Scenarios for treatment of sewage sludge from municipal wastewater treatment plants in Hanoi towards energy efficiency and resource recovery

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Abstract. Wastewater treatment plants (WWTPs) generate significant amount of sewage sludge (SS). Besides, faecal sludge (FS) generated from popularly existing septic tanks in cities need also adequate treatment. Selection of appropriate sludge treatment options is among most challenging wastewater management issues for fast growing cities. The case study has selected the central part of Hanoi city, with expected population of 2,145,437 persons by 2030, total design capacity of WWTPs 588,300 m³/day, whereas different options of SS and FS management were analysed. The calculation results shown that an energy required for operation of sludge treatment processes in scenarios 2, 3 and 4 could be fully self-sufficient. Besides, with total energy demand for operation of WWTPs was of 311,799 kWh/day, 21.3% (scenario 2), 99.3% (scenario 3) or 71.3% (scenario 4) of demand could be covered by remaining biogas produced from anaerobic co-digestion of SS and FS. A conventional SS treatment process, dewatering by centrifuge and dumping dewatered sludge to the landfill (scenario 1) did not generate any energy but required an energy of 17,371 kWh/day for SS treatment and dumping. Anaerobic co-digestion of SS, FS, other organic fractions, can be a promising sludge management solution aiming at energy efficiency and resource recovery.

1. Introduction
Over the years, along with economic development of the country, Vietnam is facing an increased population as well as the rapid urbanization, leading to the significant pressures for the urban infrastructure and public services as energy supply, water supply and environmental protection.

Research on the characteristics of sewage sludge from WWTPs (WAS) and septic tank sludge (FS) were conducted by IESE, HUCE and Institute of Water Science and Technology (EAWAG), Switzerland from September 2013 to May 2014 showed that FS and WAS had a high concentration of biodegradable organic matters and nutrients, while concentrations of heavy metals such as Ni, Pb and Zn were within the prescriptive limits for agricultural land application [1], [2]. As total nitrogen and ammonium nitrogen (NH₄⁺-N) in FS are usually high, the anaerobic treatment of FS alone is not suitable, due to low C/N ratio [3].
Anaerobic digestion has been widely used as a method to stabilize organic matters in sludge, producing biogas. Anaerobic co-digestion involves simultaneous digestion of a homogenous mixture of two or more substrates and has been promoted very recently in many WWTPs [4]. Applying anaerobic digestion of waste sources can be a potential solution to increase biogas production and reduce the total sludge mass [5]. Several researches have pointed out that anaerobic digestion for stabilization of sludge generated at WWTPs can produce biogas which can be used as fuel for thermal energy and power generation, and by this way part of energy demand in the WWTPs can be met, but the target of energy self-sufficiency hardly achievable [6]. In Vietnam, about 17% of urban wastewater is treated in 45 WWTPs, and the generated sludge is currently dewatered and dumped. Meanwhile, septic tank is a most common domestic wastewater pre-treatment solution in Vietnamese urban areas. Septic tank or faecal sludge (FS) is often dumped directly into the environment, causing serious environmental problems [7]. It is estimated that FS amount in urban centers will be 9,100 tons/day in 2020, and 13,500 tons per day in 2025 [7]. The results of previous study of the team with the batch experiments in laboratory have shown the mesophilic co-fermentation (35°C) of WAS with FS had a potential application [8].

Energy demand in WWTPs is depended upon various factors, including size, design and operation of the plant, the characteristics of wastewater, and other local conditions. This demand varies from 0.2 to 1.5 kWh per cubic metre of treated wastewater [6]. Survey results of 10 WWTPs in the US also showed that with the capacity of WWTPs from 3,780 m³/day to 272,880 m³/day, energy consumption varies between 0.28 and 1.22 kWh/m³ [2]. The energy demand for sludge treatment is used for main purposes such as electricity for stirring in the reactor (0.005 - 0.008 kW/m³ of reactor capacity with the mechanical mixing system), heating stabilization for the methane tank, sludge heating (4,200 J/kg of sludge to increase 1°C) [9], drying digested sludge, etc.

Number of WWTPs in urban areas in Vietnam in growing up. Reducing and reusing sludge from the urban WWTPs, as well as providing sludge dumping landfill areas have become an urgent issue. Anaerobic digestion of sludge is considered among feasible options. Besides, sludge drying and incineration are among options being considered. In order to find out a promising option among those, the Hanoi urban area in the south of the Red river has been selected as a case study.

