Primary sedimentation as a sustainability measure for newly built municipal wastewater treatment plants: too expensive?

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ABSTRACT

A study was performed based on the design of a new wastewater treatment plant (WWTP) to be built in Weesp, The Netherlands (about 46,000 Population Equivalents (PE)). The conventional activated sludge plant was considered among the alternatives, with and without primary sedimentation. This pre-treatment technique is considered a sustainability measure as it improves the energy balance of the WWTP. However, at the same time, the question arose about the cost effectiveness of this measure. The scope of the study was to assess whether other sustainability measures (like solar panels) can realise the same level of sustainability with lower costs. The outcome of the study indeed shows that, for a new WWTP, it is considerably cheaper to avoid primary sedimentation and focus on other measures like solar panels instead. This appeared not only to be the case for the scale of WWTP Weesp, but also for WWTPs with capacities higher than 500,000 PE. For existing WWTPs with primary sedimentation, the choice can be different as customisation is necessary.

Key words | pre-treatment, primary sedimentation, sustainability, wastewater

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INTRODUCTION

In the Netherlands, wastewater treatment and sustainability are strictly correlated: 67% of the Dutch water sector's global warming potential (GWP) is due to wastewater (Frijns *et al.* 2009). This is due to the fact that purifying wastewater entails the implementation of treatment techniques that have a high energy demand.

Several efforts have been made in the Netherlands to render the water sector more efficient in terms of energy use and production of sustainable energy, and therefore reduction of greenhouse gas (GHG) emissions (Frijns *et al.* 2013). Waternet, the public water utility of Amsterdam, has the ambition to become carbon neutral by 2020 (Waternet n.d.). For this reason, during the design of a new WWTP in the municipality of Weesp, an extensive study was conducted that took into account not only the financial aspects but also the carbon footprint of several plant configurations.

Among these configurations, two types of the typical activated sludge treatment plant (commonly referred to as University of Cape Town (UCT) process) were considered (Figure 1), one of which implemented primary sedimentation and one of which did not, and where the screened sewage water is fed directly into the biological reactor.

Primary sedimentation is normally applied to medium and large wastewater treatment plants (WWTPs) (Gori *et al.* 2013). It is normally implemented in circular or rectangular tanks (usually concrete) and 50 to 70% of the suspended solids can be removed (Metcalf & Eddy 2003). Since less suspended solids and biodegradable organic matter has to be treated in the biological reactor(s), the aeration tank volume and the aeration requirements are smaller. Moreover, primary sludge (which settles in primary sedimentation tanks) has a high biomethanation potential (van Loosdrecht *et al.* 1997; Gavala *et al.* 2003; Gori *et al.* 2013). Essentially, the overall benefit is a better energy balance of the WWTP, therefore primary sedimentation is considered a sustainability measure.

A disadvantage of primary sedimentation is that the concrete tanks, the mechanical equipment, thickeners and sludge pumps are costly, and so is their maintenance.

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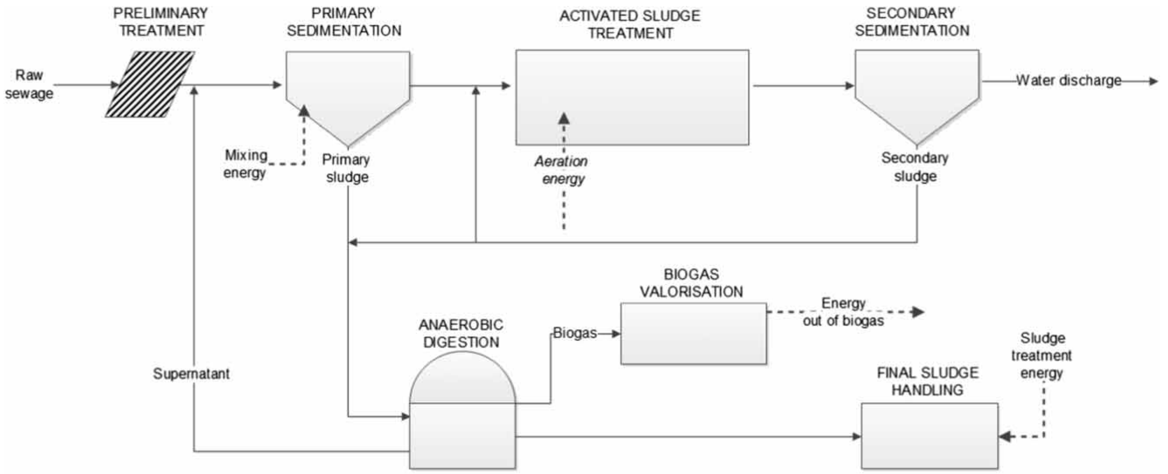

