An Assessment of Wastewater Inventory and its Energy Potential: Bangladesh Perspective

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Original article

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An Assessment of Wastewater Inventory and its Energy Potential: Bangladesh Perspective

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Abstract

Background: Everyday considerable amount of wastewater is produced by each one of us. Developed country produce more wastewater than developing country. But disposing this wastewater into the environment is an expensive task and need heavy initial investment for that reason developing country only focus on water supply not on wastewater treatment considering it's a burden and threatening the human health environment and climate change. Research shows that wastewater contain considerable amount kinetic and biochemical energy. But tapping energy from wastewater, proper inventory of national wastewater including type and characteristics of both industrial and municipal wastewater is essential which is presently absent in Bangladesh. In this paper, efforts have been taken firstly to estimate yearly total domestic as well as industrial wastewater production in Bangladesh based on reliable secondary data and monthly per capita income. Secondly, common, and emerging energy recovery technologies ideal for tapping energy from wastewater have been reviewed systematically and identified which are anaerobic digestion (AD) micro hydro powerplant (MHP), microbial electrolysis cell (MEC) and microbial fuel cell (MFC). Finally, energy potential has been estimated basing on previous research outputs and with empirical formula. At the end barrier and overcoming strategy with important recommendation has been proposed for researchers and decision makers.

Results: Estimated yearly domestic and industrial wastewater is 4.874 billion and 0.452 billion tons respectively. For energy estimation,10%-50% total wastewater has been considered. Calculation shows that, 10% wastewater can produce 2.41, 1829.09 and 1.97 GW energy yearly through AD, MHP, MEC and MFC technologies, respectively whereas 50% total wastewater can generate 9145.94 GW energy yearly by MHP only.

Conclusion: Estimated quantity of produced wastewater and energy potentials from wastewater is based on secondary data. For more reliable estimation feasibility study may be conducted by the researchers supported by stakeholders. Both wastewater producers and treatment plant owners should have noble desire backed by governmental organizations will facilitate the process. Outcomes are very significant and optimistic and it is expected that this findings not only inspired researcher, wastewater operators and policy makers of Bangladesh but also other developing countries around the globe.

Keywords. Wastewater inventory, energy potential, Anaerobic digestion, microbial fuel cell, micro hydropower plant, microbial electrolysis cell.

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1. Introduction

Worldwide water demand is increasing but water availability is reducing whereas greenhouse gas emission is also escalating with the increase of population growth and industrialization. As per United Nation wastewater development report (UNWDR) 2017 around 3857.3 trillion tonnes of freshwater are extracted and approximately 44% of this water is used up by agriculture sector through irrigation and evaporation. Rest, 56% is discharged into the environment as wastewater whereas 628 trillion tonnes as industrial and 314 trillion tonnes as municipal wastewater(UNESCO, 2017). Among this discharged wastewater, apparently 80% are not treated properly or not treated at all which generate greenhouse gas emission. Bangladesh is a south Asian developing densely populated country where around 16.5 million people living (Bangladesh Bureau of Statistics, 2018). Per capita per monthly average income varies from various cluster of people which is around 50 USD (HIES, 2016). As per Asian development report middle income group of people is around 3.7 million and their per capita monthly income also 300 USD (Bank, 2010). All the citizen does not have access to electricity only 75.92 % population has the access to electricity only and water hygiene and sanitation (WASH) though the installed capacity is 19570 MW and daily electricity production is an around 10264 MW. Out of this produced electricity renewable source is only 0.19% solar, 1.18% is hydropower and rest from fossil fuel based primary fuel(figure 1) which contribute to greenhouse gas emission (Board, 2018). In US nationwide, water and wastewater treatment plants needed around 3 to 4% of total electricity utilization. This energy consumption is in similar range for other developed countries (Gude, 2015).Oher estimate accounts that energy costs varies from 5% to 30% of the total operating costs of water and wastewater utilities worldwide(Chae and Kang, 2013). Most of the developed countries maintain the statistics of total water and wastewater production, treatment and standard for safe discharge as well monitor the total water cycle for enforcing the regulation. In case of developing country picture is totally different as do not maintain any comprehensive record of water management cycle particularly wastewater production. Some of the country do keep record of water supply but partially or even no record of wastewater production and treatment. As per UN record Bangladesh only treat 2% of wastewater and rest of the wastewater directly goes to the environment without proper treatment(UNESCO, 2017). In Bangladesh, as wastewater treatment considered as energy intensive process and initial investment is more believing that wastewater treatment does not provide any visible output that's why both wastewater producers are not interested to invest money on this sector though developed country and few developing countries are serious about the environment and greenhouse emission issue and committed to treat their wastewater before discharging to waterbody. They view wastewater as a carrier of energy not a burden and optimise the energy balance of WWTPs to the point of energy self-sufficiency or even further to be “energy-positive” (Kollmann et al., 2017).To turn this sector as an energy producer, worldwide extensive research is going on and recent results found that wastewater contain around 5- 10 times more energy than its energy requirement to treat it (Heidrich et al., 2011),(Dai et al., 2019). Wastewater contain organic and inorganic substance in terms of Biochemical oxygen demand (BOD) and chemical oxygen demand

(COD) as well as various type of microorganism. Some of these microorganism breakdowns the organic matters and capable of producing energy. Wastewater contain not only energy in the form of COD/BOD but also flowing wastewater either influent or effluent having a reasonable head is a great source of hydropower. Biological wastewater treatment technologies can produce 40-55% of the WWTP's energy needs whereas advanced and top rated wastewater treatment process can produce up to 80% of a WWTP's electricity requirements as well become energy positive by feeding electricity back into the grid, for example, in a sludge-to-energy plant in Hong Kong (Never, 2016). Though it is established that wastewater contain significant amount of energy, but extraction of energy needs appropriate technologies. Few common technologies like AD, MHP already implemented and producing energy form the wastewater treatment plant (WWTP) in the some part of the world particularly in the developed countries(Strazzabosco et al., 2020),(Bousquet et al., 2017).

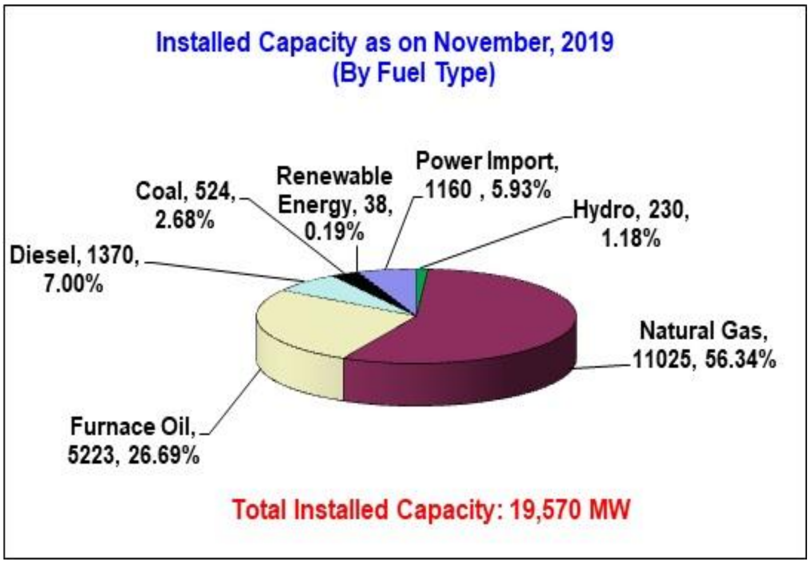

Fig 1. Total energy generation based on primary fuel and Renewable energy source.

Few other emerging technologies like photocatalysis, photo fermentation Microbial photo electrochemical system(MPEC) and MEC/MFC) are promising technologies and extensive research is in place presently but technology readiness level(TRL) still within 1-7 (Lin et al., 2018),(Demir et al., 2019),(Jafary et al., 2019),(Aiken et al., 2019).Out of these technologies

MFC and MEC are most emerging technology as energy generation and simultaneous wastewater treatment is possible. (Cusick et al., 2011),(Tartakovsky et al., 2011). For better understanding and well structuring of the entire study, it has been divided into 6 section. 1st section is introduction followed by common and emerging technology for tapping energy from wastewater which is describe in 2nd section. 3rd and 4th sections are most important and deals with total estimated wastewater production and energy production potential from generated wastewater respectively. 5th and 6th section discuss about the barrier and overcoming strategy as well recommendation and final section determine takeaway and concluding remarks of this study.

2. Potential technologies for tapping energy from wastewater

2.1 Common technologies

2.1.1 Hydropower generation from wastewater

Energy generation from wastewater through hydropower plant scheme is shown as a viable option to attain sustainability if flow rate and considerable of head is available as flow is constant although periodic fluctuation may experience. But Due to very nature, type, quality, quantity and gross head at inlet or outlet of the WWTP, implementation is limited compare to other hydropower generation project. The main limitation of this scheme to implement at WWTP is that it requires the influent/effluent to have enough kinetic energy to justify the venture. Hence, either the head or the flow rate must be substantial(Mo and Zhang, 2013) Hydro power production from wastewater utilities shows numerous merits like environmentally friendly, can be installed at the existing.

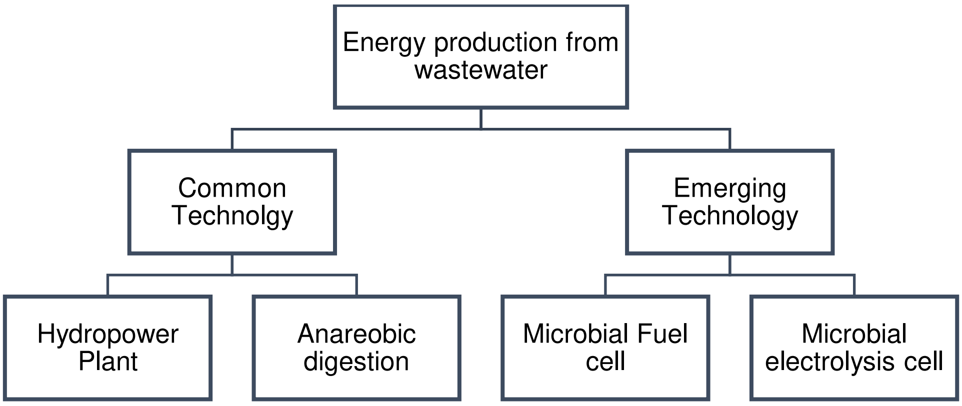

Fig 2. Energy production technologies suitable for wastewater

infrastructure that lessen the construction works, no need of water diversion system, can be adjusted to the load curve of WWTP energy consumption pattern, no need of separate transmission and distribution network. Water quality also will be improved due to the rise of dissolved oxygen intensities on the WWTP outlet (Bousquet et al., 2017).To assess hydropower potential sites, energy generation potential and economic profitability evaluation is needed based on technical and financial parameters. Technical parameters are influent and effluent flow rate for flow duration curve, upper and lower elevations for approximate gross head, type of hydro turbine and generator, control measure, power transmission and distribution arrangement. On the other hand, financial parameters include, cost related to feasibility study, engineering, design and development cost, CAPEX, OPEX. Typical hydropower generation having a flow rate and gross head of WWTP at the upstream or downstream can be calculated using Equation 1

$P= \eta \rho g Q H$------------------------------------(1)

Where P is power (kW), η is the efficiency of the turbine (unitless), ρ is the density of the water (kg/m^3) g is the acceleration due to gravity (m/s^2) Q is the flow of water through the turbine (m^3 /s) H is the head (m). WWTPs located at the plane land not having reasonable head, ''Run-of-river" system may be considered which is an alternative promising option as dams and separate reservoir is not required but constant water supply is required. When Water flows through pipe or channel to turbine, it converts kinetic energy of flowing water and drives the electrical generator. The available energy therefore depends on the quantity of water flowing through the turbine and the square of its velocity. Hydropower potential of a run of river scheme is shown at equation 2.

