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Original Research Article

Environmental assessment of energy production from landfill gas plants by using Long-range Energy Alternative Planning (LEAP) and IPCC methane estimation methods: A case study of Tehran

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ABSTRACT

This study aims to analyze the electricity generation and its environmental aspects in Tehran city by using the LEAP model and developing two scenarios, including Business-As-Usual and Sustainable-Waste-Management (SWM). The base and final years of the planning are 2012 and 2035, respectively. It is attempted to integrate two models of IPCC (Intergovernmental Panel on Climate Change) for methane flow rate estimation and LEAP to estimate Tehran's energy and non-energy emissions. By linking these two models, the energy and environmental effects of the SWM scenario are estimated. To calculate the power production of the landfill gas (LFG) plants, the gas turbine model of GE10 is selected, and an Engineering-Equation-Solver (EES) code is developed based on methane flow rate and composition data obtained from the IPCC default method in the SWM scenario. The combination of EES codes and LEAP analysis shows that the LFG plants can supply 0.5 GW h power, which is 1.4% of the total demand in 2016, but it will raise to 0.9 GW h in 2035. Although utilization of LFG plants increases the cost of electricity production, the accumulated difference of 100 years global warming potential in the studied scenarios will be 81.2 Mt CO_2 equivalent from 2012 to 2035.

Introduction

Today, it is undeniable that the electricity generation of the industry throughout the world is significantly oil dependent, and substituting other energy resources for this black gold in a short term period is impossible. As a result, with respect to the intensive demand of energy, the environmental problems have become one of the most important concerns of the human beings. Thus the necessity to move away from or at least decrease the reliance of oil as soon as possible is essential.

It is known that oil resources are distributed unevenly around the world. Over 60% of oil reserves are found in Middle East [1]. Iran is one of the most hydrocarbon-rich areas in the world and Tehran, the biggest city of Iran, is one of the major consumers of oil and gas due to high electricity demand.

Given the importance of energy supply issue, all policymakers, politicians and stakeholders in the energy sector are concerned with finding solutions for the mentioned problems [2]. The first movements for planning energy resources was after the oil shock of 1973 so that the thoughts were focused on energy conservation and energy substitution [3]. Mounting the environmental concerns in 80s, modified the criteria of the decisions and dictated the importance of considering a combination of technical, environmental, political and economic factors for planning in this field to achieve sustainable development goals (SDGs) [4].

Several research papers have discussed the energy and electricity sectors planning based on different scenarios in the literature. For instance, Mulugetta et al. analyzed power sector scenarios till 2022 in Thailand [5]. Renewable energy resources have also been an important issue in these research projects. In Canada, a multi criteria study on renewable resources and choosing the best resource among five possible resources, regarding six factors has been performed [6]. In a similar research, Kowalski et al. designed regional and national scenarios to evaluate the renewable resources until 2020 in Austria [7].

The agenda of most of the scenarios in the research articles are investment on improving fossil fuel power plant efficiencies and establishing nuclear and/or renewable power plants. In Iran, for instance, a research study evaluated impacts of price change and energy efficiency programs on the consumption of energy carriers

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as well as greenhouse gas mitigation in the Iranian residential buildings sector by employing the Long-range Energy Alternative Planning (LEAP) model [8]. Considering the importance of less dependence on oil and gas and also mitigation of greenhouse gases and environmental pollutions, using renewable resources is a very intellectual solution. Using biomass, geothermal, solar and wind power systems and also landfill gas to produce electricity with respect to their different effects is highly noticeable. An illustration of these efforts is the analysis of environmental and economic impacts of using landfill gases (LFG) for electricity generation in Korea by utilizing the LEAP model. This study aimed to indicate the electricity generation by using LFG as an effective solution for CO_2 displacement over the medium term together with additional energy profits which would reduce the global warming potential by a maximum of 75% compared to spontaneous emissions of CH_4 [9]. Another research on substituting biomass with other energy carriers in Vietnam using the LEAP model showed that this fuel substitution led to a 10.83 million-tonnes reduction in greenhouse emissions [10]. LEAP was also employed to model wind energy usage in Panama's electricity sector [11] and development of solar and wind power in Ethiopia [12].