Figure 1 | Typical Dutch UCT treatment scheme with the priority energy flows.

While in the past the advantages outweighed the disadvantages, nowadays new developments and opportunities force us to make new choices. First of all, the aeration equipment nowadays is more efficient than in the past. Secondly, other sustainability and energy producing methods (i.e. wind turbines or solar panels) are much cheaper today. Their share in the (overall) energy mix is greater which makes the energy from the grid both cheaper and 'greener' (Devabhaktuni *et al.* 2013).

The scope of this study is to assess whether the costs associated with the implementation of primary sedimentation can compete with other sustainability and energy production measures, such as solar panels.

METHODS

The new WWTP of Weesp will have a capacity of 46,000 Population Equivalents (PE) and it implements biological phosphorus removal. The thickened sludge is transported to a sludge treatment facility at the WWTP Amsterdam-West at a distance of 33 km. For this study, two of the configurations were considered: UCT without primary sedimentation (herein called configuration 1) and UCT with primary sedimentation (configuration 2). Figure 2 represents a simplified scheme of the two configurations. The influent characteristics and main plant design parameters were obtained from the static HSA Model (HochSchulGruppenAnsatz, STOWA

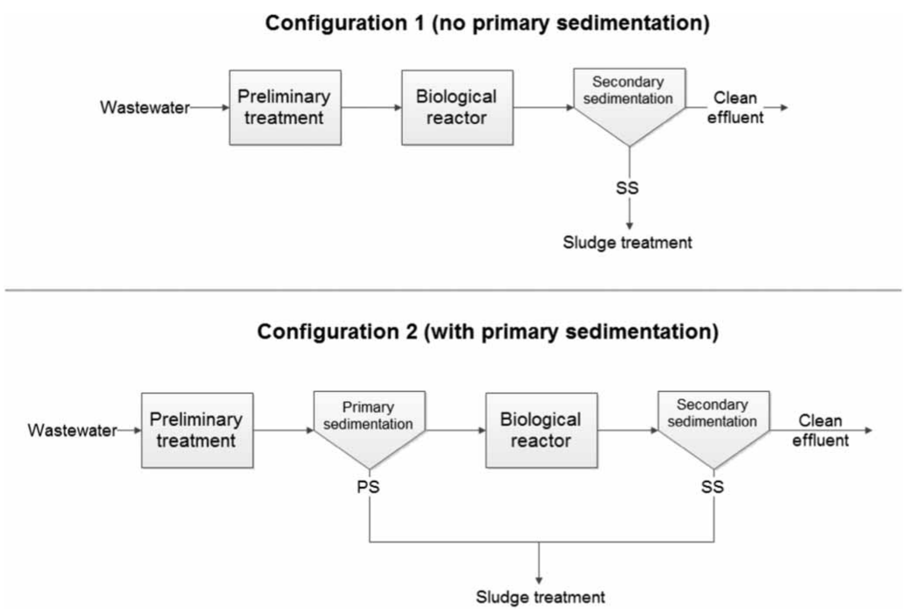

Figure 2 | Scheme of configuration 1 and configuration 2.

2007; van Nieuwenhuijzen *et al.* 2008). Table 1 presents the influent characteristics and main design parameters for both configurations.

The investment costs of the two configurations of the Weesp plant, as well as the required amount of concrete, were calculated through the use of a standard system for cost estimates (CROW). The cost assumptions for the calculation of the yearly cost are specified in Table 2.