$P =\frac{1}{2}\eta\rho QV^2$-----------------------------------(2)

where V is the velocity of the water flow and Q is the volume of water flowing through the turbine per second, η is the efficiency of the turbine (unitless) and ρ is the density of the water (kg/m^3). LucidPipe™ is an inline spherical turbine that can be installed directly in the primary channel of a pressurized system. A wide range of pipe sizes (0.61–1.52 m) and with minimum flow of 1–5.6 m^3/s, it can generate about 18–100 kW per unit. The system is already ANSI Standard and tested, certified by NSF International and approved for using in potable water systems as well as agricultural, industrial, and wastewater pipeline systems (Sari et al., 2018). Hazen-Williams Equation and Manning's equation can be used to calculate cross-sectional average velocity flow of pipe and open channel respectively. Figure 4 shows the process of calculating slope to calculate flow velocity of the wastewater

$V = k\,C\,(D/4)^{0.63}\,S^{0.54}$ ----------------------(3) [Hazen-Williams Equation]

where $S = a / b$------------------------------(4)

and $Q = V\,\pi\,D^2 / 4$------------------------(5)

V= Velocity of liquid, (m/s)

D= Pipe inside dia(m)

Q= Discharge rate (m^3/s)

S= Energy slope(m/m)

b=Length of the pipe (m)

a= head loss(m)

k is a unit conversion factor and value is1.318 for(feet and seconds) and 0.85 for SI units (meters and seconds). C is a Hazen-Williams Coefficient and value varies (within 100-150)

$V = (k_n / n)\,R_h^{2/3}\,S^{1/2}$--------------------------(6) [Manning's equation]

Where

$R_h = A / P_w$ -----------------------------------(7)

V = cross-sectional mean velocity (m/s)

k_n = 1.486 for English units and k_n = 1.0 for SI units

n = Manning coefficient of roughness - ranging from 0.01 (a clean and smooth channel) to 0.06 (a channel with stones and debris, 1/3 of vegetation)

R_h = hydraulic radius (m)

S = slope/gradient - of channel (m/m)

A = cross sectional area of flow (m)

P_w = wetted perimeter (m)

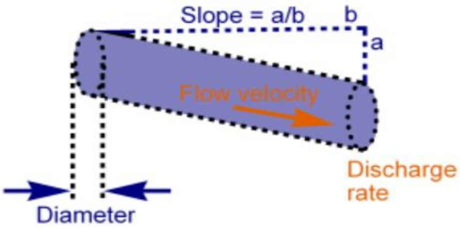

Fig 3. Pipe/channel slope and velocity relation of flowing water.

Mostly, two hydropower generation system may be installed at WWTP which has been shown at the following fig 4(a) and 4(b). In first case, hydro plant may be installed at the upstream where turbine should be more corrosion resistant, and the diversion pipe entrance must be equipped with a trash rack to control debris. For second case hydro system should be installed at the downstream, turbine face cleaner water and corrosion is not much influence on turbine. It can be noted that both possibilities can be technically implemented. In Jordan,Samara project is a best example where upstream and downstream hydropower scheme has been implemented and generating 12.5 Gwh/y and 8.6 gwh/y respectively (Esha, 2005). Delhi Jal board(DJB) of India commissioned a hydropower plant at the downstream of WWTP located at east Delhi, whose capacity is 9 million gallon per day(MGD). Effluent falls from 4.5 m above the level of water receiving stream and expected to generating around 2000 kWh electricity annually(Hydroreview, 2015) DB Patil et al. (PATEL and JARDOSH, 2018) studied feasibility of implementing hydroelectric turbine systems in WWTPs in India. On the basis of study they found that Hydroelectric turbine at the cluster of textile industries Central effluent treatment plant(CETP) located at Moharasta that would generate 26 kW that can be used at the plant itself at an average flow of 0.65 m3 /s. Table 2, shows few examples of installed hydropower plants at WWTPs across the world.

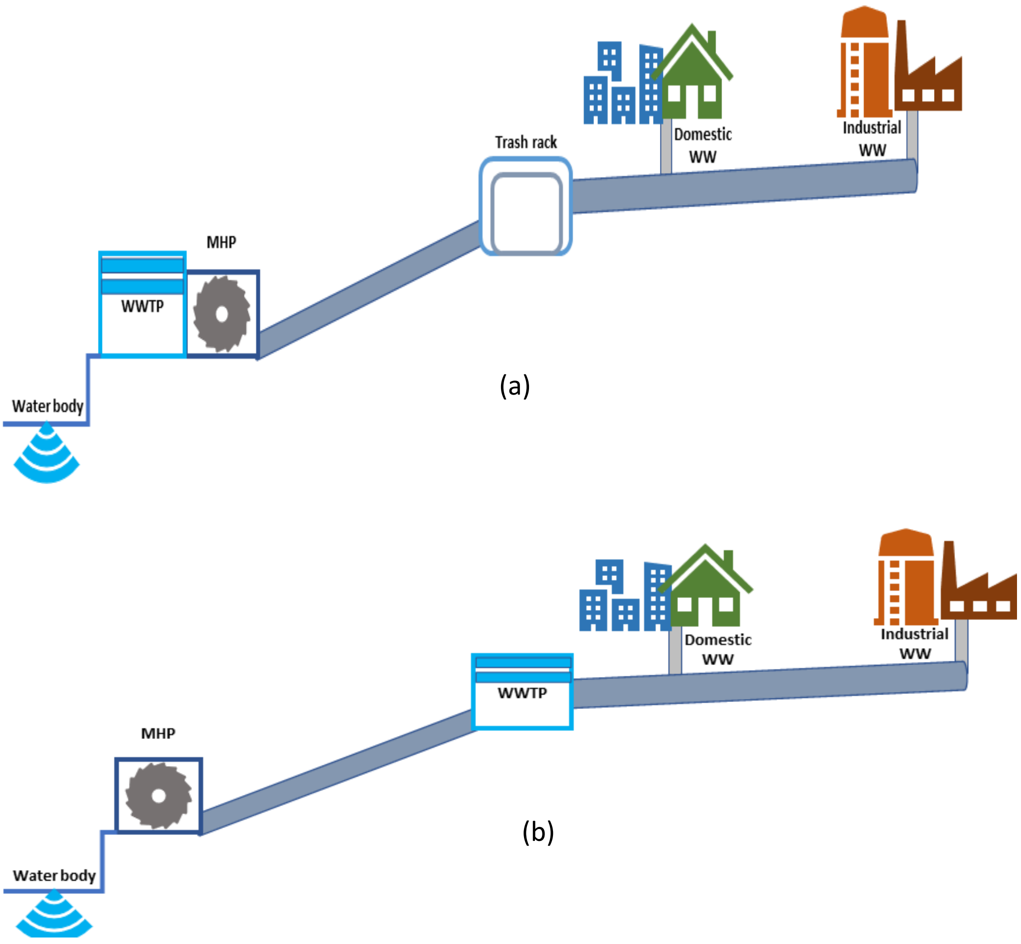

Fig. 4 (a) Downstream Effluent Micro hydropower plant (DE-MHP) (b) Upstream influent hydropower plant (Modified from C. Bousquet et al. 2017)

Table. 2: Installed hydropower capacity at some actual WWTPs worldwide (C. Bousquet et al. 2017).

Name, Location, Country	Type of Operation	Turbine used	Head (m)	Design Flow rate (m3/s)	Installed power(Kw)	Reference
Aire,Geneva, Switzerland	DTE	Kaplan	5	3.2	200	
As Samra,Jorda	USW	2 Pelton	104	3.2	2x 800	

n						
As Samra,Jordan	DTE	2 Francis	41	3.2	2x 840	
Deer Island,Boston, USA	DTE	2 Kaplan	8.8	13.1	2x1000	
Pont Loma, San diego, USA	DTE	Francis	27	7.6	1350	
Elsholt,UK	USW	2 Archimedes screw	n/a	2.6	2x90	
Emmerich, Germany	DTE	Archimedes screw	3.8	0.4	13	
La Asse, Nayon, Switzerland	DTE	Pump as turbine	94.25	0.293	220	
Engelberg, Switzerland	DTE	Pelton	54.4	0.16	50	
Grachen, Switzerland	DTE	Pelton	365	0.09	262	
La Douve 1, Leysin, Switzerland	DTE	Pelton	545	0.08	430	

La Douve 2, Leysin, Switzerland	DTE	Pelton	83	0.108	75	
Morgental, St Gallen, Switzerland	DTE	Pelton	190	0.84	1350	
Profy, Le Chable, Switzerland	USW	Pelton	449	0.1	350	
North Head, Sydney, Australia	DTE	Kaplan	60	3.5	4500	
Hsinchu, taiwan	DTE	n/a	n/a	n/a	11	
Taichung, Taiwan	DTE	n/a	n/a	n/a	68	

2.1.2 Biogas production from wastewater

Both municipal and industrial wastewater treatment plant produce huge amount of sludge produced from gravitational sedimentation in the primary settler and secondary settler. Small WWTP produce less amount of sludge and extended aeration is a good option to neutralize the sludge before disposal. On the other hand large amount of sludge generated from big WWTPs or CETP that can be utilized to generate biogas by AD (Martínez et al., 2019)(fig 5). Study shows that sludge production rate from WWTP is estimated as 0.04 kg dry matter per capita per day (Karagiannidis et al., 2011). AD is a complex process where the conversion of organic matter takes place by means of microorganisms in the absence of oxygen. The breakdown of organic matter can take place in stages namely, hydrolysis, acidogenesis, acetogenesis and methanogenesis. Biogas production occur at last stage and significantly dependent on structure of the microbial communities' present in the reactor and operating conditions applied (Karagiannidis et al., 2011).Under optimum digestion conditions, a methane yield of 315 – 400m^3/ton organic dry matter (ODM) can be expected (Bachmann, 2015).The most conventional approach to guesstimate biogas generation potential is using fixed biogas yields (Guide to Biogas From production to use, 2010),(Rao et al., 2010).To estimate biogas production potential from wastewater based on VSS, following empirical formula can be used (Equation 8).