2. Methods

2.1. Current status and future plan of WWTPs in the study area

The area selected for study was the central urban of Hanoi in the south of the Red river, covering To Lich river basin and part of Nhue river left-bank basin, with the total area of 10,863.5ha and approximately 2,145,437 populations [10]. According to the master plan for Hanoi city’s drainage to 2030, there will be 7 WWTPs in the study area including Yen So, Bay Mau, Truc Bach, Ho Tay, Yen Xa, Kim Lien and Phu Do, respectively collecting and treating wastewater for 5 basins are S1, Truc Bach, West Lake, S2 and S3 (Figure 1). S1 basin is bordered by the North of Ba Dinh district, the South of Thanh Tri district, the West of Le Duan street, and the East of Red River dike. S2 and S3 basins belong to the West of the old Hanoi city, the North borders with Tay Ho district, the South borders with 70 road, the West borders with Nhue river, the East borders with the axis of Le Duan - Giai Phong street.

Kim Lien and Truc Bach WWTPs’ capacity is 3,700 m³/day and 2,300 m³/day, respectively, Yen So WWTP treatment capacity is 200,000 m³/day, Ho Tay and Bay Mau WWTPs treatment capacity are 15,000 m³/day and 13,300 m³/day, respectively. The drainage systems of the S1, S2 and S3 basins to 2030 are combined sewage system, the capacity of the Yen Xa and Phu Do WWTPs proposed in the adjustment of the S2 and S3 basin drainage plan is 270,000 m³/day and 84,000 m³/day. All WWTPs will be built with combined sewerage system, applying activated sludge treatment methods.

At present (called scenario 1), the generated sludge of WWTPs is dewatered and dumped at landfills as illustrated in Figure 2. Only the Yen So WWTP, with capacity of 200,000 m³/day, has been designed with anaerobic digesters for sludge stabilization. Biogas collected is intended to be sent to
flare for burning out.

Yen So sludge disposal site has the area of 3.3 ha with capacity of 8,000 tons/month, operated by Hanoi Sewerage and Drainage Company. Yen My disposal site has the area of 65 ha, receiving dredged sludge from the drainage system.

**Figure 1.** Location of existing and future WWTPs in Hanoi.

**Scenario 1: Sludge generated of WWTPs is dewatered and dumped at landfills**

Primary and secondary sludge

\[ W = 99.2\% - 99.5\% \]

Sludge Thickening

\[ W = 95\% - 97.5\% \]

Thickened sludge tank

\[ W = 80\% \]

Centrifugal Dewatering

Landfills

**Figure 2.** Scheme of sludge treatment at WWTPs in Hanoi studied area (Scenario 1).

Hanoi city has produced a Waste Management Master Plan to 2030 and a vision for 2050. According to this Master Plan, municipal waste produced in Hanoi is reclaimed in Nam Son Waste Treatment Complex [11]. Currently, URENCO is operating 6 waste landfill sites in Hanoi, and is expected to run out of landfill sites in Hanoi in the next few years. Land acquisition for new landfill sites is not feasible, so the new landfills are still in the planning and it is difficult to expand the landfills. Septic tank sludge collection from households is mostly hired by private enterprises.
However, these private enterprises do not own their own sludge treatment plants or disposal sites. Number of private emptiers are still illegally dumping septage to drains, sewers, ponds or open land. At present, most of WWTPs are operating under design capacity because of a limited drainage and sewerage connection while the influent concentrations are relatively lower than the design values. Assumptions were made for the influent parameters of WWTPs for the scenario calculations.

2.2. Sludge treatment scenarios for the study area
In addition to scenario 1, three scenarios were proposed for sludge treatment: centrifugal dewatering + thermal drying + incineration (scenario 2); mesophilic anaerobic co-digestion (scenario 3), and mesophilic anaerobic co-digestion + thermal drying + incineration (scenario 4).

**Scenario 2: Dewatered sludge from WWTPs is treated by thermal drying and incineration at the centralized sludge treatment plant**

**Figure 3.** Scheme of sludge treatment in Scenario 2.

In scenario 2 (Figure 3), the dewatered sludge from WWTPs with about 80% moisture content was transported to the centralized sludge treatment plant for drying and incineration. The location was Yen My landfill, Hanoi city. The dewatered sludge was dried by heat to the water content of about 40%, and then incinerated. The ashes were reused to make construction materials. The heat recovered from incineration will be utilized for the sludge drying process.

