The net present value (NPV) based on the net cash statement is determined as follows [14]:

$$NPV = \sum_{t=0}^{N} (CI - CO) \times (1+i)^{-t} \quad (30)$$

Internal Rate of Return (IRR) is determined by the method of interpolation and is calculated by the following formula [14]:

$$IRR = i2 + (i3 - i2) \times NPV2 / (NPV2 + |NPV3|) \quad (31)$$

IV. Results and Discussion

According to the development plan of Phu Quoc in the period 2020-2030 and policies to encourage investment in the generation of electricity from solid waste of the government, such as: Taxes and other expenses, with the project to build a solid waste incinerator for electricity generation, the investor under the BOT model is entitled to the following incentives:

- Project development phase: (1) Import tax exemption for goods will be fixed assets which cannot be produced domestically. (2) In terms of investment incentives: Clean energy project owners can borrow up to 70% of the investment cost from the Vietnam Development Bank (VDB) with the government bonds interest rate for 5 years plus add 1% per year.

- Operation phases: (1) Tax exemption for the first four years and 50% tax reduction for the next nine years. The tax rate is 10% for 15 years, can be extended to 30 years. (2) Exemption of land tax and fees. (3) Environmental protection fee is waived.

The economic and technological indicators of the solid waste electric power plant in Phu Quoc is presented in Table 2.

TABLE 2. The economic and technological indicators of the solid waste electric power plant in Phu Quoc

Data	Unit	Value
The population of Phu Quoc	people	360,000-532,888
The volume of solid waste treated for electricity generation in one day	ton/year	283-419
Annual processing capacity	kton/year	103-152
Power conversion performance	kWh/ ton	341
Heat used to rotate steam turbine	kBtu/lb	47,289-70,000
Power generation capacity of plant	MW	4.7-7.0
The annual electricity generation potential	MWh/year	35,208-52,116
Total investment	M$	34.1
Lending rate	%	70%
Time for building	year	2
Operation time	year	23
Annual interest rate of loan	%	4.1%
Loan maturity date	year	15
Annual operating costs	M$	2.9-4.3
Annual grants	M$	2.0-2.9
Generation costs	$cent/kWh	6.4-5.3
Electricity price	$cents/kWh	10.05
Annual revenue	M$	3.5-5.2
Flow of Cash in	M$	5.5-8.1

Power generation capacity of the plant in 2020 is demined from 4.7 to 7.0 MW in period of 2020-2030. The cost of electricity generation in 2020 is demined from 6.4 to 5.4 cents/kWh in period of 2020-2030 (Figure 5).

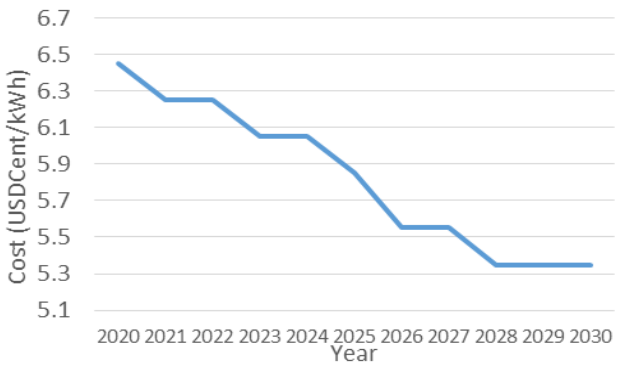


Figure 5. *Cost of electricity generation*

In the first year of operations, the results show that net profit margin was 6.3% and net margin maintained steady growth until the 18th year, except for the 13th and 17th year. By the end of the project, net margin remained at 18.9%. Return On Investment (ROI) will also maintain a growth rate from the 3rd to the 18th year and then it stays at 14.9% as shown in Figure 6.

The net cash flow of the project tends to increase from the 18th year to a staggering $ 3.4 million. In the 14th year, the net accumulated amount will be positive and eventually it will amount to $ 34.7 million (shown as Figure 7).

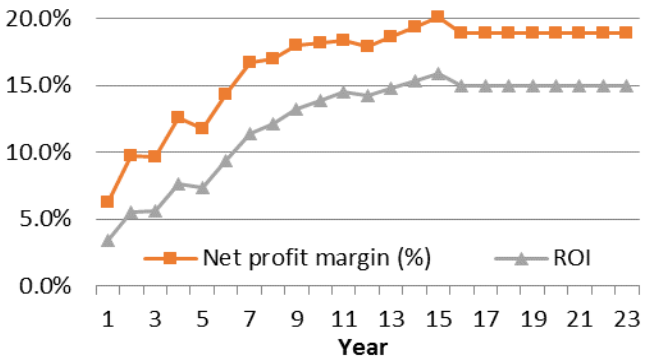


Figure 6. *Net profit margin/ROI*

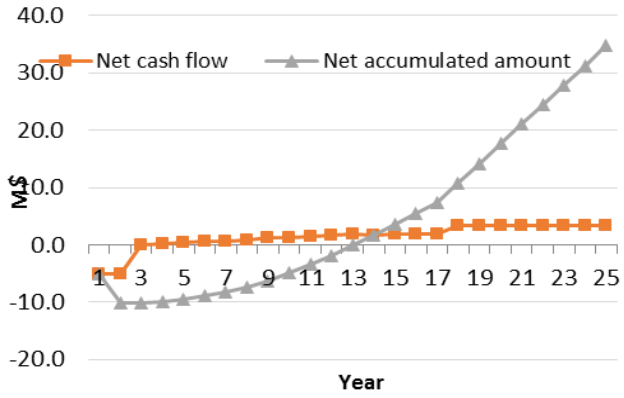


Figure 7. *Net cash flow and net accumulated amount*

The payback period is 13.01 years. The results prove that investors can recover their capital within 14 years. Then, investors will have net profits for at least the next 9 years. Therefore, it is attractive for investors to invest in this project.

Accordingly, when the basic discount rate is i_1=7%, NPV_1=$ 5.1 million; when i_2=9% then NPV_2=$ 1.8 million; when i_3=11% then NPV_3=$ -0.5 million. If the basic discount rate is 7%-9%, the economic value of this project is acceptable and if the basic discount rate is 11%, investors should consider implementing the project.

Internal Rate of Return (IRR) is determined by the method of interpolation and is $IRR = 10.5\%$

TABLE 3. NPV, IRR ACCORDING TT DISCOUNT RATE

Rate (%)	5%	6%	7%	8%	9%	10%	11%
NPV (M$)	9.9	7.3	5.1	3.3	1.8	0.5	-0.5
IRR(%)	10.5%	10.5%	10. 5%	10.5%	10.5%	10.5%	10.5%

In this project, we do not include revenue from waste heat and ash waste. However the results still allow to conclude that a solid waste generation project aiming to address environmental pollution, providing power to the power system, and achieving a return on investment of 18.9% and 14.9% should be economically viable

V. CONCLUSION

Generating electricity from urban solid waste by burning technology can apply many incentives and supports from the Government of Vietnam. The results show that the potential for electricity generation from solid waste in Phu Quoc ranges from 4.7-7.0 MW, with a corresponding electricity generation cost of 6.4-5.3 cents/kWh. The NPV of the project could reach $ 5.1 million at a rate of 7%; IRR project is 10.5%; capital recovery time is 13.01 years. Net profit margin and return on investment were 18.9% and 14.9%, respectively. With the obtained result in this research, it can be concluded that the project of generating electricity from solid waste in Phu Quoc which is high feasibility should be applied in practice.

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