$V_{bg}=m_{vs}xY_{bg}$------------------------------------(8)

where: V_{bg} is the estimated biogas production rate associated with wastewater(m^3 biogas/day); m_{vs} is the mass flow rate of volatile solids contained in wastewater (kg volatile solid/day); Y_{bg} is the biogas yield of feed material (m^3 biogas/kg volatile solid) which is approximately 0.406 m^3 /kg VSS (Peu et al., 2012).According to (McCarty, 1964), (McCarty, 1964) and based on wastewater COD , biogas/CH_4 production potential can be calculated as per the following equation(9) and (10).

$CH_4(m^3/hr)=0.4*(S_0-S_e)*Q$------------------(9)

$S_e=(1-\eta*S_0/100)$------------------------------(10)

Where, S_0 and S_e indicate influent and effluent COD in mg/l respectively; η is COD removal efficiency; Q indicate wastewater discharge rate in m^3/hr

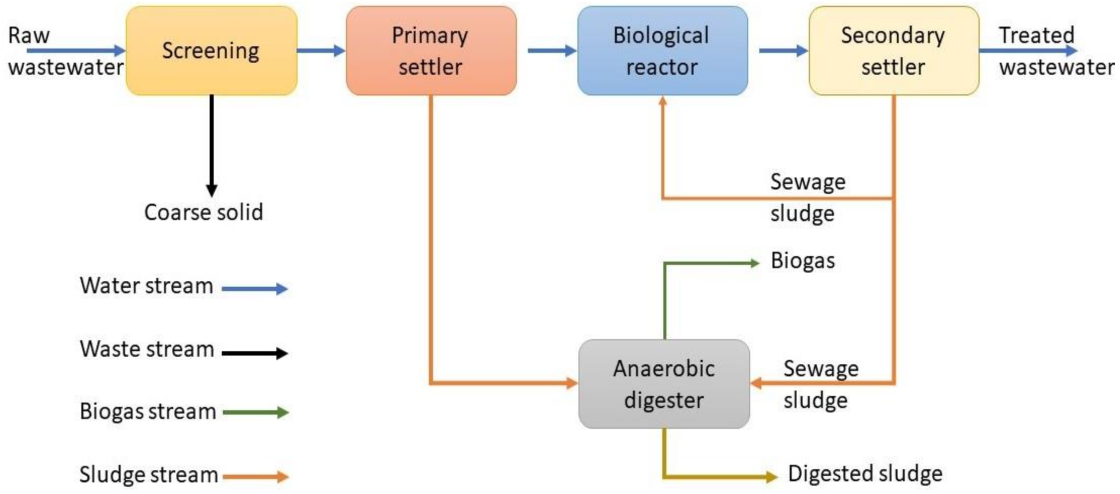

Fig 5. Schematic Illustration of biogas production from wastewater

According to international water association (IWA) wastewater report 2018, India commissioned six Sewage Treatment Plants (STPs) with a total capacity of 378 MLD. Biogas from these plants powers the majority of the STP's electricity demand and reduce 77% electricity dependence of the STPs on national grid (Shan et al., 2016).Another report about India's wastewater and solid integration plan state that waste-to-energy plant will use both10-15 tons of solid waste and around 10-20 tons of wastewater and expected to produce 21000 m^3 of biogas daily (Never, 2016).In USA, the threshold plant size is 23 MLD (EPA, 2011), the smallest WWTP equipped with a cogeneration engine was 17 MLD(Strazzabosco et al., 2020). Besides most of the developed countries are producing significant amount of biogas from wastewater. Table 3 shows the country wide biogas production.

Table 3 Biogas production from WWTPs of selective countries (Bachmann, 2015)

Name of country	Reference year	Biogas generation from WWTP	
		GWh/y	% of total biogas production
Brazil	2014	42	7
Denmark	2012	250	21
Finland	2013	126	22
France	2012	97	8

Germany	2014	3050	7
Norway	2010	164	33
South Korea	2013	969	38
Sweden	2013	672	40
Switzerland	2012	550	49
Netherlands	2013	771	20
United Kingdom	2013	761	11

2.2 Emerging Technologies

2.2.1 MFC

Microbial fuel cell (MFC) is an emerging and promising technology to produce electricity catalysing the microbes present in the waste stream simultaneously this technology also carryout wastewater treatment. MFC is like a battery cell having an anode which need to anaerobic, but cathode must be in contact with air and separate by an ion passable membrane (optional).Anode and cathode should be connected to some load to complete the circuit and wastewater as electrolyte allows to flow through the cell. Microbes available in wastewater will form biofilm over the anode surface, breakdown the organic matters and produce electron and proton ion are produced at anode and cathode as per the following formula respectively

[Eq (12)and (13)] where organic matter in wastewater is represented as Glucose ($C_6H_{12}O_6$).

The theoretical cell voltage of the overall reaction (the difference between the anode and cathode potential) determines if the system is capable of electricity generation [Eq (11)]. Practically power potential is less due to various loss. At ambient temperatures, MFCs may produce upto1.8kWh/ m^3 from a treated effluent (Hua et al., 2019),(Ge et al., 2013).It is estimated that in USA around 1960 MW of electricity can be produced from the dairy industrial wastewater (Borole and Hamilton, 2010). Electricity production from both municipal and various type of industrial wastewater are shown at table 4.

$E_{cell}=E_{cathode}-E_{anode}$ -------------------------------------(11)

$C_6H_{12}O_6 + 12H_2O \rightarrow 6HCO_3 + 30H^+ + 24e^-$ ------(12)

E_{anode}=-0.429 Volt vs SHE

$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$---------------------------------(13)

$E_{cathode}$=1.235 Volt vs SHE

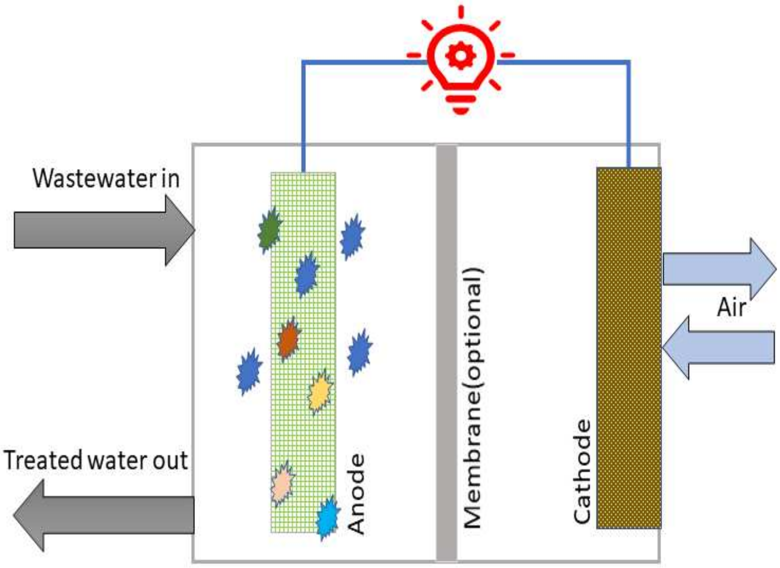

Figure 6 Schematic diagram of MFC

Table 4. Energy recovery from various wastewater substrates in MFCs

Type of MFC	Type of wastewater	Energy production rate (mW/m^2)	COD Removal rate (%)	Reference
Two chamber MFC	Municipal	25	30	(Rodrigo et al., 2007)
Single chamber	Domestic	-	65	(Pepé Sciarria et al., 2013)

MFC				
Single chamber MFC	Agricultural	45	86	(Min et al., 2005)
Two chamber MFC	Agriculture	-	88	(Gude, 2018)
Single chamber MFC	Dairy	20 W/m^3	91	(Mahdi Mardanpour et al., 2012)
Single Chamber MFC	Pharmaceutical	177.3 W/m^3	-	(Gude, 2016)
Single chamber MFC	Hospital	14 W/m^3	-	(Gude, 2016)
Single chamber MFC	Dairy	5.7 W/m^3		(Gude, 2016)
Double chamber MFC	Effluent from AD	42 W/m^3	-	(Gude, 2016)
Single chamber MFC	Domestic	3.7 W/m^3	-	(Gude, 2016)
Double chamber	Distillery	63.1		(Gude, 2016)

MFC				

2.2.2 MEC

An MEC is a form of MFC where both anode and cathode are anaerobic and have a membrane in between is optional. Unlike MFC instead of produce electricity, in the cathode chamber, e- and H+ ions are combined to generate H_2 gas. However, H_2 formation at cathode chamber is not spontaneous i.e. it requires an external bias. A small amount of electricity (with acetate this is in theory 0.114 V, in practice <0.25 V shown in Eq (14)), is required to generate the H_2 gas (Call and Logan, 2008). This is substantially less energy than is required to produce H_2 through water electrolysis, typically 1.8-2.0 V (Lu and Ren, 2016). A schematic of an MEC is shown in Fig 7. When wastewater act as electrolyte and flow to the anode chamber and be in contact with anode surface, microbes of wastewater form a biofilm and colonizing anode surface. The metabolic activity of the biofilm, electrons and protons are freed, and electrons are transferred to the anode (as final electron acceptor) and proton pass subsequently to the cathode via an external circuit. At the cathode, which plays the role of an electron donor, the reduction of H+ to molecular H_2 gas takes place. Anode and cathode reactions are shown at the [Eq (15),(16) and (17)].

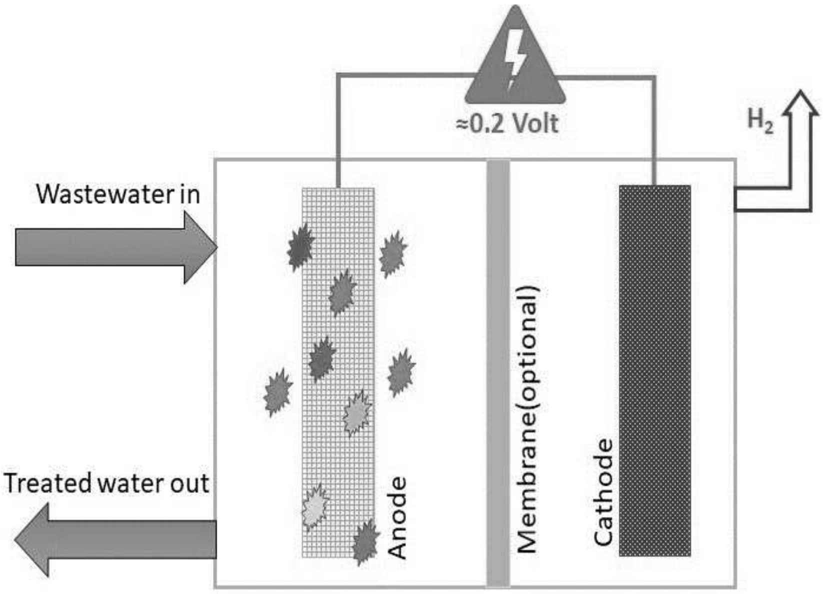

Figure 7 Schematic diagram of MEC

$E_{cell}=E_{cathode}-E_{anode}$ ---(14)

=-0.14 Volt vs SHE

$C_6H_{12}O_6 + 2H_2O \rightarrow 4H_2 + 2CO_2 + 2C_2H_4O_2$(Acetic acid) ------(15)

$C_2H_4O_2 + 2H_2O \rightarrow 2CO_2 + 8H^+ + 8e^-$ --------------------------------(16)

E_{anode}=-0.279 Volt vs SHE

$8H^+ + 8e^- \rightarrow 4H_2$---(17)

$E_{cathode}$=-0.414 Volt vs SHE

As wastewater contain organic and inorganic substance strength is indicated by COD so H_2 yield production rate based on COD can be evaluated by the following equations [Eq (18) and (19)]. is calculated as

$Y_H = (nH_2M_{H2})/ (V_L{}^* (COD_i - COD_f))$--------------------------------(18)

$nH_2 = V_HP/ RT$---(19)

where, Y_H is H_2 yield in mg-H_2/mg-COD; nH_2 is the moles of recovered hydrogen recovered calculated from the ideal gas law based on the volume of hydrogen recovered, M_{H2} is the molecular weight of hydrogen, and V_L is the volume of liquid in the anode chamber, reactor influent COD is CODi and effluent COD is CODf for continuous process as well as batch process; V_{H2} is the volume of H_2 measured at 1 atm pressure; P (atm) is the pressure and R the gas constant (0.08206) and T the absolute temperature (303 K) at the time of gas sampling. For glucose considering representative of wastewater for experimentation, the maximum molar yield of H_2 is 12 mol-H_2/mol-glucose, and based on COD,

H_2 yield Y_{H2} = 0.126 g-H_2/g-COD (Virdis et al., 2011).