The total energy demands of both configurations were calculated from the gross energy demand of the technical processes and the energy production from the biogas that is produced from the sludge at the sludge treatment plant (WWTP Amsterdam-West).

For both the configurations the yearly CO_2 footprint was calculated based on the net energy demand, the reinforced concrete used for construction, the chemicals used and the sludge transport. The CO_2 equivalent factors were retrieved from the Ecoinvent database (Wernet *et al.* 2016). Direct CO_2, CH_4 and N_2O emissions from the biological process were disregarded.

The cost of energy production with subsidised solar panels is 0.033 €/kWh (0.040 with VAT), while the cost for non-subsidised panels is 0.125 €/kWh (0.151 with VAT) (Lensink & Cleijne 2016). Subsequently, the 'price of sustainability' can be calculated by going through the CO_2 reduction allowed for by solar panels (found as an avoided emission caused by the use of grey energy). However, this is only applicable if the solar panels are considered to be carbon neutral. This is not the case, but on average the CO_2 footprint of solar panels is much lower than that of fossil fuels (Nugent & Sovacool 2014). Thus, the price of

Table 1 | Main influent characteristics and design parameters

Parameter	Unit	Configuration 1	Configuration 2
Load (150 g TOD)	PE	46,000	
Max flow rate	m^3/h	1,800	
DWF flow rate	m^3/h	652	
Pre sedimentation tank surface	m^2		475
Primary sludge production	kg ds/d		2,674
BOD/N before the activated sludge	–	4.4	3.3
Design temperature	°C	10	10
Sludge load	kg BOD/kg ds/d	0.067	0.075
Volume anaerobic tanks	m^3	1,304	
Volume anoxic tanks	m^3	836	1,024
Volume aerobic tanks	m^3	6,480	3,314
Secondary sludge production	kg ds/d	2,426	1,424
Aeration capacity	kg O_2/h	439	364
Effluent nitrogen total standard yearly average	mg/L	10	10

Table 2 | Yearly costs calculations specifics

Useful life for civil engineering works	30	years
Useful life for mechanical components	15	years
Useful life for electrical components	15	years
Useful life for process automation	7	years
Factor for foundation costs (*)	1.78	
Interest rate for capital costs	3.75%	
Energy costs	0.10	€ per kWh, incl. VAT
Personnel costs	100,000	€ per fte per year
Sludge handling costs (no prim. sed.) (secondary sludge)	492	€ per ton ds dewatering + processing + sludge transport, incl. VAT
Sludge handling costs (with prim. sed.) (primary sludge)	432	€ per ton ds dewatering + processing + sludge transport, incl. VAT
Sludge handling costs (with prim. sed.) (secondary sludge)	499	€ per ton ds dewatering + processing + sludge transport, incl. VAT
$FeCl_3$ (40% solution)	120	€ per ton excl. VAT
$FeClSO_4$ (41%)	124	€ per ton excl. VAT (for orders >10 ton)
$AlCl_3$ (30,7%)	125	€ per ton excl. VAT
Polyelectrolytes (42%)	1,850	€ per ton excl. VAT
Maintenance costs		
Civil works/constructions	0.5	% of construction costs
Mechanical components	2	% of construction costs
Electrotechnical	4	% of construction costs
Process automation	10	% of construction costs
Maintenance devices/ general services	10	% of construction costs/ general services

*Incompleteness surcharge, insurance, taxes, permits, utilities, land survey, fees, installation costs, consultancy costs – and supervision, interest during construction, contingencies and VAT.

sustainability for subsidised solar panels is 0.059 €/kgCO_2; for unsubsidised solar panels it is 0.225 €/kgCO_2.

RESULTS

Table 3 shows the costs for both configurations. Table 4 shows the results of the calculation of the CO_2 footprints.

Detailed tables with cost components and energy use can be found in Giorgi (2017).

As expected, configuration 1 is cheaper but has a higher CO_2 footprint (it is less sustainable). Therefore, a 'price of sustainability' was calculated by dividing the difference in yearly costs between the two configurations and the difference in yearly footprints. This amounted to 1.40 €/kg CO_2. By dividing the difference in yearly costs by the difference in yearly energy demand, this is 0.83 €/kWh.

