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Proposing solutions to improve municipal solid waste burning efficiency of small scale capacity power plants in Vietnam

Thai Minh Thi NGUYEN¹, Ngoc Loi DUONG², Thanh Phong TRAN¹,
Laetitia PEREZ¹[0000-0001-6340-0317], and Laurent
AUTRIQUE¹[0000-0002-7611-4923]

¹ LARIS, Polytech Angers, University of Angers, France

² GEE, Environment and Energy JSC, Ho Chi Minh City, Vietnam
thaiminhthi.nguyen@univ-angers.fr, info@catec.com.vn,
{thanhphong.tran,laetitia.perez,laurent.autrique}@univ-angers.fr

Abstract. This article focuses on studying the composition of Vietnam's solid waste and evaluating its calorific value to increase its electricity generation capacity. Accordingly, the author studies the current status of solid waste treatment in Vietnam as well as its negative impacts on the environment. Poor classification and pretreatment with outdated technology cause many difficulties for the thorough treatment of solid waste. This study proposes solutions and processes for treating waste materials to help increase the calorific value and improve the efficiency of the heat generation and utilization processes. This not only helps reduce environmental pollution and greenhouse gas emissions but also helps increase electricity generation capacity to utilize heat from the solid waste treatment process. Research results show that the proposed solution has contributed to solving the difficult problem of solid waste treatment but also helped increase clean energy sources, contributing to sustainable development for Vietnam in the future.

Keywords: municipal solid waste · renewable energy · small scale generator plant · Vietnam

1 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 municipal solid waste (MSW). In Vietnam, approximately 60,000 tons of household waste are released into the environment daily, with urban household waste accounting for around 55%-60% of this total. Addressing energy needs, solid waste treatment, improving economic feasibility and improving the environment are urgent issues in this country.

The MSW management system includes production, on-site treatment and storage, collection, transportation, treatment and recycling of waste [1, 2], and also includes recycling, incineration, waste-to-energy (WtE) conversion, composting or landfilling [3, 4]. Due to the backwardness of waste treatment technology, convenience, and cost considerations [5], many developing economies resort to primitive disposal methods such as open burning, open dumping, and landfilling [3, 6] for managing MSW [7]. In contrast, developed countries strategically manage MSW, viewing it as a valuable resource for sustainable development [8, 9]. For instance, they utilize MSW for energy production [10], extracting raw materials, and as a resource for various sustainable initiatives [11], thereby almost completely eliminating landfilling rates [12].

The National Statistics Office forecasts that electricity demand in the commercial sector will increase every year. In the vision to 2030, the power generation capacity structure will change significantly with coal thermal power expected to account for 56% of total net power generation capacity, hydropower accounting for 16.5%, oil and gas accounting for 13%, and energy renewables accounting for less than 4% [13]. The problem is that coal emits CO_2 and hydroelectricity causes earthquakes. The urgent issue is to solve the current situation of pollution caused by MSW and to contribute an important proportion to renewable energy.

This research will try to overcome the above shortcomings by designing effective small scale capacity power plants using WtE. The paper is structured as follows: management of MSW in Vietnam is presented and modeled in Section 2. Section 3 addresses proposal solutions for improving WtE efficiency. Next, numerical results and discussions are shown in Section 4. The last section will propose concluding remarks and future perspectives.

2 Situation of solid waste treatment in Vietnam and Mathematical Model

2.1 Situation of solid waste treatment in Vietnam

According to statistics over the last five years, the amount of MSW generated in Vietnam is approximately 64.8 thousand tons per day (equivalent to 23.64 million tons per year). Alarming forecasts show that the volume of MSW generated is increasing by an average annual rate of 10%-16%. Similar to other developing countries in the world, Vietnam is also applying outdated and polluting waste treatment methods such as open landfilling and rudimentary incineration due to a lack of technology and cost. The Ministry of Natural Resources and Environment reports that more than 60% of this waste is treated by landfilling, with less than 20% being buried hygienically and 43% of the waste being buried in an open unhygienic way. The accumulation of waste in unsanitary landfilling poses a significant threat to everyday soil, water and air quality, especially in large urban centers. A fairly modest amount of waste recycled is 10%. Adding to the concern, nearly 14% of MSW is burned manually and releases toxic dust and fumes into the atmosphere [13].