Table 5. Representatives of hydrogen production from wastewater by MEC

MEC Capacity (L)	External power required kWh/kg COD	COD Removal (%)	H_2 production rate (m^3H_2/ m^3/d)	Reference

40	0.40	75±9	-	(Hui Guo et al., 2019)
120	0.75	16	0.015	(S. E. Cotteril, 2017)
100	0.63	33	0.007	(S. E. Heidrich, 2012)
10	0.9	66-76	0.04	(Gil Ceria et al., 2012c)
1000	1.15	62	Trace	(R. D. Cusieck et al., 2011)

3. Water and Wastewater cycle management in Bangladesh

3.1 General overview of water supply system in Bangladesh

Three types of water utilities ensure the smooth supply of water to the consumers of urban, peri urban population as well as industry and service organizations, these are Water Supply and Sewerage Authorities (WASAs), City corporations and Pourashavas, In addition to these Bangladesh Export Processing Zones (BEPZA), Economic zone authorities (EZA), and private deep tube wells are suppling domestic and industrial water to the private consumer in case they are not recipients of supply facilities. Various tier of authorities' issue licences for sinking deep tube wells and drawing ground water for respective consumptions. DWASA, Chittagong WASA, Rajshahi WASA, Khulna WASA are responsible of water supply and sewerage management of the metropolitan cities of Dhaka, Chittagong, Rajshahi and Khulna. In addition to WASAs, Bangladesh has 532 urban areas classified into 11 City Corporations and 318 Pourashavas (Municipalities) run by elected Pourashava councils. Pourashavas are further classified as A, B and C categories. Urban areas are categorized as larger city corporations or A, B, and C class based on the annual minimum of annual revenues collection (Bangladesh Bureau of Statistics, 2018). Water supply to the respective city corporations and most of the pourasovas are carried out by their own arrangement through coordination with local government engineering department and public health department- important organs of government. Among all the cities Dhaka being the capital city and more than 2 million citizens are living at the city. Dhaka WASA supplying 2550 MLD and produce approximately 91 litre/person wastewater every day. But treating these huge amount of wastewater only one Sewage treatment plant (STP) treating only 20% of total waste stream (DWASA Audit-Report-2017-18). For Treatment of industrial wastewater generated from different industries within EPZs, there are central ETP, and induvial ETPs but full potentials are not utilized. For treating textile, garments, and leather industries wastewater there are separate ETPs are in place, but all are not fully operational due to cost, lack of awareness and less stringent of regulation. Out of other industries, some of them have ETPs but most of the industries are not use ETPs or not operational though as per Department of Environment (DoE) under Ministry of Environment and Forest (MoEF) of Bangladesh, reported that number of ETPs increased from 535 in 2011 to 1773 until May 2019 (Haque, 2020).Regarding monitoring and quality assurance of wastewater discharge, DoE, look after limited ETPs, Ministry of Textile and Jute looks after operational activities of respective ETPs from 2014. BEPZA is responsible of water supply and sewerage services within EPZs. Besides, BEZA is planned to construct 100 zones throughout the country as well as centralized STPs and ETPs in each of these zones. Regarding the fate of rural wastewater does not have any statistics.

3.2 Wastewater discharge regulation

According to DoE, Environment Conservation Rules, 1997 of Bangladesh, there are standard value for different effluents parameters based on industry which need to follow before discharging into the environment. Following table summarizing the parameters with limit for compliance(The Environment Conservation Rules, 1997).

Table 6. DoE standard of municipal and industrial effluent of Bangladesh

Type and source of Effluent	Parameters limit for compliance						
	pH	BOD	COD	TDS	SS	Oil&	Others

						Grease	
Municipal ww		40	-		100	-	Coliform 10/ml
Sugar industry ww	6-9	150	200-400	-	150	10	-
Food processing, dairy industry ww	6-9	150	200-400		100	10	-
Textile industry ww	6.5-9	150	200-400	400	100	10	
Pulp & paper industry ww	6-9	30-50	300-400		100		-
Distillery	6-9	500	-	-	150	10	
Tannary/leather industry ww	6-9	100	200-400	2100	-	-	-
Oil refinery ww	6-9	30	-	-	100	10	-

3.3 Inventory of domestic and industrial wastewater of Bangladesh

Though various organizations are responsible for water supply and wastewater management but very few STP/WWPTs for municipal wastewater treatment though there are CETPs, ETPs, in the various industries either centrally or individually are in place. But there is no central statistics or data base of wastewater production generation and discharge. As there is no database, so for assessing total domestic wastewater production, income base economical estimation approach has been adopted where total population, citizens monthly earning both middle class group of people's monthly income (Bank, 2010) and average per capita per month income has been considered according to equation 20, supply water also be calculated by equation 21 (Campos and Von Sperling, 1996). Produced wastewater,

WWp (litre/person/day) = 57.9 + 8 0*X--------------------------(20)

W_p(litre/person/day)= X/(0.021+0.003*X) ----------------------(21)

Where, X is Number of minimum salaries per month (0.5 and 3.0 based on average and middle class groups salary respectively considering 100 USD a unit)

Total estimated wastewater inventory is presented on the following table 7. On the other hand for calculating industrial wastewater, major industries operating at the major cities, BEPZAs industries situated at different EPZs, textile and leather industries as a whole, pharmaceutical industries, vegetable oil industries, dairy mills , pulp and paper industries have been considered. There are about 28,065 industrial establishment in Bangladesh, mostly located in the large towns of Dhaka, Chittagong, Khulna, Rajshahi, Barisal and Sylhet (David et al., 2010) . As these industries are not maintaining statistics complete statistics of wastewater production that's why quantification of Industrial wastewater has been carried out by consulting various literatures, industrial association reports, annual report of major industries which tabulated at table 8.

Table 7. Domestic wastewater inventory of Bangladesh

Area/water supply authority/group of people based on income	No of people (Million)	Wastewater production rate (Ltr/per/day)	Wastewater production based on average Income (USD/person/month	Total Wastewater production Million m^3/yr
Dhaka WASA	20	91	-	664.33
Chittagong WASA	6	91		199.6
Middle income group	37	91.6	300	1241.11
Rest of the population	122.57	61.9	50	2769.28
Total domestic wastewater production				4874.32

Table 8. Industrial wastewater inventory of Bangladesh

Type of	Wastewater	pH	BOD	COD	Reference	Reference

industry	production, (million m^3/yr)		mg/l	mg/l	Year for quantification	
Dairy	14.56	6-11	600-2000	800-4500	2017	(Datta et al., 2019) (Envirocheme, 2015)
Textile	288	6-11	350-600	1200-1750	2019	(Hossain et al., 2018)
Leather	30		490-610	1610-1750	2016	(Chowdhury et al., 2018)
Pharmaceutical	0.188	9-12	20-500	900-1600	2012	(Paper et al., 2015)
Sugar mills	7.080	5.5-7.1	500-8200	800-12000	2008	(Karim, 2008)
Paper mills	25.112	7-7.5	90-150	320-810	2010	(Rahman and Kabir, 2010)
Vegetable oil	5.6	2-7	42-4340	640-17000	2018	(Ahmad et al., 2020)
Chemical and Plastic industries	3.65	6.1-9	2354-2615	2912-5239	2019	(Nasr et al., 2007)
BEPZA	37.595	-	--		2018	(BEPZA Annual Report, 2018)
Other(10% of all industries)	41.177					
Total	452.952					

4. Estimated energy potential of wastewater sector in Bangladesh

4.1 Selecting suitable technology for harnessing energy from wastewater

In the previous paragraph 2, both common and emerging technologies which are already implemented and potential to implement have been discussed in depth. Integrating energy generation technology with wastewater treatment process is not straight forward- need details study for technical as well as financial point of view. Integration is most suitable for newly planned WWTPs if consider during planning stage. As already mentioned before that due to high cost of treatment and initial heavy investment is required that's why developing countries ignore this issue and indirectly damaging the environment, health and total ecosystem. Adequate data, analysis of previous data on wastewater collection, treatment and discharge, cost analysis of action and no action in terms of wastewater treatment will instigate to plan, think and consider for harnessing energy from this unexplored sector. Well composed plan, careful prefeasibility and feasibility study, engineering, and development strategy will lead to integrate energy harvesting technology to the WWTP. Figure 8 illustrate the probable step to be followed for deciding energy tapping steps from any WWTPs in general. In this figure both common and emerging technologies have been considered for energy generation from wastewater. Initially prefeasibility study needs to be carried out to find out which technology match better based on the detail discussion on the section 2. If no technology is suitable, then decision may be taken to drop the plan for integrating energy generation option from that WWTP. If single or two technologies suits for integration then carry out feasibility study, based on feasibility study if it is found that implementing single technology AD or MHP then engineering and development step may be considered before installation and commissioning.

