Evaluation of biogas potential from livestock manures and rural wastes using GIS in Iran

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Abstract

The increasing demand of energy, fossil resource limitation and environmental pollution due to fuels combustion has motivated researchers to study about renewable sources of energies. Biogas is a renewable energy resource which is produced through decomposing organic waste under anaerobic conditions and is mainly composed of methane (60%) and carbon dioxide (35–40%). Anaerobic digestion of livestock manure and rural waste, which need to be managed properly to prevent pollution, can be used for sustainable biogas production, reduction of unpleasant odors and microbial pathogens and production of rich fertilizers. This study addresses on how utilization of information such as rural and livestock population, land-use maps and geographic information system (GIS) can be employed to develop a model for evaluation of biogas production from livestock manure and rural household waste, in Iran. The model can be used to identify the appropriate locations for construction of biogas production plants. Moreover, the analysis process used in the current study relies on more spatially detailed information about the available biomass and suitable sites for biogas plant construction, compared to the previous studies conducted in Iran. The results showed that 2740 million m³/year of methane can be annually produced using livestock manure and rural wastes.

1. Introduction

World’s energy demand is growing fast because of population explosion and technological advancements. The limitation of fossil fuel resources and negative environmental effects need special attention to be paid to reduction of fossil energy use. Alternatively, renewable energy sources should be increased. A renewable energy option is biogas and its application is growing fast, in many countries. It is primarily composed of methane and carbon dioxide gas and its production plant, according to the level of technology and economic aspect, is appropriate for farmers of developing countries [1]. It can be produced by bacteria that decompose organic matter in anaerobic conditions. Organic materials such as animal, human and plant wastes are biodegradable and some parts of them can be fermented under special conditions without oxygen and can be converted into biogas. Almost any wet organic matter is suitable for fermentation or anaerobic digestion. In general, wastes from livestock (manure and fodder wastes), plant wastes (straw and forage), household wastes (human waste, household garbage and sewage) are suitable types of biomasses for biogas production.

Conversion of organic waste, such as livestock manure, and rural wastes into biogas is important from different aspects: high energy released from biogas, i.e. heating value, that can be directly used as an alternative to fossil fuels; significant effect of using this technology on environment and human health through hygienic disposal of wastes; and generation of rich fertilized from sludge (soft slurry) and biogas plant output that can increase the efficiency of agricultural crops accordingly. The best place to establish a biogas reactor should be close to the source of biomass materials in order to overcome the difficulties of fuel transportation and rural waste disposal. From a long time ago, livestock wastes have been a source of energy and value-added source for livestock production, in many countries. From an energy point of view, the biogas generated will be used for electricity generation and/or heat generation [2]. The biogas also can be fed to the gas network after purification process.

In Iran, livestock waste accumulation has caused unfavorable conditions due to creating a favorable environment for growth and spread of microbes, in addition to intolerable odor and insects. At the same time, many farmers have to provide their energy supplies...
by local trucks and tankers, which in turn cause some financial losses, indirectly. Many studies have been carried out on assessing the potential of biogas production from wastes in many countries. For example, the potential of biogas production from farm animal manure and slaughterhouses was studied in Malaysia. The results showed that the amount of 49.4589 million m³/year of biogas (equivalent to 27.8 × 10⁶ kWh/year) can be produced annually in Malaysia [3]. Another research investigated the potential of biogas production from organic waste and its usage for power generation, in Indonesia. They selected 391 different locations with theoretically, technically and economically potential capacity for construction of biogas production plant [4]. A number of other studies have also estimated the amount of biogas that can be produced from organic wastes and have proposed how far biogas can contribute to providing energy requirements for power generation and transportation sectors [2.5–7].

In Iran, the amount of available biogas which can be obtained from livestock manure and slaughterhouse waste was reported as 8600 million m³/year [8]. However, they did not outline a proper model, based on geographic information, to find an appropriate location for biogas production plants. Since biomass is a geographically dependent renewable resource, in addition to determining the proper type of biogas plant, finding the suitable location place for construction is also very important. Since industrial animal husbandry is very limited in Iran and most livestock are raised by rural families, the fixed volume biogas unit (Chinese type) has been recommended for Iran situations [9]. Geographical Information Systems (GIS) is a powerful tool that enables integrating data of various constraining and favoring factors and performing spatial analyses for feasibility of evaluation and location optimization. Several studies have concentrated on site selection for biogas plants so far [10–16], e.g. this analysis tool has been used to locate the suitable sites for establishing biogas plants that utilize manure resources, in New York State [17]. Also, the optimal location for biogas production in south Finland has been determined based on geographic information system (GIS) [18] and a GIS-based method has been presented for evaluating the potential of biogas production from livestock waste (including beef and pork) and forage crops, in Poland [19].