When comparing these calculated key figures with the key figures of solar energy (0.225 €/kgCO_2 and 0.125 €/kWh (non-subsidised)) they appear to be very high.

This means that it would be much cheaper to be equally sustainable by not applying primary sedimentation, but matching the energy demand difference with solar panels.

To get an indication of the economy of scale the same calculations were performed for a plant designed for 500,000 PE, with the same characteristics. The cost estimations of the 500,000 PE plant were made by linear and square root upscaling. The investment costs of the several civil and mechanical/electrical parts of the WWTP's were estimated individually. Upscale units are cubic metres per hour, cubic metres or square metres depending on the facility (e.g. the secondary clarifiers are scaled with square metres, civil from the cost sheet (linear) and mechanical/electrical squared from the capacity (surface 500,000 ie/surface 46,000 ie)). The yearly costs were calculated with the cost rates as the 46,000 PE WWTP, shown in Table 2 (see Giorgi 2017). The results are summarised in Table 5.

The values of the key figures were indeed reduced, but are still high compared with the key figures for solar panels. Figure 3 shows the results in a graph with the relation between the plants' scale and the key figures for energy cost and of CO_2 footprint for primary sedimentation and solar panels.

An exponential trend line was hypothesised, because when building a treatment plant the investment costs versus the plant capacity exponentially decrease due to the principle of the economy of scale. This line flattens due to the fact that, at bigger scales, more separate unit operations will be built (because of the constraints on the maximum diameter), therefore the upscaling is not squared anymore but linear. Gratziou *et al.* (2006) demonstrated that this is the case for several types of wastewater treatment systems. Since the costs of energy production and CO_2 reduction are based on the yearly costs, that are in turn proportional to the investment costs, the trend line is expected to assume an exponentially decreasing shape. Therefore, as it can be seen from Figure 3, primary sedimentation is not expected to compete with solar panel at any realistic scale for the Netherlands.

Table 3 | Investment and yearly costs and yearly net energy demand for the two configurations

Parameter	Configuration 1	Configuration 2
Investment costs	€ 22,933,000	€ 26,096,000
Yearly costs	€ 2,593,000	€ 2,942,000
Net energy demand*	705,695 kWh/y	274,621 kWh/y

*Net energy demand, gross energy demand of all equipment minus sustainable production from biogas, sludge incineration, etc. (see Giorgi 2017).

Table 4 | CO_2 footprints of the two configurations

Parameter	Factor	Unit	Configuration 1	Configuration 2
Energy in total	0.67	kg CO_2/kWh	829,798	794,273
Energie out total	−0.67	kg CO_2/kWh	−355,994	−609,893
Energy (net)	0.67	kg CO_2/kWh	473,804	184,380
Reinforced concrete	0.057	kg CO_2/kg concrete	11,746	11,853
Polyelectrolytes (PE)	2.13	kg CO_2/kg PE active	22,964	21,992
$AlCl_3$	0.537	kg CO_2/kg $AlCl_3$	0	14,976
Sludge transport	0.115	kg CO_2/ton.km	54,276	73,914
CO_2 footprint		kg CO_2/year	**562,789**	**307,116**

Table 5 | Differences in costs, energy consumption and CO_2 footprint between the two configurations for a capacity of 500,000 PE

Parameter	Unit	Value
Additional investment costs	€	18,247,000
Additional yearly costs	€	2,566,000
Delta energy use	kWh/y	4,686,000
Delta CO_2 production	$kgCO_2$/y	2,781,000
Euros per kWh saved	€/kWh	0.55
Euros per $kgCO_2$ saved	€/$kgCO_2$	0.92

A sensitivity analysis was performed both on the calculations for the small scale plant and for the larger scale plant. It was performed in such a way that the considered factors were tuned in the direction in which they could improve the primary sedimentation's business case. Even when all the factors were tuned at the same time, primary sedimentation still was more expensive than solar panels, for both the scales. For more details about the sensitivity analysis, the reader is referred to Giorgi (2017).