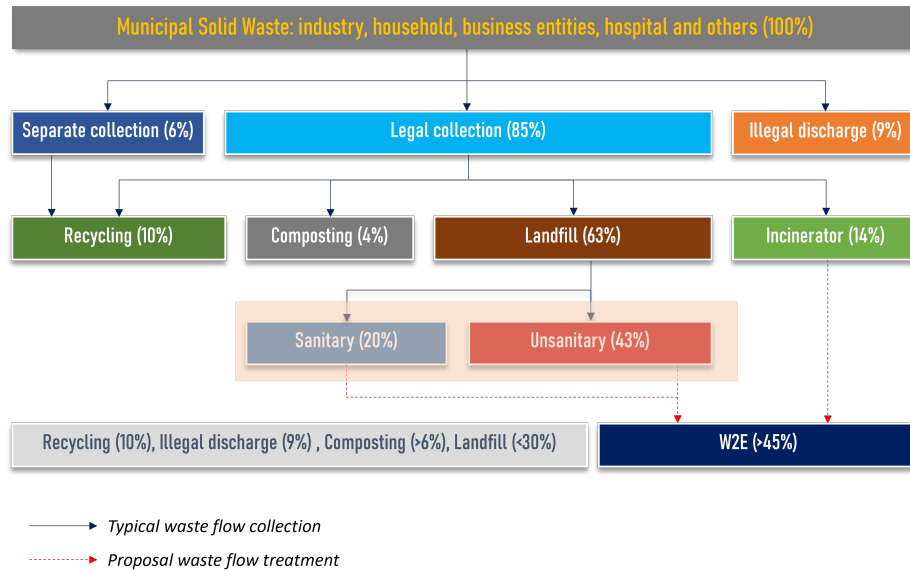


Fig. 1. Typical waste flow collection and treatment [13]

To cope with this urgent environmental crisis, the Prime Minister has issued a comprehensive National Environmental Protection Strategy to 2030, with a vision to 2050, as stated in Decision No. 450/QĐ-TTg issued on April 13, 2022. Within its framework, an important initiative has been launched to improve the capacity of MSW management in Vietnam and develop a roadmap. Implement a direct program to reduce the proportion of MSW treated by landfill technology to 30% of the total amount of MSW collected by 2025. Figure 1 shows that up to 63% of waste is landfilled and that 14% is burned, which are the valuable source of raw materials. The authors propose solutions in the Section 3 to not only help reduce this rate but also increase the rate of reusing waste as a clean and sustainable energy source. Accordingly, the manually burned waste combined with the amount of unsanitary landfilled waste can be processed as a source of raw materials for waste incineration system to generate electricity and help increase the rate of WtE up to 45%.

MSW is often burned at special waste-to-energy plants, which use heat from fires to create steam to generate electricity or heat buildings. According to statistics from the U.S. Energy Information Administration by 2023, many countries in the world have waste-to-energy plants. The use of waste-to-energy plants is relatively high in Japan (75%) and in some European countries, specifically Denmark (67%), Belgium (48%), Switzerland (47%), UK (42%), France, and Germany about 30% [14]. This can be explained by policy factors, financial investment, technological development and partly because there is little free space for landfills [2].

2.2 Dataset and mathematical model of MSW

Similar to developing countries, the MSW generation is actually estimated at an average of 0.8 kg/cap/day. Generation rates are forecast to increase in 2025 to 1.6 kg/cap/day. The current estimates for average composition of the MSW in Vietnam listed in Table 1 below are indicative based on dry basic (average moisture of MSW is about 20%-30% [15]).