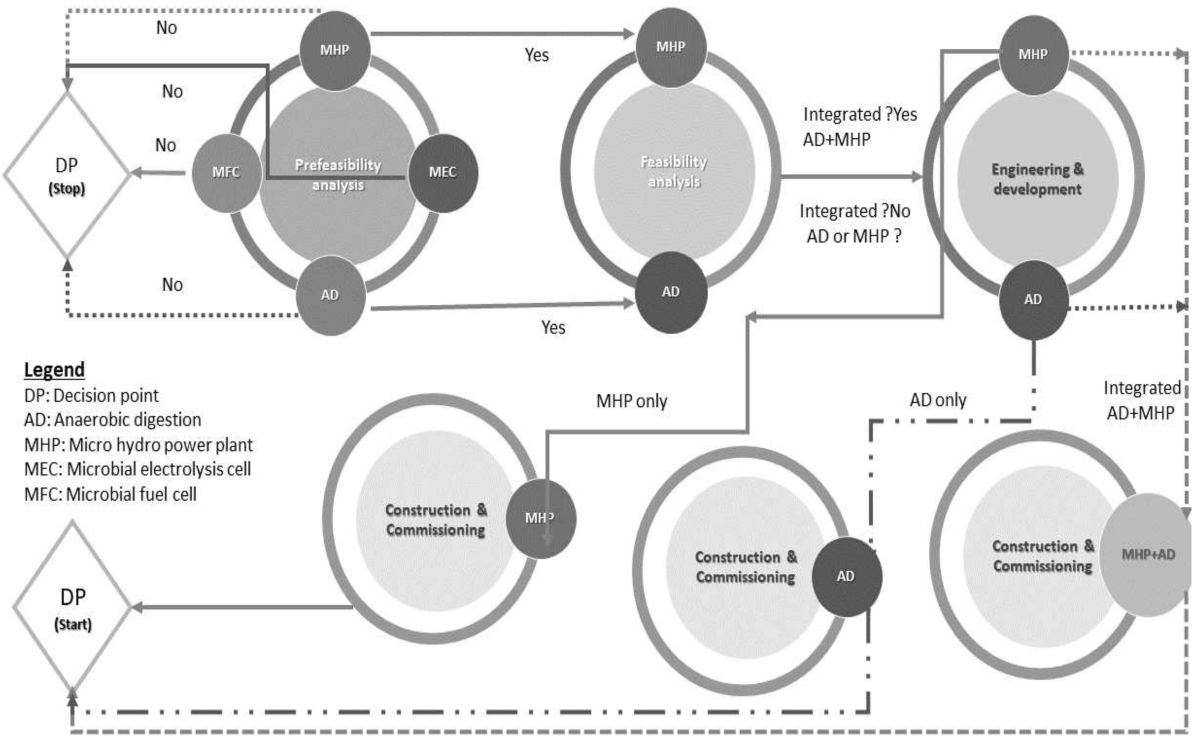

Fig 8. Flow diagram of integrating energy generation technologies at WWTP.

4.2 Calculation of energy potential from wastewater

All the estimated wastewater will not be possible to utilize for energy generation, may be certain percentage can consider for harnessing energy. Accordingly, 10 scenarios both single and integration of two technologies have been considered for energy estimation. Table 9 describe the 10 scenarios starting from 10% domestic wastewater (DWW) and 10% Industrial wastewater (IWW) corresponding to implementable technologies for harvesting energy.

Table 9 Possible scenarios for energy potential calculation

Scenario	% of DWW (millm^3/y)	% IWW (millm^3/y)	Technology
1	10	10	MHP
2	10	10	AD
3	10	10	MHP+AD

4	25	25	MHP+AD
5	50	50	MHP+AD
6	10	10	MFC
7	10	10	MEC
8	10	10	MEC+MFC
9	25	25	MEC+MFC
10	50	50	MEC+MFC

For calculating the hydropower potential through micro-hydro power plant (MHP) scheme, in scenario 1, 3,4 and 5, gross head has been considered only 1 metre (m). Overall efficiencies for hydropower generating systems can vary from 50 to 70%. Therefore, to determine a realistic power output, the theoretical power must be multiplied by an efficiency factor of 0.5 to 0.7 (Saket, 2008). In scenarios 2, 3,4 and 5, for calculating biogas generation by anaerobic digestion (AD) from sewage sludge of wastewater has been consider.Biogas is produced from two type of wastewater sludge, primary sludge and activated sludge and production rates are 380 ml/g VS and 612 ml/g VS respectively (Hanjie, 2010).Two key factors are important when assessing the biogas potential from sewage sludge (1) the amount of sewage sludge available to be digested, and (2) the biogas yield that can be achieved (Rao et al., 2010). It is reported that BOD_5 and COD values of domestic wastewater were found at STP of DhakaWASA, are 500 mg/l and 2500 mg/l respectively (DWASA Report,.2018) As per ref (Hamilton et al., 2014) wastewater contain TVS and TS are 1420 mg/l and 3124 mg/l respectively. For calculation of energy potential from wastewater by MFC is based on the real time experimental results which is 3.7 W/m^3(Gude, 2016). Finally calculation of hydrogen by MEC from wastewater is calculated based on the practical assumption which is ($15L\text{-}H_2/m^3$-influent/day) (Aiken et al., 2019) and energetic estimation has been done considering 1 kg of H_2 is equivalent to 33.33 kWh energy (H_2 data).

Table 10 Scenarios wise calculated energy potential

Scenario	Total wastewater (million m^3/y)	Technology	Calculated gas production by AD or MEC Biogas/H_2	Equivalent Potential energy (GWe/y)
1	532.709	MHP	-	1829.09
2	532.709	AD	0.372 mill m^3/yr	2.418
3	532.709	MHP+AD	0.372 mill m^3/yr	1831.508
4	4478.770	MHP+AD	0.931 mill m3/yr	4478.770
5	9152.540	MHP+AD	1.86 mill m3/yr	9152.540
6	532.709	MFC	-	1.971
7	532.709	MEC	679.455 mill ltr/yr	18.909
8	532.709	MEC+MFC	679.455 mill ltr/yr	20.88
9	4478.770	MEC+MFC	1698.637 mill ltr/yr	52.19
10	9152.540	MEC+MFC	3397.275 mill ltr/yr	104.4

4.3 Results and Discussion

Estimated energy potential is based on 10-50% of generated domestic and industrial total wastewater. Wastewater inventory is based on limited archived secondary data, unavailable information and statistics have been reasonably assumed. About the proposed technologies, MHP at WWTP, effluent is a well-recognised means of recovering electricity by taking advantage of constant discharge from WWTPs and some head though depend on the site. Archimedes screw, water wheels and other turbines deliver reliable performance when applied to downstream scheme. However, if hydro scheme is applied to untreated wastewater, then percussion must be taken against corrosion. During pre-feasibility study, in addition to flow rate, gross head can be estimated through geographical information system(GIS) and power potential can be estimated (Almaliki, 2019). Large-scale applications in Australia, UK and Ireland, Jordan, Austria have proven the economic viability of hydropower technologies in WWTPs. For assessing hydropower potential in this paper, as there is no data on gross head and not consider any head other that 1 m, so assuming a range of head from 0.25 to 10 m, and considering only 10% of total wastewater, a big difference can be noticed which shown at fig 11. Sometime head is hard to find out for WWTP at plane land but following the fig 3, slope can be increased to get an enhanced flow velocity according the Hazen Williams and manning equations (Eq 3 and 6) by storing effluent in a separate reservoir and that effluent can be channelled for urban or peri urban agriculture. According to equation (2) exponential power potential can be calculated if flow velocity can be increased by double then power will be increased by quadruple times. As mentioned before that either upstream or downstream scheme of hydropower plant may be planned though corrosion is a significant barrier for upstream scheme. From table 2, it shows that there are good number of wastewater hydropower plants are operational using the upstream influent. Using corrosion resistant material for turbine and associate components which are direct contact with influent may solve this issue. Stainless steel, grey cast iron, composite material, alloy steel etc are suitable to encounter this issue (Kehrein et al., 2020). Regarding AD Technology, using WWTP sludge as feedstock to generate biogas is kind of similar technology to produce biogas from municipal solid waste, cattle manure which is practicing long before in Bangladesh and other part of the developing country. The production of biogas by AD from sludge is currently the most widely used energy recovery method worldwide. About 80% of the biodegradable COD fraction in the sludge can be converted into biogas. Traditional AD technology is common but harnessing additional biogas from wastewater need advance technology and developed country are adapted and major part of energy requirement of treating process is meeting up by energy generation from biogas. Fig 10 and 12, shows that, in terms of equivalent energy potential AD's contribution is not significant but can be considering after feasibility study. Regarding MEC and MFC, both technologies still not commercialized but carry much potential as simultaneous wastewater treatment is possible with these processes though bioremediation is not consistent. A typical WWTP with aerobic activated sludge and anaerobic sludge digestion process consumes approximately 0.6 kWh of energy per m^3 of wastewater treated, (McCarty et al., 2011).Wastewater treatment by lagoons, trickling filters require 0.09-0.29, 0.18-0.42kWh/m^3 of energy respectively (Logan, 2008). Reducing this energy consumption and extracting energy from wastewater, dedicated study is going on for example at least 12 plants in Europe and the USA have been reported as reaching more than 90% energy self-sufficiency. The European research project Power-step is currently elaborating designs for energy neutral and energy-positive WWTPs through six different case studies (Kehrein et al., 2020).These research outcome inspire to adopt such technology which will exhibit double benefit simultaneously like MEC and MFC. In addition to electricity and hydrogen generation by MEC and MEC, three product groups are particularly possible to extract from wastewater These are (1) Bulk chemicals, like biofuels, platform chemicals and plastics.(2) High-value chemicals, like pharmaceutical precursors, antibiotics and pesticides and (3) Inorganics like nutrients, struvite which can serve as fertilisers. As performance of MEC/MFC still not stablet till that time hydropower is the most viable option to integrate with wastewater treatment process. Fig 12 shows that energy generation from MHP exhibit most promise compare to any other common and emerging technology. If 50% wastewater can be utilized then more than 9000 GW/yr of power can be explored and according to fig 10, hydropower production varies significantly with head.

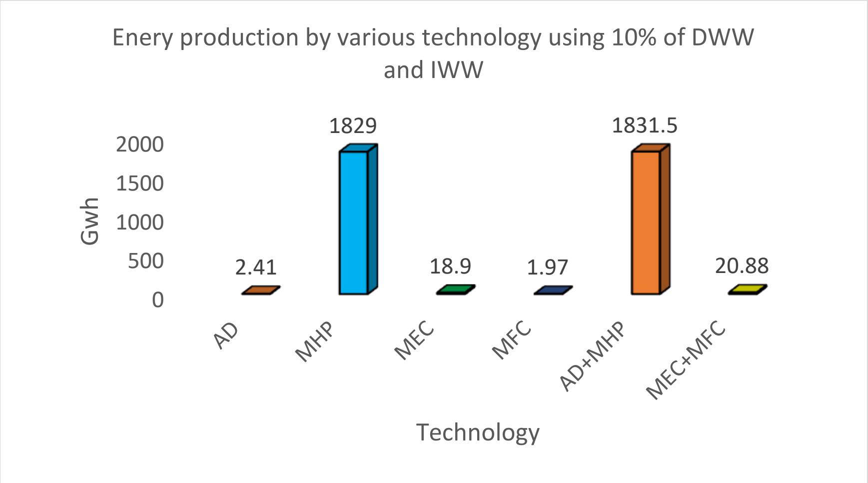

Fig 9 Energy potential based on different technology

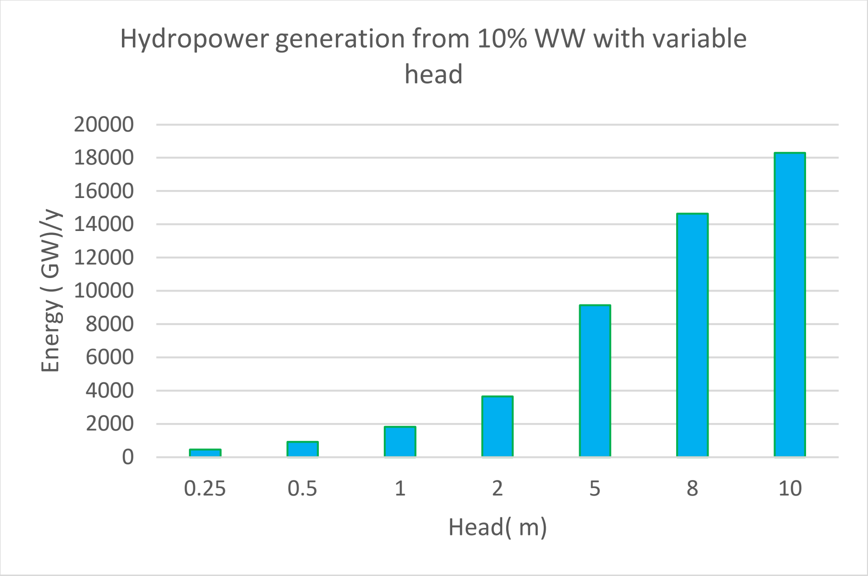

Fig 10. Hydropower potential based different head.