The energy potential from landfills has also been the subject of some research papers recently. For instance, Scarlat et al. [13] measured the energy potential of all waste generated in Africa and indicated if African governments decide to recover it and generate electricity, it can meet a considerable amount of demand. In addition, Ahmed et al. [14] estimated LFG capture and developed methods for the applying LFG as a renewable energy resource. They used the Intergovernmental Panel on Climate Change (IPCC) model and concluded that an average annual LFG amount of 17,200 tonnes obtained in Iskandar, Malaysia can be utilized as a fuel for efficient and economically justified power generation in the power plant.

As it can be seen, although many researchers have developed sustainable scenarios for long term energy generation in different regions of the world, a comprehensive long term study of the LFG potential for electricity generation in Tehran as the largest city of Iran has not been conducted yet. Moreover, although some papers in the literature have investigated landfill energy generation potential by different methods, no study has coupled the IPCC method with LEAP and developed a special coding for electricity generation by this method. This study can be used as a useful reference for energy planners in Iran for investment on LFG based power plants which will help to meet the electricity demand of the city as well as mitigating CO_2 emissions.

By assuming that Tehran should meet its own consuming electricity demand, the scope of this study is to analyze the electricity supply sector of Iran's largest and the most populated city from 2011 to 2035 in order to observe the changes in electricity production and distribution and also environmental issues when feasible Sustainable Waste Management scenarios are applied. Different from the studies in the literature, present study estimates the amount of methane production from the landfill gases by linking LEAP to the IPCC methane estimation method. Moreover, to forecast the potential of electricity generation by gas turbine power plant from the LFG, an EES coding is developed.

Methodology

Tehran is the capital of Iran with a population of about 8.3 million. It is also one of the largest cities in western Asia. With respect to population, a large amount of daily wastes for disposal in landfills is imaginable. In fact, about 7500 tons of wastes are taken from Tehran every day. Hence, significant effects of correct waste management on global warming, economics and energy supply of this city is obvious. For instance, by using biogas extracted from the landfills, policymakers can not only meet carbon reduction goals, but also plan for supplying more energy demands by adding an abundant and promising renewable energy source.

Landfill power production configuration

Landfill gas is created during the anaerobic decay of natural and wet substances in municipal solid waste (MSW). Based on the landfill design and its management and also waste composition, moisture and many other factors, landfills are accessible to accumulate and utilize this profitable renewable resource for power generation.

For a landfill restoration that prevents greenhouse gas emissions into the air, the emissions must be continuously taken out under the controlled conditions. Punctured tubes are buried into the landfill body and interconnected by a pipework system. By utilizing a blower, the gas is sucked from the landfill. A well planned gas gathering system will adaptably catch the landfill gas from different spots and handful high temperatures, leachate, condensates and air content along these lines, guarantee an expense proficient accumulation and in addition stable landfill gas quality. The main components of a typical landfill gas for energy system including separator, compressor, acid gas removal column and gas turbine generator are depicted in the Fig. 1.

Long-range Energy Alternative Planning (LEAP) model

In this research, energy and environmental modeling is carried out for Tehran. In many similar studies as cited in the introduction, LEAP has been employed as a tool for forecasting, planning and optimizing the future conditions of energy and environmental systems. LEAP software is used in this research obtaining all of the generation, transmission, distribution and consumption details to assess the scenarios which anticipates the environmental and technological behavior of the proposed system. LEAP is able to model both supply and demand sides and keeps economic aspects available for users. It can provide a widespread database of fuels, environmental effects and various technologies of energy systems (entailing: conversion, generation, transmission and distribution

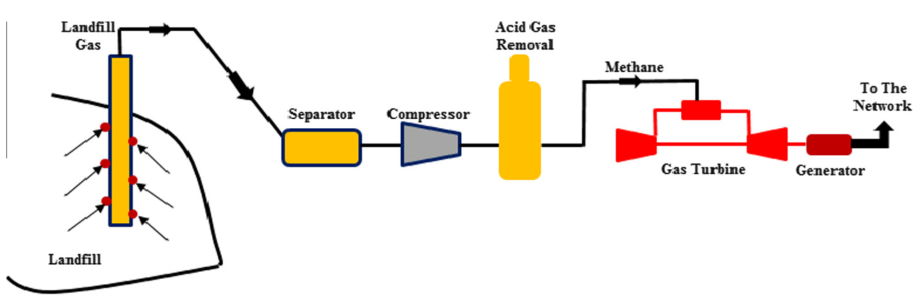

Fig. 1. Landfill power production configuration.