Table 1. Estimated composition and chemical characteristics of MSW [16,17]

Component	Range (%)	Avg. C	H	N	S	O	A	
Organics	50.2 – 68.9	59.50	40.50	5.95	2.39	0.66	43.53	5.00
Plastic and nylon	3.4 – 10.6	6.50	76.39	9.97	0.38	0.94	3.36	10.00
Paper and carton	3.3 – 6.6	5.00	40.35	5.55	0.68	0.65	40.80	5.50
Metal	1.4 – 4.9	3.00	4.25	0.27	0.44	0.00	0.00	0.00
Glass	0.5 – 2.0	1.50	0.40	0.10	0.13	0.00	0.00	0.00
Inert	14.9 – 28.2	20.00	26.30	3.00	2.00	0.50	0.20	68.00
Rubber and leather	0.0 – 5.0	2.5	69.71	7.09	0.27	0.66	4.48	10.00
Tissues	1.5 – 2.5	2.00	46.32	5.45	0.69	0.57	39.97	2.45

The net calorific value of MSW has a significant impact on its physical chemical characteristics. Since this communication aims to use MSW as fuel for WtE, it is necessary to analyze its chemical composition. Its information is important for evaluating alternative processing and heat-energy recovery options [18]. They included the ultimate analysis parameters of MSW such as carbon (C), hydrogen (H), nitrogen (N), sulfur (S), oxygen (O) and ash (A) which are represented in Table 1.

Table 2. Literature correlations of moles for estimating the energy content of MSW

No. Correlation formula	Reference
M1 $H_n = 2.326(0.145C + 0.610(H - 0.125O) + 0.040S) + 0.02326N$	[19]
M2 $H_n = 0.3517C + 1.1626H + 0.1047S - 0.111O + 0.0628N$	[20,21]
M3 $H_n = 0.3414C + 1.4445H + 0.125(N - O - 1) + 0.093S$	[22-24]
M4 $H_n = 0.341C + 1.323H + 0.0685 - 0.0153A - 0.1194(O + N)$	[25]
M5 $H_n = 0.3491C + 1.1783H + 0.1005S - 0.1034O - 0.0151N - 0.0211A$	[24,26]

Table 2 shows the literature correlations of mathematical models which were proposed by Dulong (M1, 1880), Boie (M2, 1953), Dulong-Berthelot (M3, 1957), IGT (M4, 1978) and Channiwala-Parikh (M5, 2002) for predicting the energy content of MSW using percentages by weight of carbon (C), hydrogen (H), nitrogen (N), sulfur (S), oxygen (O) and ash (A). Where H_n is net calorific value of MSW ($MJkg^{-1}$) [24,27].

The energy content of MSW H_n , H_{wet} based on the dry and wet basis could be estimated by this formula [28]:

$$H_n = H_{wet} \times \frac{100}{100 - \%RH} \quad (1)$$

Therefore, the total energy of of MSW per day will be calculated from the following equation:

$$W_i = m_s \times H_n \times \frac{(100 - e_i)}{100} \quad (2)$$

where $e_i = 15\% - 25\%$ is total heat loss coefficient of the incinerator. m_s is the mass of waste received (kg/day). The total heat energy recovery is estimated by this formula:

$$W_h = \eta_h \times W_{inc} \quad (3)$$

where $\eta_h = 75\% - 80\%$ is heat energy recovery efficiency.

The waste incinerator unit is combined with a power plant boiler and steam turbine, the electricity that can be generated is estimated according to the useful energy and will be calculated from the following equation:

$$W_e = \eta_t \times \eta_e \times W_h \quad (4)$$

where $\eta_t = 70\% - 80\%$ is steam turbine efficiency and $\eta_e = 30\% - 40\%$ is electricity generation efficiency.