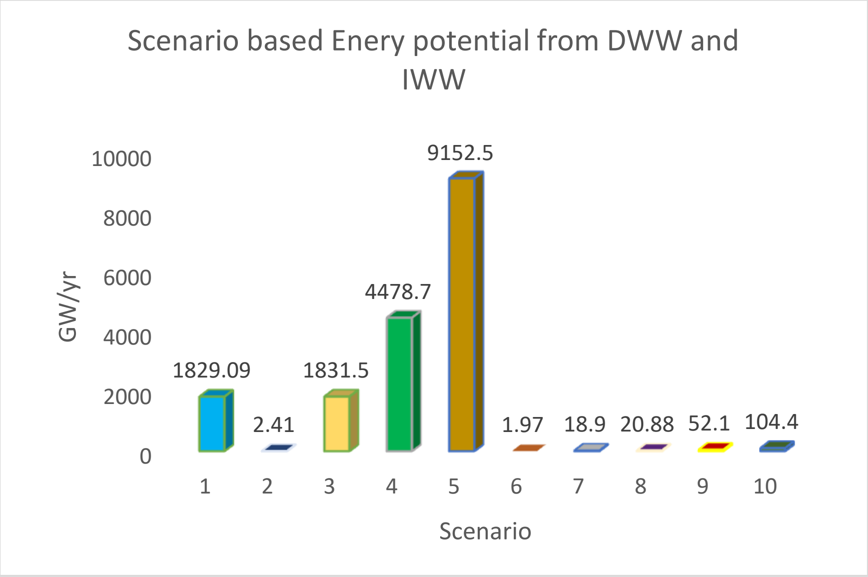

Fig 11 Scenario based energy potential

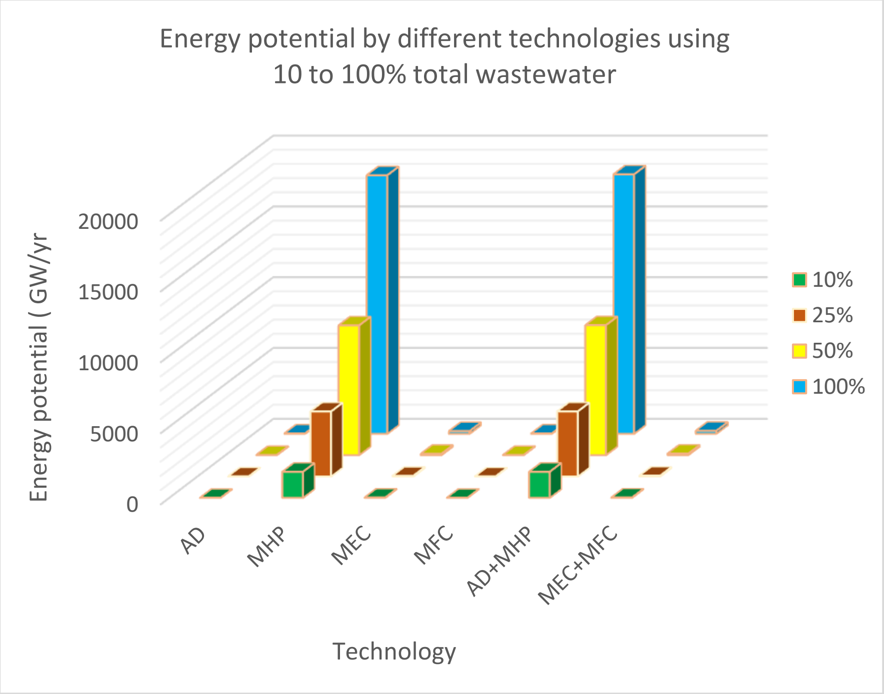

Fig 12 Estimated energy potential by different technologies using10 to 100 % wastewater

5 Potential barrier, overcoming strategy and recommendation to tap energy from wastewater sector

5.1 Barrier and overcoming strategy

There are several hurdles to explore the wastewater sector is a potential source of renewable energy, it is a kind of fixed source as every day wastewater will produce, need careful planning focus, intention, consensus, technical know-how and expertise. Among the potential barriers regulatory, policy, lack of awareness, lack of knowledge and lack of interest, technical, financial, are the most significant.

Out of these barrier, policy and regulations system plays a vital role because if policy is supported by regulations and low which is to implement by low enforcing agency of government then all citizen and stakeholders are obliged to follow that. For example, If policy is like that, all consumers irrespective of individual, institution or industrial must have to keep a record about the wastewater production either individually or centrally and regulatory body can monitor the activities in terms of wastewater generation, discharge, treatment, effluent quality and all other related matters then majority of the problem will be solved. Data and information on wastewater generation, treatment and use is essential for policymakers, researchers, practitioners, and public institutions in order to develop national and local action plans for protecting environment and productive use of wastewater. Regarding lack of awareness, interest, knowledge can be nurture, enriched and grow by changing view perspective. If most of the citizen know the consequences of releasing untreated or inadequately treated wastewater into the environment, then will be careful about discharging untreated wastewater. Knowing the harmful effects on human health, negative environmental impacts, and adverse implications on economic activities will lead all concern to enhance their awareness, interest and knowledge. Bangladesh is a developing densely populated country, human development index (HDI)is one of the lowest compare the other nation which greatly depend on per capita energy consumption. If energy production can be harnessed from renewable source like wastewater then not only energy generation will be increased but also overall countries position will be elevated. In this connection motivation, publicity by various institution is essential to encourage strong will and keen interested to explore this untapped potential energy source. In regards of technical and financial analysis, through pre-feasibility study by software analysis and not investing much time and money potential site with source can be identified. To do this public educational and research organization can play a vital role on this aspect. Loyal to the rules and regulations, a biding by the instructions, self-awareness above all coordinated effort by all stakeholders are the winning strategy for any kind of challenge or barrier. As wastewater is considered as a valuable resource so like other resources, from of recycle, reuse and recovery (RRR) perspective, nine bottlenecks have been identified and grouped into three categories

- Economics and value chain
  (1) Process costs.
  (2) Resource quantity.
  (3) Resource quality.

(4) Market value and competition.
(5) Utilisation and application.
(6) Distribution and transport.

- Environment and health

(7) Emissions and health risks.

- Society and policy

(8) Acceptance.
(9) Policy.

All these bottlenecks somehow related with previously mentioned barriers and possible to address by following above mentioned strategy. However, the successful implementation of RRR in wastewater sector heavily depend on policy and legislative frameworks, market values and the competitive situation, as well as user acceptance of a recovered energy and willingness to pay for that.

5.2 Recommendation

In line with sustainable development, for exploring the untapped potential of wastewater in the context of developing country particularly for Bangladesh in addition to following overcoming strategy discussed above following suggestions are recommended:

- A proper and consolidated inventory of wastewater is essential-that can be developed by holistic approach by all stakeholders like water producers, consumers and policy and regulatory body.
- A prefeasibility as well as subsequently feasibility analysis may be carried out by local authority by the public university focussing new STP/CETP/WWTP.
- For technical and financial viability analysis, a pilot project both for AD and MHP may be planned, funded, developed, and implemented by WASA/BPDB/autonomous body or public private partnership (PPP) basis.
- In terms of energy generation system integrating into the STP/CETP/WWTP local resource may be explored or developed collaborating with the local university or national

public/ private research institution for capacity building and attaining self-dependency on technical expertise.

- As hydropower potentiality is outperform other common and emerging technology, so it is strongly recommended to plan and execute a pilot project anywhere in the country where wastewater flow rate and gross head are optimum to get a hands on experience to scale up further at the other WWTPs as well.

6 Conclusion

According to government plan 10% renewable energy is expected but till time only 0.19% solar, 1.18% is hydropower has been integration with total production system. Only 75.92 % citizen has access to electricity. To increase the electricity generation and increase the share of renewable energy sources is the top priority of Bangladesh. In this situation, energy investment for wastewater treatment is not the priority for the WWTPs stakeholder. But if wastewater can produce a reasonable percent of energy utilizing its potential then all concern will be interested to treat their wastewater and discharge the treated water to the environment. As wastewater treatment is an expensive and energy intensive process that's why most of the wastewater disposed to the nearby waterbody causing environment pollution, greenhouse gas emission. Developing country like Bangladesh need to focus also for treating her wastewater for better good and harnessing energy from this untapped source of renewable energy like developed world. There are few emerging technologies have been discussed in detail to understand how these technologies would be integrated with wastewater treatment process. A methodology has been also suggested to evaluate implementable technology at the WWTPs. Based on the previous empirical formula and experimental data of other literatures, an approximate estimation has been completed considering 10 scenarios. Out of these, scenario 1, using only 10% of total generated wastewater produce 2.41, 1829,18.9 and 1.97 Gwe/yr energy through AD, MHP, MEC and MFC technologies, respectively. For MHP, 1 m gross head has been deemed and considering 0.25 m to 10 m gross head, MHP shows expected performance and outperformed other process. This energetic study focussing on ignored and untapped resource- wastewater which is otherwise viewed as burden to society can be source of potential source of renewable energy. Findings of the study will aid to decide by the stakeholders of industries, energy producers, wastewater utilities, policy makers and regulatory bodies to tap energy from this dirty and ignored sector. Study outcome also will be an inspiration for the researchers and scientist to explore the potential renewable energy source. Potential barriers, overcoming strategy also highlighted. Finally, few important recommendations have been suggested to implement and integrate with the mainstream of wastewater treatment, resource recovery and power generation.

Declaration

Availability of data and materials

All data generated or analysed during this study are included in this published article.

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

The theoretical framework, research design, data analysis, and inferences drawn was solely carried out and approved the final manuscript by the author.

