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# Anaerobic digestion industries progress throughout the world

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**Abstract.** Anaerobic digestion is a process where microorganisms degrade organic matter in the absence of oxygen to produce biogas, mainly composed of methane and carbon dioxide. Recent years have seen a strong development of anaerobic digestion units worldwide, especially in USA, Europe and China. Countries like China, Germany, USA, Italy, UK and France are seen leading in the biogas sector in the world due to long establishment, intensive research and government incentives for renewable energy as well as waste management solution option. Asian countries have also shown their interests in the biogas technology. With more proper research and studies on-going, Asia will see the growth of biogas sector in the next few coming years. Even though African countries are in their primary phase to develop this biogas technology and there are still more hurdles to overcome, there have been interests, development and implementation work to apply this technology for its potential renewable energy production as well as its waste management solution.

## 1. Anaerobic digestion progress throughout the world

Anaerobic digestion is a process where microorganisms degrade organic matter in the absence of oxygen to produce biogas, mainly composed of methane and carbon dioxide. Biogas can be used as heat, or combined heat and power generation or after upgrading bio-methane can be used as biofuel or injected into the natural gas grid. The residual material, called digestate, contains undigested organic matter from the substrate, residual compounds produced during anaerobic digestion and microorganisms. It is rich in minerals such as nitrogen and phosphorus and can be used as organic fertilizer. Anaerobic digestion has thus the double advantage of presenting a sustainable process for waste management and both renewable energy and fertilizer production while reducing greenhouse gas (GHG) emission [1].

Recent years have seen a strong development of anaerobic digestion units worldwide, especially in USA, Europe and China (Table 1). USA presents the highest total biogas production but originating from landfill at 75% [2]. In this country there are 1,497 anaerobic plants in 2013 [3] treating sewage sludge, biowaste, agricultural and industrial wastes. On the other hand, biogas production in Germany is mostly based on agricultural and industrial wastes (Table 1).

China, with 26.5 million plants in 2007 [2,4] produces biogas which mainly originates from sewage treatment (Table 1) but there are about 40 million domestic small biogas plants [5] and these provide



households with gas for cooking and lightening. Such domestic biogas plants are also spread in India (4 millions), Nepal (0.25 million) and the rest of Asia (0.25 million) [5–7].

**Table 1.** Production of biogas in 2013 in USA, Germany, China, Britain, France and Italy adapted from Deng et al [2].

	Biogas production (ktoe)	Landfill (%)	Sewage (%)	Others (%)
USA	5095	75	2	23
Germany	4213.4	6.3	9.2	84.5
China	3727.5	24	70	6
Britain	1723.9	85.5	14.5	-
France	526.2	84	8	8

In India, according to Rao et al [8], the total installed capacity of energy generation from solid biomass and waste till 2007 was 1227 MW against a potential of 25700 MW from municipal solid wastes, crop residues and agricultural wastes, sewage sludge, animal manure and industrial wastes (distilleries, dairy plants, pulp and paper, poultry, slaughter houses, sugar) which could reduce the energy supply deficit in the country [8]. It was estimated that the biogas potential in India in the year 2040 was in the range from 310 to 655 billion m<sup>3</sup>/year [9] compared to current biogas production in India which is about 2.07 billion m<sup>3</sup>/year [10]. This great potential for biogas expansion is also good to combat current indoor air pollution in India [11].

Other Asian country for an example in Iran, a study on the evaluation of biogas potential from livestock manures and rural wastes using GIS in Iran has been conducted. It was observed that about 2740 million m<sup>3</sup>/year of methane can be annually produced using livestock manure and rural wastes [12]. Another study in Iran on the potential of electricity generation through anaerobic digestion of agricultural and livestock/slaughterhouse wastes was also conducted in the year 2016 [13]. The study observed that Khuzestan province with the highest amount of agro-wastes (7.61 million tons) had the maximum electricity generation potentials of 82.83 MW. Meanwhile, Sistan and Baluchestan province which have the highest amount of livestock/slaughterhouse wastes (10.69 million tons) had the maximum electricity generation potentials of 164.23 MW. The study also observed total potential of electricity generation for the country from agricultural and livestock/slaughterhouse wastes of about 2828.26 MW, with a minimum of 10,693.5 thousand tons CO<sub>2</sub>eq/yr or 1.5% annual GHG emissions could be avoided [13].