**Scenario 3: Combined treatment of the thickened WAS from WWTPs and FS by mesophilic anaerobic digestion, centrifugal dewatering and composting**

**Figure 4.** Scheme of sludge treatment in Scenario 3.

In scenario 3 (Figure 4), the thickened sludge from WWTPs (WAS) with moisture content range 95% to 97.5% was co-treated with FS by mesophilic anaerobic digestion (35°C) at the centralized sludge treatment plant located in Yen My landfill. FS with about 90% moisture content was collected and transported to the centralized sludge treatment plant. WAS and FS were mixed and heated before being pumped to the anaerobic digester. The digested sludge with 95% moisture was dewatered to 80% moisture before being transported composting at Cau Dien composting plant. The liquid phase separated from the sludge concentration and sludge dewatering processes was circulated and treated.
with wastewater at WWTPs. Biogas generated from anaerobic digestion was collected and stored in gas tanks. Biogas was used as fuel for Combined Heat and Power (CHP) generation system, as the source of energy (heat, electricity) for plants operation.

**Scenario 4: Combined treatment of the thickened WAS from WWTPs and FS by mesophilic anaerobic co-digestion, centrifugal dewatering, thermal drying and incineration**

![Diagram of sludge treatment in Scenario 4](image)

**Figure 5.** Scheme of sludge treatment in Scenario 4.

In scenario 4 (Figure 5), the digested sludge was dewatered to 80% moisture, then dried to the moisture content of about 40% before incineration. The ash was utilized to make construction materials. Collecting, transporting FS and WAS as well as the use of biogas generated was kept the same as scenario 3. The heat gained from the incineration process was combined with the heat generated from biogas for the sludge treatment system.

2.3. *Calculation of energy demand in scenarios*

The input parameters of WWTPs were given in Table 1. The characteristics of influent wastewater of Kim Lien, Truc Bach and Yen So WWTPs were showed in Table 2. Ho Tay and Bay Mau WWTPs have been operated that the parameters for calculation were the design parameters. Yen Xa and Phu Do WWTPs are under construction, the parameters in the influent wastewater to WWTPs were based on the design data.

**Table 1.** Urban wastewater treatment plants in the study area [10].

| No. | Wastewater Treatment Plant | Collection area (ha) | Service population until 2030 (people) | Capacity of WWTPs to 2030 (m³/day) |
|-----|---------------------------|----------------------|---------------------------------------|-----------------------------------|
| 1   | Yen So                    | 3,006.4              | 474,000                               | 200,000                           |
| 2   | Bay Mau                   | 217.5                | 41,200                                | 13,300                            |
| 3   | Truc Bach                 | 38.6                 | 9,541                                 | 2,300                             |
| 4   | Ho Tay                    | 180.0                | 301,000                               | 15,000                            |
| 5   | Yen Xa                    | 4,902.1              | 1,080,000                             | 270,000                           |
| 6   | Kim Lien                  | 33.9                 | 15,696                                | 3,700                             |
| 7   | Phu Do                    | 2,485.0              | 224,000                               | 84,000                            |
|     | Total                     | 10,863.5             | 2,145,437                             | 588,300                           |
Table 2. Wastewater quality of existing WWTPs in Hanoi [12].

| Parameters          | Unit | Truc Bach and Kim Lien | Yen So |
|---------------------|------|------------------------|--------|
|                     |      | Design Influent | Actual Influent | Design Effluent | Design Influent | Actual Influent | Design Effluent |
| BOD₅                | mg/L | 150               | 94               | 20              | 100 - 250      | 50               | 10-20            |
| COD                 | mg/L | 225               | 189              | 35              | 200 - 500      | 132              | -                |
| TSS                 | mg/L | 180               | 86               | 20              | 120 - 300      | 71               | 50               |
| Total Nitrogen      | mg/L | 40                | 44               | 15              | 20 - 40        | 34               | 10               |
| Total Phosphorous   | mg/L | 5                 | 18               | 1               | 4              | 28               | -                |

The quantity of FS generated in the study area was showed in Table 3.