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Figures

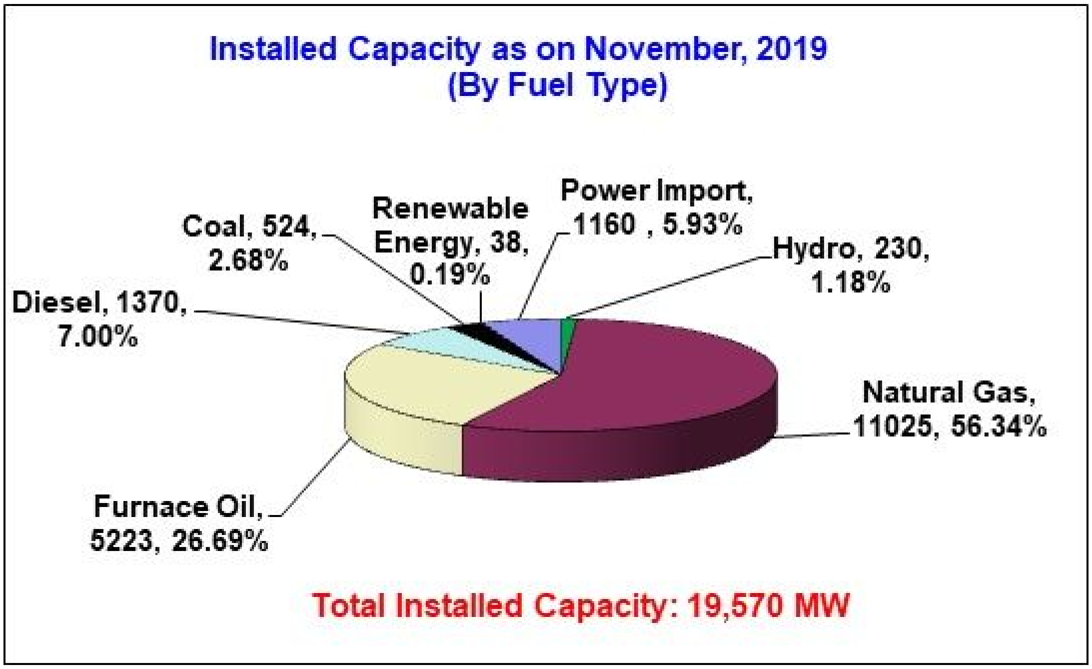

Figure 1

Total energy generation based on primary fuel and Renewable energy source.

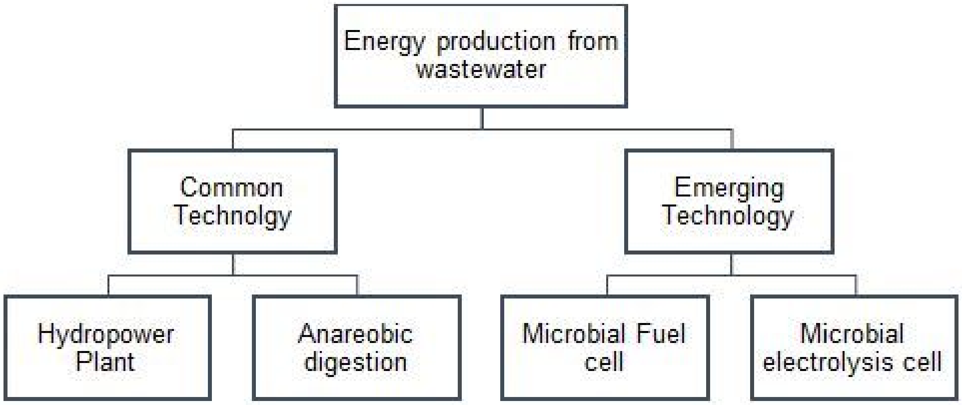

Figure 2

Energy production technologies suitable for wastewater

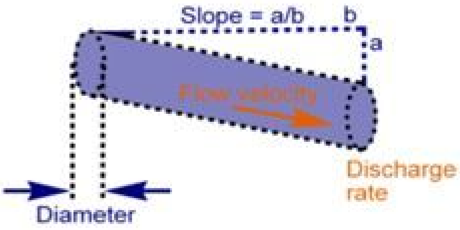

Figure 3

Pipe/channel slope and velocity relation of flowing water.

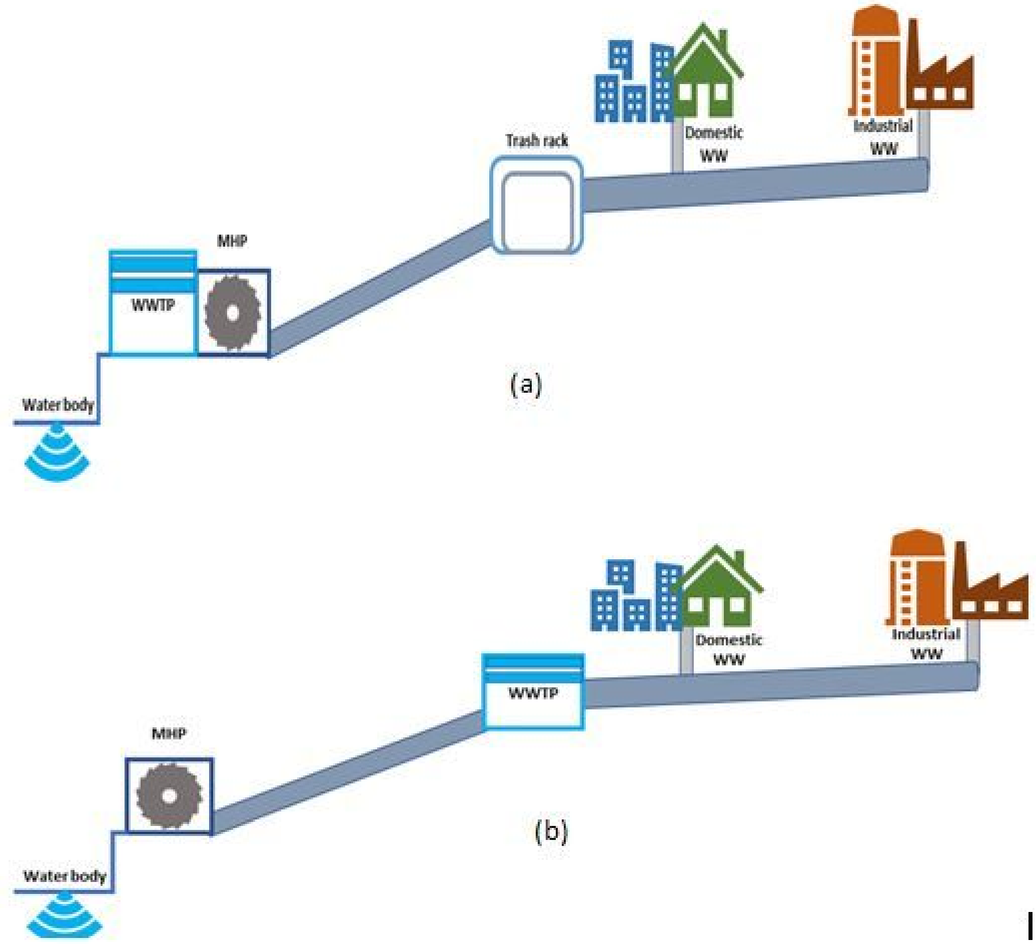

Figure 4

(a) Downstream Effluent Micro hydropower plant (DE-MHP) (b) Upstream influent hydropower plant (Modified from C. Bousquet et al. 2017)