DISCUSSION

An important remark to mention here is that the results are specific for the situation in Weesp in the Netherlands and they cannot be taken out of their context. Both wet weather flow (WWF) and dry weather flow (DWF) can be different for other regions depending on water consumption behaviour, precipitation regimes, etc., resulting in smaller sedimentation tanks, changing in turn the financial aspects connected to the implementation of primary sedimentation. Moreover, the outcome of the calculations will change accordingly with organic loads, characteristics of the sludge, the prices, etc.

Therefore, to evaluate the application of a primary sedimentation for a completely different WWTP in another country, a customised cost assessment should be performed. Nonetheless, the results do give an indication of the fact that it is fairly likely that constructing primary sedimentation for a new WWTP is now an obsolete process to apply (in terms of energy and CO_2 reduction costs).

There are two pros to primary sedimentation that have not been considered in this study: grease and sand removal. However, the savings represent few percentage points of the

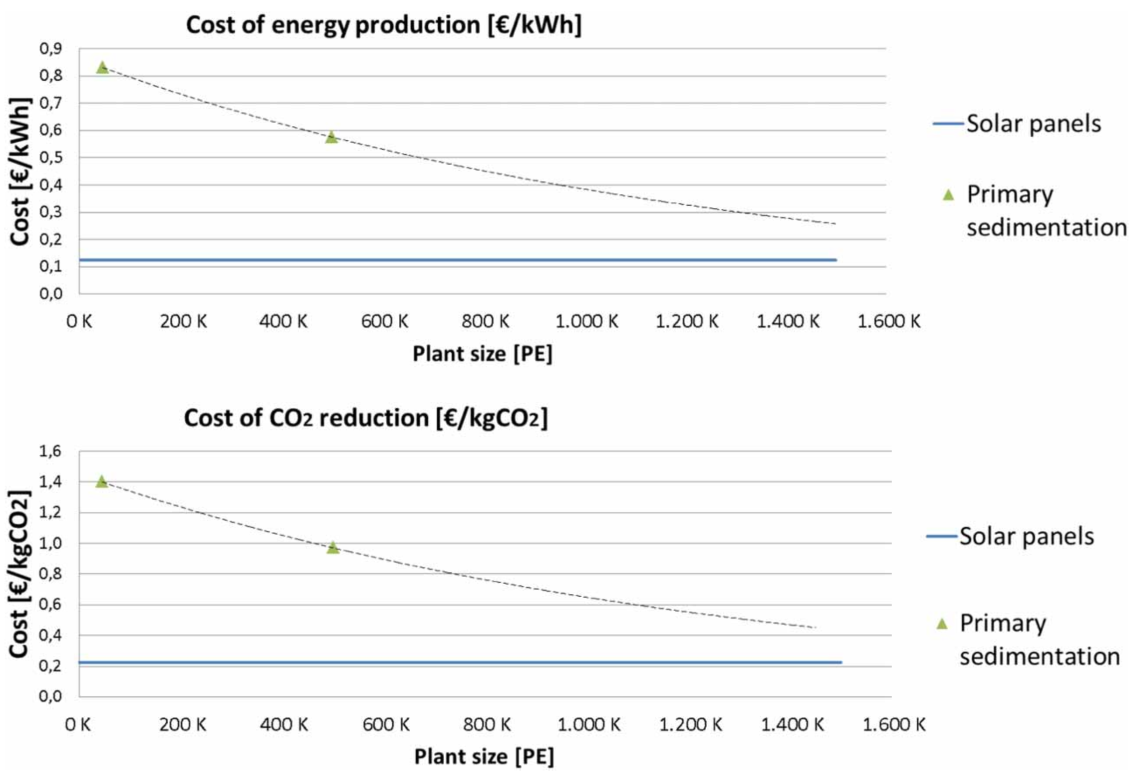

Figure 3 | Graph relating the scale of the plant with the cost of energy production (above) and with the cost of CO_2 reduction (below).

total investment, which again does not change the fact that configuration 2 would still be too expensive.