Table 3. The quantity of faecal sludge (FS) in the study area.

| Parameters                        | Formula - Symbol | Unit        | Values   | References |
|-----------------------------------|------------------|-------------|----------|------------|
| Population calculated             | Nₙ               | Person      | 2,145,437.0 | [10]       |
| Site area                         | Sₙ               | ha          | 10,863.5  | [10]       |
| Number of users per household     | Nₙᵢ             | person/household | 4.3       | [14]       |
| Number of households in study area| H = Nₙ / Nₙᵢ    | household   | 498,939.0 |            |
| Number of households to be emptied FS per day (3 years per 1 time for desludging) | Hₙ = H/(3*365) | household/day | 456.0     |            |
| FS volume of a household          | Wₜₜ             | m³/household | 1.5       | [14]       |
| Total volume of FS generated per 1 day | Wₚₜ = Hₙ * Wₜₜ | m³/day      | 683.5     |            |
| The density of FS                 | Sₚ             | t/m³        | 1.02      | [1]        |
| Total amount of FS generated per 1 day | Bₚₜ = Wₚₜ * Sₚ | t/day       | 697.1     |            |
| Moisture content of FS            | Pₚ             | %           | 90.0      | [1]        |

Energy demand in sludge treatment plants include electricity for sludge pumps, stirring, pumped recirculation and the thermal energy was provided for the processes of anaerobic digestion, thermal drying and incineration sludge. Heat demand of the anaerobic digester including heating was required to raise the feed sludge to the operating temperature of the digester (35°C) and to compensate for heat loss through the walls, floor, and roof of the digester. [9], [13]

3. Results and discussions

3.1. The amount of sludge to be treated in the study area

The quantity of generated sludge from the wastewater treatment processes in WWTPs was calculated and summarized in Table 4.
According to Table 3, the volume of FS generated was 683.5 m$^3$/day and VS average concentration of FS is 20.1 g/L [1]. According to Table 4, the total volume of the thickened sludge from WWTPs was 3,731 m$^3$/day and VS average concentration was 28.9 g/L [2]. The VS amount of FS was 11.3% of the total VS amount of combined FS and WAS. On the other hand, the results of the batch experiments in laboratory to assess the ability of mesophilic fermentation of WAS with FS shown that co-digestion of FS and WAS at different mixing ratios from 0% FS to 50% FS (by %VS amount of FS in mixture of FS and WAS) provided from 269 NmL to 295 NmL CH$_4$ per gram of fed substrate VS; methane yields ranged from 63.8% to 75.6% [8]. This VS amount ratio of FS and WAS mixture was relatively consistent with the mixing ratio of FS and WAS in the batch experiments. The values of methane yield show promising sludge-to-energy option with anaerobic co-digestion of FS and WAS.

The generated sludge amount of Yen So WWTP in Table 3 was calculated with the actual influent concentration BOD = 50 mg/L and TSS = 71 mg/L [12]. Table 5 showed the amount of sludge generated after the SBR tank when the actual influent concentration was approximately 24.6% of the generated sludge mass with the maximum influent concentration and 7.5% of the generated sludge mass with the minimum influent concentration. Currently, sludge treatment facilities at Yen So WWTP are operating under design capacity. If FS is treated with the sludge of Yen So WWTP, it will increase the efficiency of sludge treatment facilities, and the amount of recovered biogas will increase, the energy (electricity, heat) will be generated from biogas increase.

### Table 4. Sludge generated at WWTPs in the study area.

| WWTPs (Treatment Technology) | The quantity of generated sludge of the treatment process |
|------------------------------|---------------------------------------------------------|
|                              | Unit | Primary sludge | Secondary sludge/SBR | Primary sludge + Secondary sludge/SBR | Thickened sludge | Digested sludge | Dewatered sludge |
|------------------------------|------|----------------|----------------------|---------------------------------------|-----------------|----------------|-----------------|
| Kim Lien (A2O)               | tons/day | 7.96 | 16.81 | 24.77 | 11.74 | 1.47 |
|                             | m$^3$/day | 7.80 | 16.73 | 24.53 | 11.69 | 1.41 |
|                             | Moisture, % | 98.00 | 99.20 | 98.80 | 97.50 | 80.00 |
| Truc Bach (A2O)             | tons/day | 4.95 | 10.45 | 15.40 | 7.30 | 0.91 |
|                             | m$^3$/day | 4.85 | 10.40 | 15.25 | 7.26 | 0.88 |
|                             | Moisture, % | 98.00 | 99.20 | 98.80 | 97.50 | 80.00 |
| Yen So (SBR)                | tons/day | 589.5 | 589.5 | 58.95 | 32.43 | 8.11 |
|                             | m$^3$/day | 586.6 | 586.6 | 58.66 | 32.26 | 7.78 |
|                             | Moisture, % | 99.50 | 99.50 | 95.00 | 95.00 | 80.00 |
| Bay Mau (CAS)               | tons/day | 34.41 | 191.90 | 226.31 | 48.25 | 9.65 |
|                             | m$^3$/day | 33.74 | 190.95 | 224.68 | 47.86 | 9.26 |
|                             | Moisture, % | 99.00 | 99.50 | 95.00 | 95.00 | 80.00 |
| Ho Tay (SBR)                | tons/day | 197.98 | 197.99 | 56.57 | 9.90 |
|                             | m$^3$/day | 197.00 | 197.00 | 56.18 | 9.50 |
|                             | Moisture, % | 99.00 | 99.00 | 95.00 | 96.50 | 80.00 |
| Phu Do (SBR)                | tons/day | 987.81 | 987.81 | 329.27 | 49.39 |
|                             | m$^3$/day | 982.90 | 982.90 | 327.32 | 47.42 |
|                             | Moisture, % | 99.00 | 99.00 | 97.00 | 97.00 | 80.00 |
| Yen Xa (CAS)                | tons/day | 475.07 | 2770.20 | 3245.27 | 770.46 |
|                             | m$^3$/day | 465.75 | 2756.42 | 3222.17 | 739.64 |
|                             | Moisture, % | 95.00 | 95.00 | 95.00 | 80.00 |
Table 5. The amount of generated sludge of Yen So WWTP.