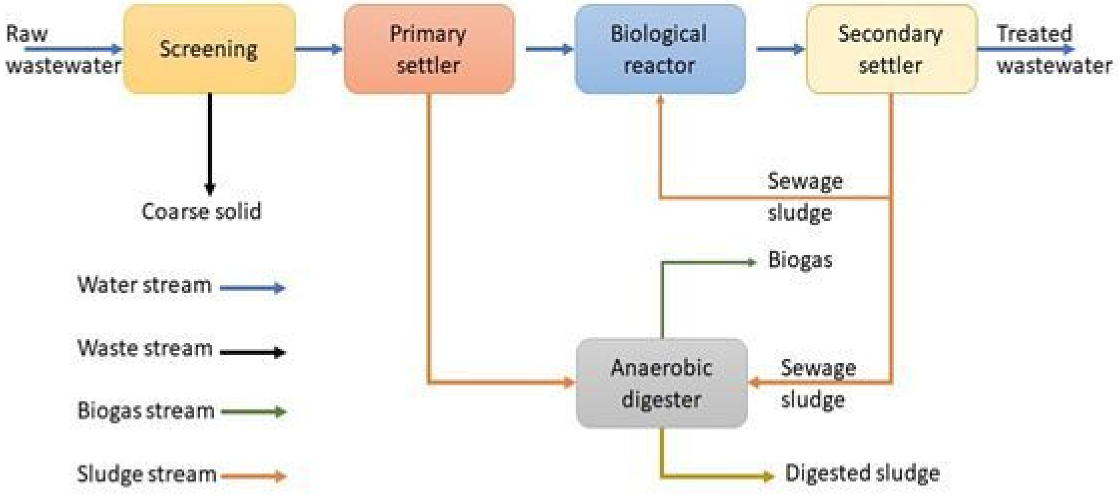

Figure 5

Schematic Illustration of biogas production from wastewater

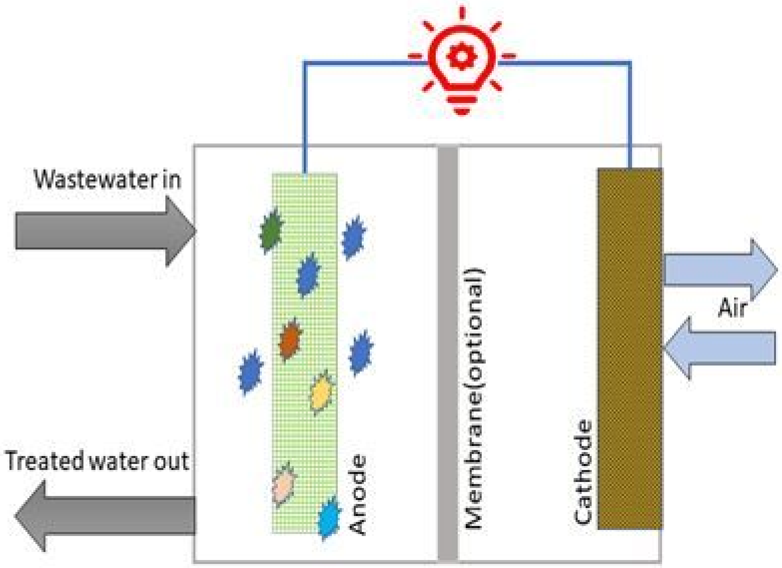

Figure 6

Schematic diagram of MFC

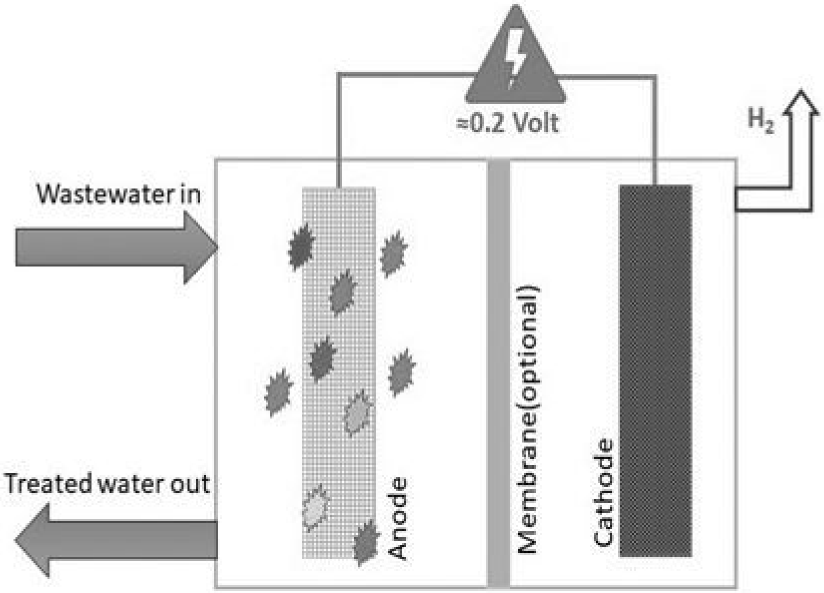

Figure 7

Schematic diagram of MEC

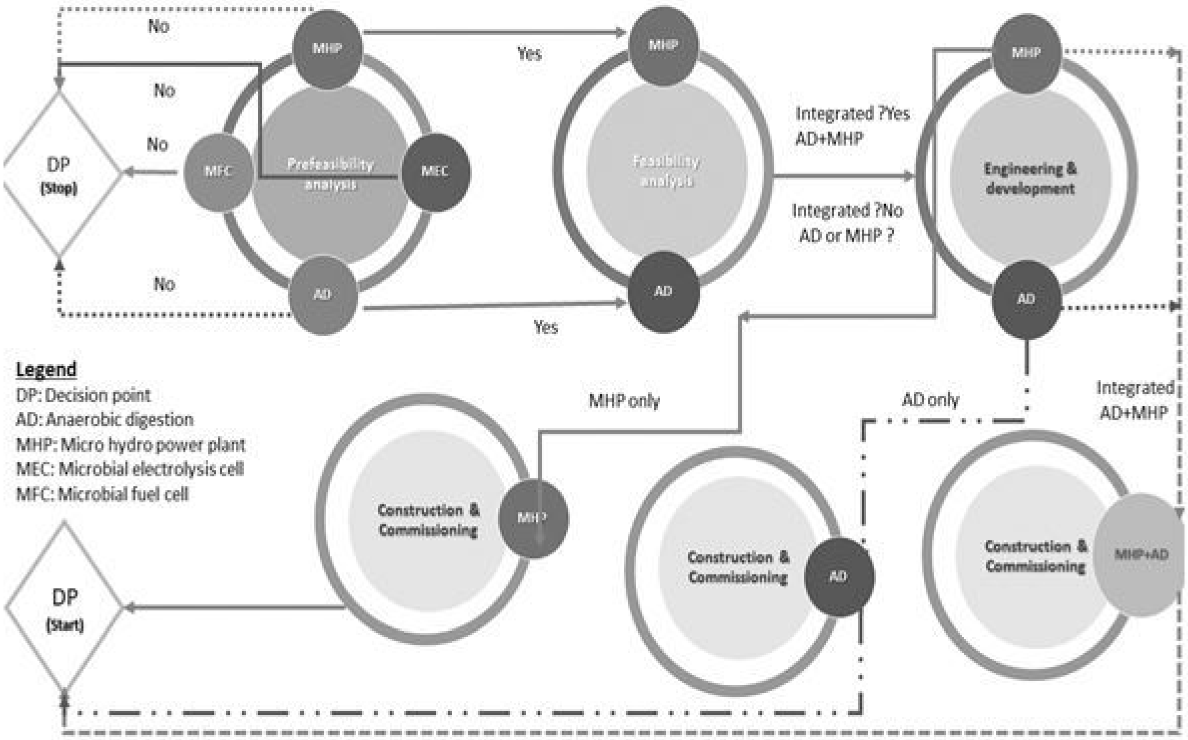

Figure 8

Flow diagram of integrating energy generation technologies at WWTP.

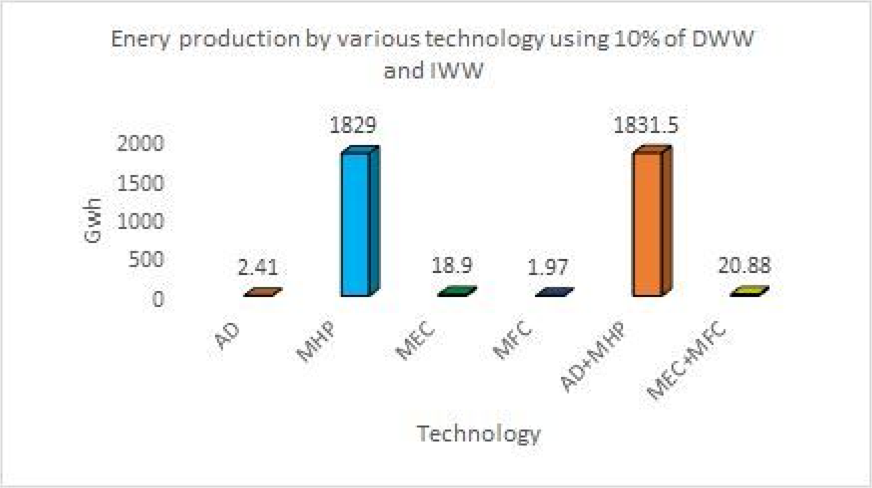

Figure 9

Energy potential based on different technology

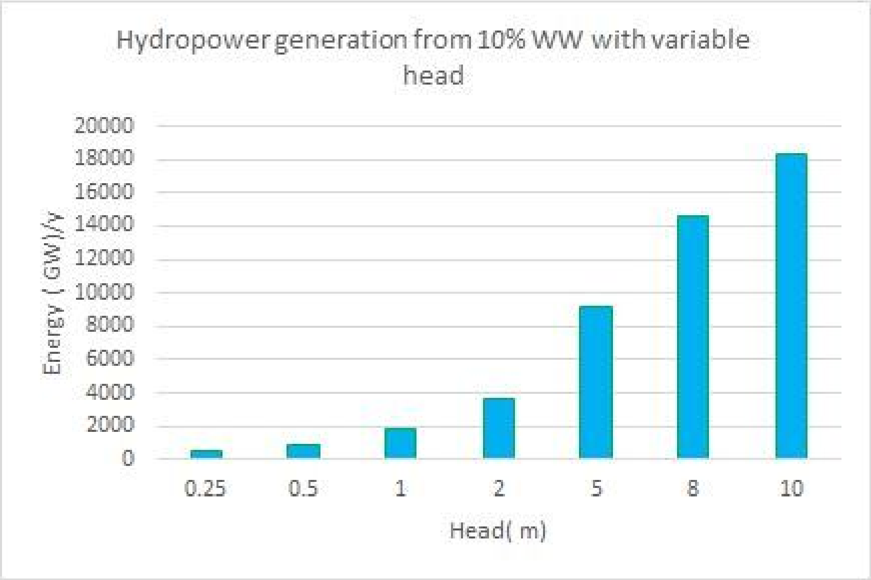

Figure 10

Hydropower potential based different head.

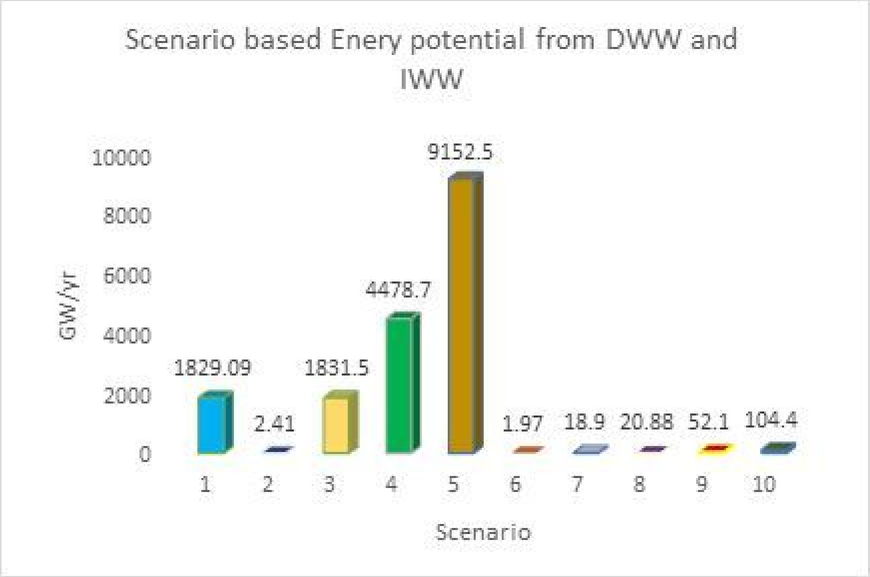

Figure 11

Scenario based energy potential

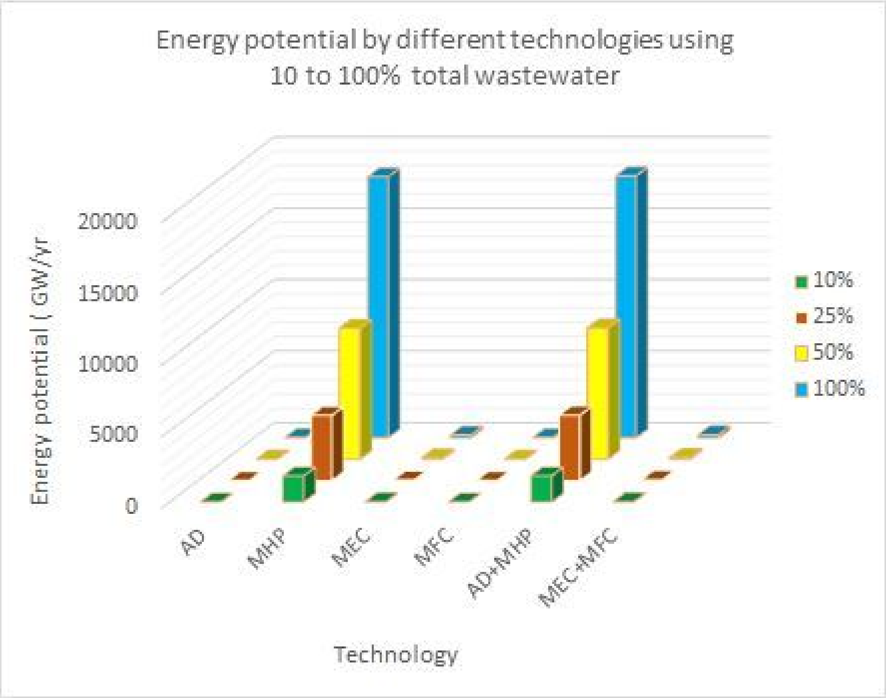

Figure 12

Estimated energy potential by different technologies using10 to 100 % wastewater