3 Proposal solution for improving efficiency of WtE

3.1 Proposal technical solutions for WtE

MSW are collected by specialized vehicles according to national standards (I-input). The MSW receiving area is enclosed and creates continuous negative pressure thanks to the exhaust fan supplied to the incinerator to reduce odors and supply hydrogen carbon generated from garbage to the incinerator. As referenced in some documents above and actual investigation, Vietnam's domestic snake litter has a very high humidity of 70%-80%. That makes it very difficult to burn MSW due to its low calorific value and the need to replenish materials to burn this amount of MSW. In addition, burning wet MSW will produce a lot of toxic gases to the environment.

Therefore, the research team proposed pretreatment (shredding, tearing) and pressing garbage to separate it into two phases: the aqueous phase (characterized by muddy water, the density depends on the characteristics of the garbage and varies according to the seasons of the year) and the solid phase (with a humidity of 50%-60%). Wastewater continues to be separated into two phases: the water phase (will be transferred to the water treatment system to qualify as domestic water for the whole plant) and the solid phase (also known as dry sludge with very high organic density, which can be used as fertilizer or put into incinerators).

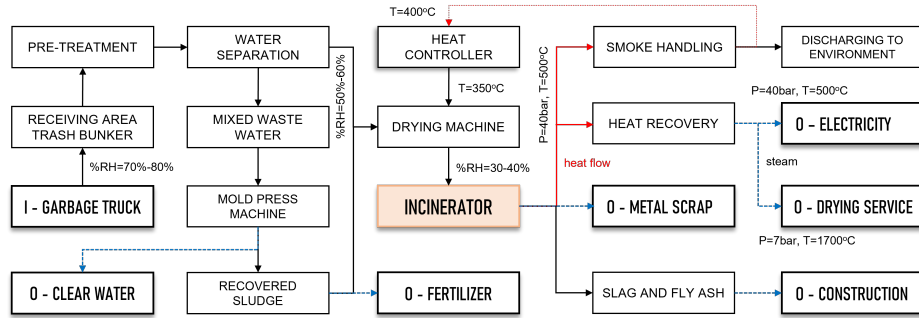


Fig. 2. Presentation of proposed process of WtE.

MSW after pressing and dry sludge continues to be put into the incinerator. The incinerator follows the technology of recording steps, MSW entering the furnace will participate in the process of volumetric combustion. The stages of the incinerator must comply with national environmental regulations. The waste heat will be used by the heat recovery boiler system. This steam will be passed through the steam turbine (used for plant, grid connection, sale to other users) or/and semi-saturated steam (used for drying, heating, and other industries). Exhaust fumes are treated for dust and harmful gases before being released into the environment. In addition, the heat released from here can be recovered for drying the incinerator's inlet. This helps reduce the garbage moisture once again to 30%-40%. The waste from the incinerator can also be utilized as slag ash, fly ash used as building materials, steel and scrap metal.

This process not only helps to increase the efficiency of heat recovery from burning MSW by reducing humidity, but also helps to make use of all resources discharged from incineration (wastewater, fertilizer, ash, scrap metal, electricity, saturated vapor, etc ...). From there, it helps reduce costs and increase revenue for the project. Waste-to-energy implementation has been proven to have a positive impact on global warming due to reductions in greenhouse gases (such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O)) compared to the baseline case (i.e., waste dumping, open burning and landfilling with biogas collection) [29].

3.2 Proposal economic solutions for WtE

The project to establish a household solid waste incineration plant to generate electricity from heat recovery is a long-term project with many cash inflows and outflows, so the formula to calculate the NPV of the project is as follows [30–32]:

$$NPV = \sum_{t=1}^T \frac{CI(t) - CO(t)}{(1 - i)^t} \quad (5)$$

where NPV is the net present value (\$US). $CI(t)$ is the cash inflows in year t (\$US) including electricity sales, steam sales, ash and slag sales, scrap (iron and

steel) sales and MSW disposal fees. $CO(t)$ is the cash outflows in year t (\$US) including capital costs, operational costs and asset depreciation costs. t is the economic life of the project (years). $i = 8.5\%$ is the weight average cost of capital or the discount rate.