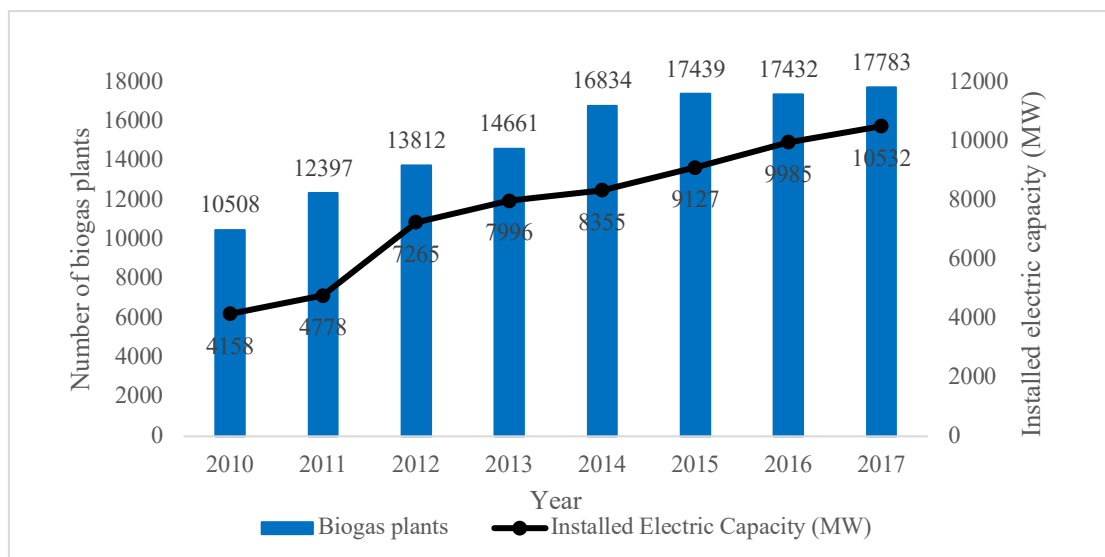
In Malaysia, the study of the potential and challenges of anaerobic digestion technology implementation for biogas production from various waste water treatment and waste management industries in Malaysia has been investigated [14]. In the study, Malaysia has the potential of electricity generation capacity of 2135 MW with the reduction of 11.35 Mt of CO<sub>2</sub> equivalent by the year 2020 through anaerobic digestion [14]. The potential substrates for anaerobic digestion plants in Malaysia are palm oil mill effluent (POME), sewage sludge (SS), chicken manure, swine manure, dairy manure, sheep manure, goat manure, banana, animal blood, animal rumen and food waste [14–19].

In comparison to other Asian country, Vietnam has installed many biogas plants for manure management especially in the central Vietnam with the primary increase supported by the introduction of financial compensation from the government in combination with international organizations such as SNV Netherland Development Organization [20]. According to Roubik et al [20], there was about 110,000 and 200,000 small-scale biogas plants constructed from year 2003 until 2013 and from year 2013 until 2018, respectively with the support from SNV Netherland Development Organization and other organizations. Those biogas plants were constructed for small-scale farmers for manure management practice as well as an alternative for energy source such as a substitute for conventional cook stoves [20,21]. In his survey, most of the biogas plants (from 141 biogas plants surveyed) in central Vietnam are mostly fed with pig manure (54% of total biogas plants surveyed) with others fed with mixture of pig manure and human excreta (41% of total biogas plants surveyed) or mixture of pig manure, human excreta and other animal manures (5% of total biogas plants surveyed) [20]. However,

29% of the biogas plants surveyed have encountered at least one problem with most frequent problem is linked to leakages from the reactors leading to the emissions of undesired methane ( $\text{CH}_4$ ) [22].