This study was performed on the case of a plant to be newly built. A special case is represented by a plant that needs to be retrofitted. In that case, if primary sedimentation tanks are already present, a calculation should be performed taking into account what the yearly costs would be to repair the tanks versus their demolition and the implementation of a treatment scheme like the one of configuration 1.

Finally, it is important to remember that there is no one-size-fits-all solution. For instance, for a water authority that has no option of matching the carbon dioxide emissions with solar panels or wind turbines, primary sedimentation should still be implemented if CO_2 reduction is the goal.

CONCLUSIONS

Primary sedimentation can be an expensive sustainability measure when compared with solar panels, even at larger scales. This means that for the same carbon footprint it is much cheaper not to implement primary sedimentation, but to make up for the energy difference through the installation of solar panels.

The recommendation that stems from this study is that, for future plants that will be built (or retrofitted), the option of not implementing primary sedimentation should be considered: a thorough financial and sustainability analysis should be performed in order to make sure that no other cheaper sustainability measures are available.

REFERENCES

Devabhaktuni, V., Alam, M., Depuru, S. S. S. R., Green, R. C., Nims, D. & Near, C. 2013 Solar energy: trends and enabling technologies. *Renewable and Sustainable Energy Reviews* **19**, 555–564.

Frijns, J., Mulder, M. & Roorda, J. 2009 Climate footprint and mitigation measures in the Dutch water sector. In: *Climate Change and Water, International Perspectives on Mitigation and Adaptation*. IWA, London, UK, pp. 73–80.

Frijns, J., Hofman, J. & Nederlof, M. 2013 The potential of (waste) water as energy carrier. *Energy Conversion and Management* **65**, 357–363.

Gavala, H. N., Yenal, U., Skiadas, I. V., Westermann, P. & Ahring, B. K. 2003 Mesophilic and thermophilic anaerobic digestion of primary and secondary sludge. Effect of pre-treatment at elevated temperature. *Water Research* **37** (19), 4561–4572.

Giorgi, S. 2017 *Wastewater Sludge Treatment, Energy Recovery and Sustainability: the Waternet Case*. MSc Thesis. Retrieved from: https://dspace.library.uu.nl/handle/1874/356829.

Gori, R., Giaccherini, F., Jiang, L. M., Sobhani, R. & Rosso, D. 2013 Role of primary sedimentation on plant-wide energy recovery and carbon footprint. *Water Science and Technology* **68** (4), 870–878.

Gratziou, M., Tsalkatidou, M. & Kotsovinos, N. 2006 Economic evaluation of small capacity sewage processing units. *Global NEST Journal* **8** (1), 52–60.

Lensink, S. M. & Cleijne, J. W. 2016 Eindadvies basisbedragen SDE+ 2017. Retrieved from: www.ecn.nl.

Metcalf & Eddy, Burton, F. L., Stensel, H. D., Tchobanoglous, G. 2003 *Wastewater Engineering: Treatment and Reuse*. McGraw-Hill, New York, NY, USA.

Nugent, D. & Sovacool, B. K. 2014 Assessing the lifecycle greenhouse gas emissions from solar PV and wind energy: a critical meta-survey. *Energy Policy* **65**, 229–244.

STOWA 2007 *The Limits of the Activated Sludge Process-Limits and Possibilities* (in Dutch). STOWA report 2007-24, Utrecht, The Netherlands.

van Loosdrecht, M. C., Kuba, T., van Veldhuizen, H. M., Brandse, F. A. & Heijnen, J. J. 1997 Environmental impacts of nutrient removal processes: case study. *Journal of Environmental Engineering* **123** (1), 33–40.

van Nieuwenhuijzen, A. F., Van Bentem, A. G. N., Buunen, A., Reitsma, B. A. & Uijterlinde, C. A. 2008 The limits and ultimate possibilities of technology of the activated sludge process. *Water Science and Technology* **58** (8), 1671–1677.

Waternet n.d. Wie zijn wij? Retrieved November 13, 2017, from: https://www.waternet.nl/over-ons/wie-zijn-wij/.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E. & Weidema, B. 2016 The ecoinvent database version 3 (part I): overview and methodology. *The International Journal of Life Cycle Assessment*, **21** (9), 1218–1230.

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