The internal rate of return (IRR) which is the annual rate of growth that an investment is expected to generate, is calculated using the same concept as NPV, except it sets the NPV equal to zero.

$$NPV = \sum_{t=1}^T \frac{(CI(t) - CO(t))}{(1 - IRR)^t} = 0 \quad (6)$$

To evaluate the economic efficiency of the project, we propose a steam sales solution for services for food drying, for humidification purposes, for the pharmaceutical or food and beverage industry, etc. Therefore, we propose the following production scenarios: Scenario 1 (100% steam and 0% electricity), Scenario 2 (70% steam and 30% electricity), Scenario 3 (50% steam and 50% electricity), Scenario 4 (30% steam and 70% electricity) and Scenario 5 (0% steam and 100% electricity). According to current policy and in the Vietnamese market, steam and electricity selling prices for Vietnam Electricity Company are listed in Table 3. This table also presents economic parameters of a project with a capacity of 200 *ton/day*.

Table 3. The economic parameters of project

No.	Symbol	Description	Type	Unit	Value
1	I_0	Initial investment capital	CO	\$US	Scenario
2	i	Medium-term loan interest	CO	%/year	8.5
3	c_o	Operation cost	CO	\$US/year	3,500,000
4	c_d	Depreciation	CO	\$US/year	1,250,000
5	p_e	Electricity price	CI	\$US/kWh	0.1
6	p_s	Steam price	CI	\$US/ton	22
7	p_a	Ash and slag price	CI	\$US/ton	6
8	p_i	Scrap (iron and steel) price	CI	\$US/ton	200
9	p_d	MSW disposal fee	CI	\$US/ton	20

4 Numerical results and Discussion

4.1 Technical solution results of WtE

According to a report by the General Statistics Office, the average population of each district is about 135 thousand people [33]. With the forecast that the possibility of generating solid household waste is 1.6 *kg/cap/day* [34] by 2025, the research team proposes to implement a power plant to generate electricity with a capacity of about 200 *tons/day* by using heat recovery from MSW treatment.

Table 4. The energy content of MSW component by models (dry basic)

Waste component	M1	M2	M3	M4	M5
Organics	14.50	16.54	17.22	16.19	16.57
Plastic and nylon	39.41	38.21	40.07	38.71	37.95
Paper and carton	14.32	16.22	16.71	16.13	16.35
Metal	1.83	1.84	1.77	1.82	1.80
Glass	0.28	0.27	0.17	0.32	0.26
Inert	13.18	12.89	13.46	11.70	11.28
Rubber and leather	30.48	30.86	31.78	30.90	30.70
Tissues	16.34	18.29	18.70	18.18	18.45

Combining data from Table 1 and Table 4, it is possible to estimate the calorific value of MSW with the condition that the moisture content of the waste is from 60% - 80% and is shown in Table 5. In which, H_{na} is the average calorific value, H_{n+} is the highest threshold calorific value and H_{n-} is the lowest threshold calorific value. These calorific values are calculated in MJ/kg . Then, the average calorific values M_{a1} in MJ/kg and M_{a2} in MJ/kg of all models are calculated, where the energy conversion rate is $1MJ = 238.9kcal$.

Table 5. The energy content of non-treated MSW

Model	H_{na}^{60}	H_{n+}^{60}	H_{n-}^{60}	H_{na}^{70}	H_{n+}^{70}	H_{n-}^{70}	H_{na}^{80}	H_{n+}^{80}	H_{n-}^{80}
M1	8.37	11.12	6.04	6.28	8.34	4.53	4.18	5.56	3.02
M2	9.02	11.87	6.59	6.77	8.90	4.94	4.51	5.93	3.30
M3	9.39	12.35	6.86	7.04	9.26	5.15	4.69	6.17	3.43
M4	8.80	11.58	6.41	6.60	8.69	4.81	4.40	5.79	3.21
M5	8.85	11.62	6.47	6.64	8.72	4.85	4.43	5.81	3.24
M_{a1}	9.52	12.55	6.94	7.14	9.41	5.20	4.76	6.27	3.47
M_{a2}	2,274	2,997	1,658	1,706	2,248	1,243	1,137	1,499	829