| Unit process                        | Maximum values TSS = 300 mg/L, BOD₅ = 250 mg/L | Minimum values TSS = 120 mg/L, BOD₅ = 250 mg/L | Actual values TSS = 71 mg/L, BOD₅ = 50 mg/L |
|-------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Sequencing batch reactor (SBR)      | 7,791.0                                       | 2,385                                         | 587.0                                         |
| Centrifugal thickening              | 779.1                                         | 238.5                                         | 58.7                                          |
| Anaerobic digester                 | 428.5                                         | 131.2                                         | 32.3                                          |
| Centrifugal dewatering             | 103.4                                         | 31.6                                          | 7.8                                           |

3.2. Energy for sludge treatment

The energy demand and generated energy of the scenarios were shown in Table 6.

Table 6. Comparison of sludge treatment energy for the study area according to treatment scenarios.

| No | Parameters                                                                 | Unit                     | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|----|---------------------------------------------------------------------------|--------------------------|------------|------------|------------|------------|
| 1  | Sludge mass of WWTPs treated                                              | tons/day                 | 896.6      | 896.6      | 3,757.4    | 3,757.4    |
| 2  | Amount of FS generated                                                    | tons/day                 | -          | -          | 697.1      | 697.1      |
| 3  | Total amount of FS and WAS sludge mixture                                 | tons/day                 | 896.6      | 896.6      | 4,454.5    | 4,454.5    |
| 4  | Total energy generation from CHP                                          | kWh/day                  | -          | -          | 371,536    | 371,536    |
| 4.1| Electricity generation from CHP                                          | kWh/day                  | -          | -          | 144,486    | 144,486    |
| 4.2| Heat generation from CHP                                                  | kWh/day                  | -          | -          | 227,050    | 227,050    |
| 5  | Energy demand for pumping, stirring, heat exchanger, ....                  | kWh/day                  | -          | 428        | 27,342     | 27,342     |
| 6  | Energy demand for liquor circulation                                      | kWh/day                  | -          | 11         | 26         | 32         |
| 7  | Energy demand for thermal drying                                          | kWh/day                  | 0          | 747        | 0          | 547        |
| 8  | Energy demand for incineration                                            | kWh/day                  | 0          | 210        | 0          | 154,089    |
| 9  | Total energy demand for transporting sludge to treatment                  | kWh/day                  | 17,371     | 4,817      | 34,464     | 20,284     |
| 10 | Energy generation from incineration                                       | kWh/day                  | 0          | 72,576     | 0          | 53,141     |
| 11 | Total energy demand for sludge treatment                                  | kWh/day                  | 17,371     | 6,213      | 61,832     | 202,294    |
| 12 | Total energy generated from sludge treatment                              | kWh/day                  | 0          | 72,576     | 371,536    | 424,677    |
| 13 | Energy is collected from 1 ton of sludge treated                          | kWh/ton                  | 0          | 80.9       | 83.4       | 95.3       |
| 14 | Surplus energy after sludge treatment processes                           | kWh/day                  | -17,371    | 66,362     | 309,705    | 222,383    |
| 15 | Energy demand for WWTPs with a total capacity 588,300 m³/day              | kWh/day                  | 311,799    | 311,799    | 311,799    | 311,799    |
| 16 | Excess energy for the Hanoi city                                          | kWh/day                  | -329,170   | -245,437   | -2,094     | -89,416    |
| 17 | Energy recovery fraction                                                  | %                        | 0          | 21.3       | 99.3       | 71.3       |