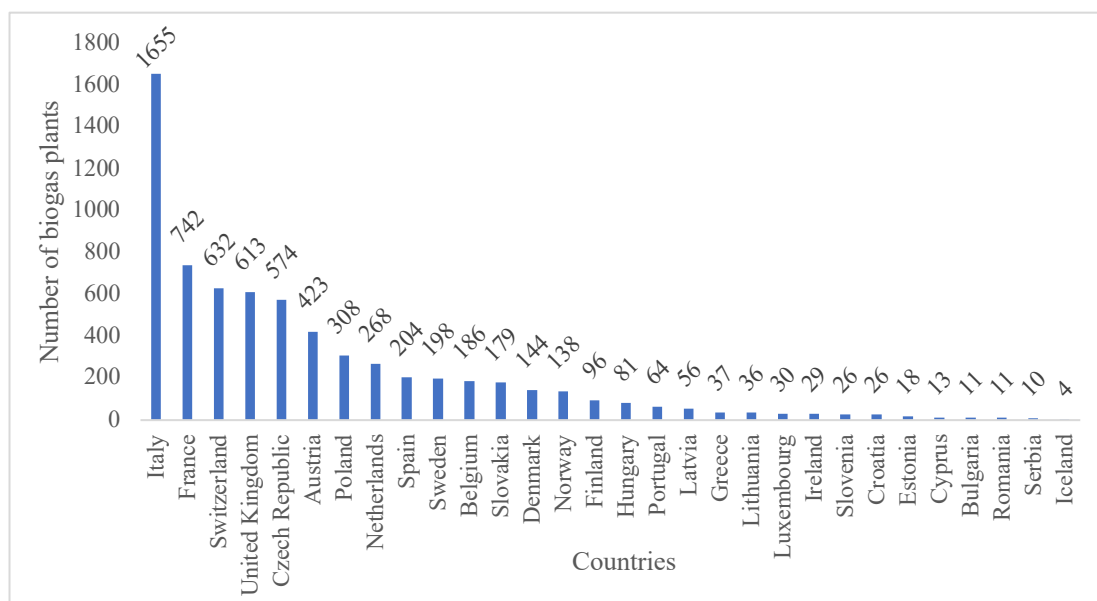
In Africa, anaerobic digestion is still at an early stage even though recent initiatives have shown an increase of interest for the technology [23]. National biogas programs have been implemented in Kenya, Uganda, Ethiopia, Tanzania, Rwanda, Cameroon, Burkina Faso and Benin where these countries are seen as the model for startup for other African countries without assistance from other countries [23]. The biogas technology in Africa is not just seen as an option for renewable source for electricity but also for solving waste management problems [23]. However, there are still problems to overcome for anaerobic digestion implementation in Africa such as requirement for stronger commitment from the government, more communications, awareness and knowledge to be expanded to the public, government and private sectors as well as more commercialization especially from stakeholders and investors [23–25].

As the world leader in biogas electricity production, The European Union (EU) has 17,783 plants that were counted in 2017 with more than 10 GW installed electric capacity [26] compared to global biogas capacity of 15GW in 2015 [27]. Commitment to European Union (EU) requirements to increase renewable energy sources (RES) for electricity by 2020 as well as the high feed-in-tariffs and high state incentives for renewable energies has led to a rapid increase of agricultural anaerobic digestion plants [28–32]. Therefore, an increase of 69% of biogas plants in Europe can be seen within seven years from 2010 to 2017 with an increase of 153% of installed electric capacity (MW) as shown in Figure 1. With more than 10,000 plants (Figure 2), Germany presents the highest biogas production in Europe, the main part originating from agricultural biogas plants (Table 1). This is also similar to Italy with the second highest number of biogas plants in Europe (Figure 2), with 80% biogas plants fed with substrates from agriculture [29]. In France and the United Kingdom (Britain), biogas production mainly originates from landfills (Table 1), however a growing number of agricultural plants in these countries and the ban of organic waste landfilling might reverse these trends [29]. The development of biogas in Europe has gone beyond than its use for electricity and heat. Biogas upgrading to biomethane has started as an alternative to the direct use of biogas for heat and power. In addition, biomethane is increasingly used as vehicle fuel or for injection into the natural gas grid [27]. However, the limitation of biogas upgrading to biomethane is that upgrading the existing biogas plants are not profitable compared to the construction of new biomethane plants [33].



**Figure 1.** Number of biogas plants in Europe from 2010 to 2017 with installed electric capacity [26].





**Figure 2.** Number of biogas plants in Europe in 2017 excluding Germany with 10971 biogas plants [26,34].

## 2. Conclusion

Overall, worldwide, the increase of biogas technology implementation and the development of anaerobic digestion shows that this technology is seen as a solution for waste management and as an alternative for renewable energy. More works are on-going to improve the facilities and research in anaerobic digestion. Countries like China, Germany, USA, Italy, UK and France are seen leading in the biogas sector in the world due to long establishment, intensive research and government incentives for renewable energy as well as waste management solution option. Asian countries have also shown their interests in the biogas technology. With more proper research and studies on-going, Asia will see the growth of biogas sector in the next few coming years. Even though African countries are in their primary phase to develop this biogas technology and there are still more hurdles to overcome, there have been interests, development and implementation work to apply this technology for its potential renewable energy production as well as its waste management solution.

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