The results in Table 5 demonstrate that the average energy content in MSW of Vietnam is low i.e. $M_{a1} = 830-1,500 kcal/kg$ or $M_{a2} = 3.47-6.27 MJ/kg$ in case of moisture 80%. This result is also consistent with the report in [34] (i.e. 900-1,200 $kcal/kg$) while the refuse derived fuel production from MSW requires at least 7 MJ/kg . Therefore, the average moisture content of input waste is 70%, which is reasonable for burning waste to generate electricity. The technical solution proposed by the authors in the above section (Fig. 2) has helped solve this problem, as the moisture content of the garbage has been reduced by 30%-40% due to the willingness and drying of the heat recovery controller.

Based on the technical solution to burn waste with a low calorific value, the results show that the system can generate an electricity capacity from 2.15-3.89 MWh . If the specific enthalpy of vaporization is 2775.36 kJ/kg at 170 °C and 7 bar (700 kPa) atmospheric pressure [35], this electrical capacity corresponds to 9.37-16.95 (kJ/kg) saturated steam $W_s(t/h)$ (shown in Table 6). In the next section, we will calculate the economic solution results of the proposed project waste-to-energy.

Table 6. The technical solution results of WtE

Parameter	H_{na}^{60}	H_{n+}^{60}	H_{n-}^{60}	H_{na}^{70}	H_{n+}^{70}	H_{n-}^{70}	H_{na}^{80}	H_{n+}^{80}	H_{n-}^{80}
$m_s(t/h)$	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33
$H_n(MJ/kg)$	9.52	12.55	6.94	7.14	9.41	5.20	4.76	6.27	3.47
$W_i(MJh)$	63.46	83.37	46.26	47.59	62.73	34.69	31.73	41.82	23.13
$W_h(MJh)$	47.59	62.73	34.69	35.70	47.05	26.02	23.80	31.36	17.35
$W_e(MJh)$	14.16	18.66	10.32	10.62	14.00	7.74	7.08	99.33	5.16
$W_e(MWh)$	3.93	5.18	2.87	2.95	3.89	2.15	1.97	2.59	1.43
$W_s(t/h)$	17.15	22.60	12.50	12.86	16.95	9.37	8.57	11.30	6.25

4.2 Economic solution results of WtE

From the results of this technical solution combined with the five proposed production scenarios, we calculate the economic efficiency of each scenario such as average profit before tax (PBT), NPV, IRR, payback time (PP) based on output/input parameters (heat and steam capacity, initial investment capital, number of years of asset depreciation, loan interest rate, cash inflow, cash outflow,...). The average project life cycle is 25 years. We note that the sign (*) means the maximum value.

Table 7. The efficiency of economic solution results of WtE

Scenario	$S1$	$S2$	$S3$	$S4$	$S5$	$S1^*$	$S2^*$	$S3^*$	$S4^*$	$S5^*$
$I_0(\$M)$	8.00	11.20	12.00	12.80	16.00	8.00	11.20	12.00	12.80	16.00
$W_s(t/h)$	12.86	9.00	6.43	3.86	0.00	16.95	11.87	8.48	5.09	0.00
$W_e(MWh)$	0.00	0.49	1.08	1.67	2.55	0.00	0.77	1.54	2.32	3.49
$CI(\$M)$	3.77	3.46	3.44	3.42	3.39	4.45	4.14	4.11	4.08	4.05
$CO(\$M)$	2.28	2.59	2.74	2.89	3.48	2.28	2.59	2.74	2.89	3.48
$PBT(\$M)$	1.49	0.87	0.70	0.53	-0.09	2.18	1.54	1.37	1.20	0.57
$NPV(\$M)$	16.40	11.89	9.96	8.69	4.02	22.64	18.04	16.06	14.73	9.98
$IRR(\%)$	21.79	11.56	8.72	7.42	2.26	29.67	16.91	13.86	12.45	6.60
$PP(year)$	5.5	9.8	11.7	13.1	21	4.1	7.1	8.3	9.2	13.9