In scenario 2, the dewatered sludge of WWTPs with about 80% moisture content was transported to the centralized sludge treatment plant to dry and incinerate. Combining the thermal drying process
with the incineration of sludge may significantly reduce the energy expenditures for thermal drying. Incineration reduces sludge volume dramatically. The heat recovered from incineration was approximately 72,576 kWh per day that ensuring the energy demand for the sludge treatment plant. Meanwhile, the total energy demand for sludge treatment was 6,213 kWh/day. The surplus energy form scenario 2 was 66,362 kWh/day. Considering a WWTP with a capacity of 588,300 m$^3$/day, approximately 0.53 kWh of energy was used for each 1 m$^3$ of wastewater treated [9], the energy required to provide for the wastewater treatment was 311,799 kWh/day. The surplus energy could supply 21.3% of the energy required for WWTPs.

In scenario 3, with a biogas production as 88,702 m$^3$/day from treatment of 4,454.5 tons of FS and WAS sludge mixture per day, energy generation from CHP was gained as 371,536 kWh/day, with 144,486 kWh power and 227,050 kWh heat per day. The energy consumption for pumping, mixing, heating sludge, etc. was 27,342 kWh/day; for liquor recycling was 26 kWh/day and total energy transporting sludge was 34,464 kWh/day. Meanwhile, scenario 4, the total energy gained from sludge mixture treatment processes included the energy from the biogas produced from digestion plus the energy gained from the incineration of sludge was higher than the energy gained of scenario 3 as 14.3%. The total energy demand for the sludge treatment process of scenario 3 was lower than the energy consumption of scenario 4 as 69.4%. Thus, the surplus energy supplied to the WWTPs and other purpose of scenario 3 and scenario 4 were 309,705 kWh/day and 222,383 kWh/day, respectively. Considering a WWTP with a capacity of 588,300 m$^3$/day, approximately 0.53 kWh of energy was used for each 1 m$^3$ of wastewater treated [9], the energy required to provide for the wastewater treatment was 311,799 kWh/day. The surplus energy of scenario 3 and scenario 4 could supply 99.3% and 71.3% of the energy required for WWTPs, respectively.

Meanwhile, scenario 1 not only required the landfill sites but also required the energy for sludge transporting from WWTPs to the landfill as 17,371 kWh/day. Including the energy provided for the WWTPs in the study area, the total energy demand for scenario 1 was 329,170 kWh/day.

Compared to the traditional sludge treatment technology, the proposed sludge treatment scenarios demonstrate the benefits of mesophilic anaerobic digestion such as reducing the landfill site area; reusing the digested sludge to improve soil properties and make fertilizer; generation biogas to recovery energy.

4. Conclusions and recommendations
The analysis and comparison between 4 scenarios of sludge treatment from WWTPs in the central urban area of Hanoi have shown the benefits in energy aspect of mesophilic anaerobic co-digestion by producing a large amount of biogas. The thickened sludge from WWTPs was co-treated with FS by mesophilic anaerobic digestion (35°C) at the centralized sludge treatment plant, the biogas production was 88,702 m$^3$ per day, energy generation from CHP was gained as 371,536 kWh/day, with 144,486 kW power and 227,050 kWh heat per day. The recovered energy in this solution can self-supply 21.3%, 99.3% and 71.3% of the energy required for treatment wastewater in WWTPs with the capacity of 588,300 m$^3$/day in the scenarios 2, 3 and 4, respectively.

In the near future, the drainage system in the existing urban areas in Vietnam will remain a combined system, whereas septic tanks will still exist [14]. The urban development planning issues will need to be suitable. In order to ensure self-sufficient energy for the treatment complex from recovered energy, the solutions recommended are: to 1) co-treat sewage sludge with faecal sludge and organic solid waste for enhancement of biogas production; and 2) to have pre-treatment of sludge and other wastes before anaerobic digestion for the system stabilization and maximum biogas generation [8]. In addition, it is necessary to conduct further benefit-cost analyses to evaluate the potential practical application of the sludge treatment processes.

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