This study aims to investigate convenience of biogas production from livestock manure and rural waste, in Iran, and develop a map for allocating the appropriate location for biogas plants based on the geographic information system.

2. Materials and methods

The theoretical biogas potential is defined as the possible amount of gas production from biomass, such as livestock manure and rural wastes, in a region. This potential can be calculated using parameters including livestock weight, the ratio of the annual manure generation to livestock weight and volume of methane production per kilogram of waste as shown in Table 1. With this purpose, information about the number of livestock, rural population, the average amount of wet waste produced by each person and biogas production per kilogram of livestock manure and rural household waste was collected from the Statistical Center of Iran [20], Agriculture Ministry of Iran and previous literature [9,21–25].

The retrieved information was classified based on livestock’s types, i.e. cow, sheep, and goat (Table 2). However, it is clear that only a fraction of the total waste can be collected since there are always some constraints preventing collection or some alternative applications for the waste. The available waste can be obtained by applying these constraints [2].

The average weight of livestock was estimated according to the dominant races of the area. As stated in Table 1, livestock weight was considered in the range of 500–620 and 50–60 kg for heavy and light livestock, respectively. The total amount of livestock waste can be calculated by multiplying the waste mass by the effective population number. Based on the average of rural waste for individuals and rural population, the total amount of waste could be also calculated. The theoretical methane potential was calculated for each province of Iran according to Eq. (1) by using the methane potential from each feedstock material.

\[
\text{TMP} = (rp \times dw \times 0.13) + (cp \times awm_c \times 0.14) + (sp \times awm_s \times 0.1)
\]

where \(\text{TMP}\) denotes the theoretical methane potential (m³/year), \(rp\) is the rural population, \(dw\) represents the degradable waste produced per person (kg/year), \(cp\) is the cow population and \(sp\) is sheep and goat population. \(awm_c\) stands for annual weight of cow manure and \(awm_s\) is the annual weight of sheep and goat manure. Accordingly, the amount of producible biogas depends on the amount of waste that can be accessed and the total solids of the waste that can be obtained from livestock or other sources. These two parameters can be considered together as availability coefficient which equals to 0.13, 0.14 and 0.10 for rural waste, cow manure and light livestock, respectively [2,22].

Due to incomplete anaerobic conversion of the feedstock in biogas plants, the available methane potential is less than the theoretical potential. Therefore, in the calculation of biogas potential, accessibility coefficient of 70% for livestock manure and rural waste was applied [2]. The total amount in terms of m³/km²/year was then calculated by summation of the values obtained from these two sources of biogas production. For presentation of the available methane potential, it was assumed that the biomass would spread uniformly over the entire area of each province [26].

The amount of energy produced from methane (MJ/year) was calculated based on Eq. (2):

\[
E_{\text{methane}} = \text{AMP} \times \text{ECM}
\]

here, \(\text{AMP}\) represents the available methane production (m³/year) and \(\text{ECM}\) is the coefficient of methane energy content (MJ/m³) that is considered to be equal to 36 MJ/m³.

In order to visualize the spatial distribution of methane production, annual methane potential was saved in a geo-referenced database with considering the type of biomass. ArcGIS was created to allow spatial data to be illustrated using the information of both rural and livestock populations. The same methodology was also applied to each source of information, rural population or

<table>
<thead>
<tr>
<th>Material type</th>
<th>Livestock weight</th>
<th>The ratio of The annual livestock manure to livestock weight</th>
<th>Volume of produced biogas m³/kg</th>
<th>Methane content %</th>
<th>Volume of methane m³/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cow manure</td>
<td>500–620</td>
<td>2.6</td>
<td>0.26–0.28</td>
<td>50–60</td>
<td>0.14</td>
</tr>
<tr>
<td>Sheep &amp; goat manure</td>
<td>50–60</td>
<td>3.36</td>
<td>0.22–0.24</td>
<td>40–50</td>
<td>0.1</td>
</tr>
</tbody>
</table>
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