The results of calculating the effectiveness of the economic solution of the waste incineration power generation project are shown in Table 7 and Figures 3a-3b. Accordingly, the total energy recovered from waste incineration is taken as an average value at 80% humidity with the value average value ($S1$ to $S5$) and upper threshold value ($S1^*$ to $S5^*$), respectively for the five proposed scenarios. In fact, the system's operational design at the lower threshold value is not considered. The results show that the more the scenario utilizes selling steam, the more effective it is than selling electricity. Specifically, $S1$ has a NPV of 16.4\\$M and an IRR of 21.79% with a payback period of 5.5 *years*, corresponding to 9.96 \\$M, 8.72%, 11.7 *years* for $S3$ and 4.02 \\$M, 2.26% , 21 *years* for $S5$.

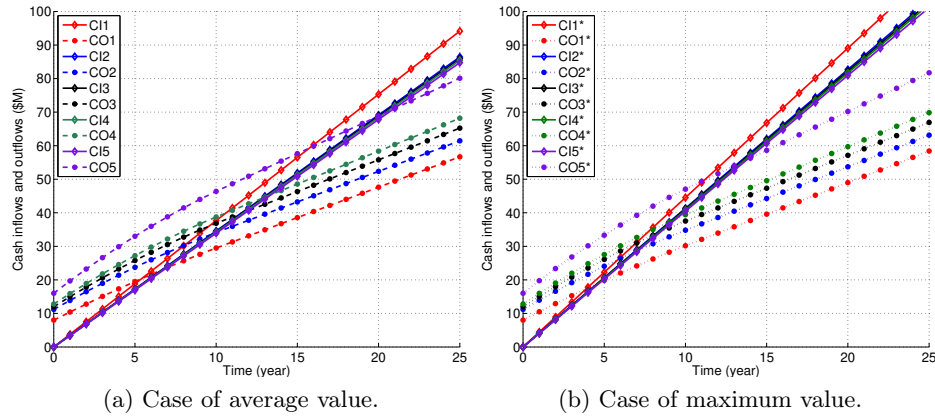


Fig. 3. Representation of economic solution results.

This result is even more surprising with maximum operating capacity. Indeed, $S1^*$ has an NPV of 22.64\$M and an IRR of 29.67% with a payback period of 4.1 years, corresponding to 160.6 \$M, 13.86%, 8.3 years for $S3^*$ and 9.98 \$M, 6.6%, 13.9 years for $S5^*$. Reality shows that steam sales not only depend heavily on customers near the location of the power plant, but also lack stability in output over the contract period. Meanwhile, electricity sales are always more stable and the contracts are longer-term. The final result shows that selling both electricity and steam like Scenario 2 and Scenario 3 is completely feasible. Furthermore, if the capacity is designed and maintained to operate close to the above threshold value, the efficiency will be higher.

5 Conclusion

This article studies the composition of domestic solid waste in Vietnam and evaluates its calorific value to increase the total heat energy recovered. In terms of structure, the average calorific value of MSW in Vietnam is low at 830-1,500 kcal/kg and has a high moisture content of 60%-80%. Therefore, this is not considered a source of raw materials to process waste into energy in developed countries, and the common rate of waste treatment by landfilling is 63%. The authors have proposed technical solutions for wet waste treatment to reduce moisture to 30%-40% to increase specific heat capacity by taking advantage of heat sources that are often released into the environment. Five operating scenarios are proposed as economic solutions to evaluate efficiency through calculating NPV, IRR and payback period. Accordingly, the scenario of both generating electricity and selling steam is the most effective and completely feasible in practice in Vietnam. In a harmonious way, the scenario $S3$ has an NPV of 9.96 \$M, an IRR of 8.72% with a payback period of 11.7 years with the average power, corresponding to 160.6 \$M, 13.86%, 8.3 years for the scenario $S3^*$ with the maximum power.

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