Analysis of greenhouse gas generation models at household waste landfills for ecosystem applications

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Abstract. The control and minimization of greenhouse gas emissions is an important task of modern ecology. One of the sources of greenhouse gases is landfills of household waste (LHW). A special feature of LHWs, as a source of greenhouse gases, is the complexity of estimating emissions. The fact is that the production of greenhouse gases (mainly methane) at LHW is a long process, time-consuming and dependent on many factors. In particular, the rate of putrefaction of organic waste depends on environmental parameters, such as temperature, humidity, and precipitation patterns. Knowing the estimates of greenhouse gas emissions, it is possible to develop an appropriate technology for their disposal, taking into account the regional features of the location of landfills. A mathematical model of gas formation on LHWs is required to solve the problem of predicting greenhouse gas emissions from these landfills. Currently, there are several generally accepted models of LHW. This paper reviews the three main models used in world practice: LandGEM, EPER-Germany, and TNO in terms of their universality and applicability for describing LHW from Siberia region. It was shown that the most promising model is LandGEM.

1 Introduction

The impact of greenhouse gases on climate change is an urgent environmental problem. Significant sources of greenhouse gases are landfills for household waste (LHW). When organic waste rotts, various gases are released, of which methane is the most dangerous in terms of the greenhouse effect. Since methane is 21 times higher than CO_2 in terms of the greenhouse effect [1], one of the most common ways to minimize the consequences of gas formation at PBW is to collect landfill gas and then use it as fuel [2-3]. However, in the case of Siberia, such a method of disposal may have problems with economic feasibility due to climate conditions. An alternative approach to the problem of landfill gas is the reclamation of landfills using green spaces [4-5].

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Closed artificial ecosystems, such as experimental biotechnical life support systems [6-7], can also be used as a basis for developing technologies for the disposal of gaseous waste [8] from landfills.

Mathematical modelling of the system reduces either to the selection of a function from the variables of the system that best describes the experimental data, or to the identification of key mechanisms of the process and their mathematical description [9]. In both cases, the resulting model needs to be verified – to check the possibility of describing a real system and select parameters for describing a specific system.

Not all parameters of the system and its mathematical model can be obtained by direct measurement. A number of parameters, so-called "fitting" parameters [10], can be determined only by trying to describe the dynamics of a real system using a model. One of the problems of modern mathematical modelling is the fact that in case of a sufficiently large number of fitting parameters, the model can describe any dynamics, but only in the section used for validation without a guarantee of correct prediction of future dynamics.

The aim of this work was to review three popular mathematical models of gas formation on the LHW for the number of fitting parameters and their applicability to the description of LHW for Siberia conditions.

2 Materials and methods

Various mathematical models are used to describe the process of generating greenhouse gases from LHW. The LandGEM model [11-12] recommended by the US Department of Environmental Protection, is widely used. Other common models of gas formation on LHW are EPER-Germany [11-14] and TNO [11, 14].

The LandGEM Model.

The Land GEM model is described in detail in [11] and is based on extensive empirical material from landfills in the USA and Canada. The model equation has the form:

$$Q_{CH4} = \sum_i \sum_j k * L_0 \left(\frac{M_i}{10}\right) \exp\left(-kt_{ij}\right) \quad (1)$$

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Where Q_{CH4} is the amount of methane released per year (cubic meters per year,), k is the gas generation constant, i is the year number, j is the number of the tenth part of the year (i.e. approximately a month), L_0 is the maximum gas generation, M_i is the rate of garbage delivery to the landfill, t_{ij} is the time. Carbon dioxide emissions are calculated from methane emissions obtained in the model using an empirical proportionality coefficient. In addition to methane and carbon dioxide, the emissions of another 50 pollutants are calculated. The coefficients of the model can be empirically estimated, and the model is widely used in the United States and around the world. There is a free software implementation of the model, which is a Microsoft Excel workbook.

As can be seen from (1), the model is based on the assumption that the decay of organic matter is described by a simple exponential law. Fitting parameters include k and L_0.

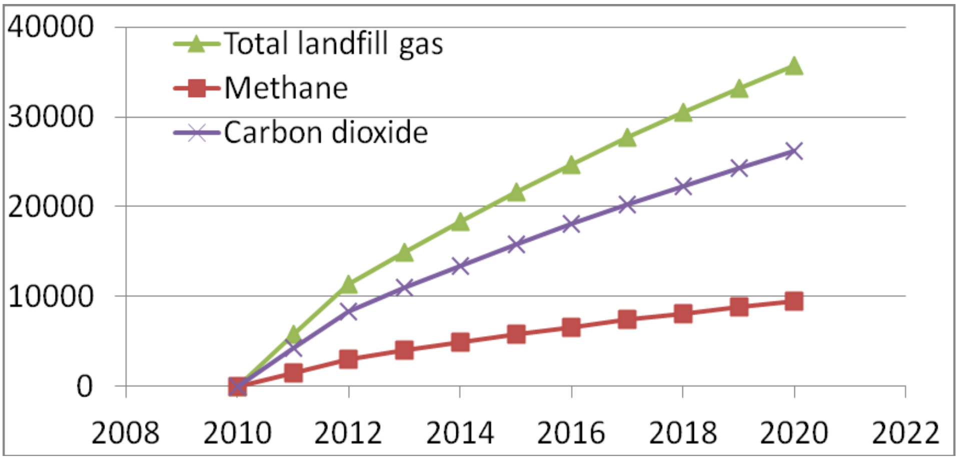

Fig. 1. Example of calculating the total amount (tons) of landfill gases, methane and carbon dioxide in the LandGEM v 3.02 model produced by Krasnoyarsk LHWs. Scenario with garbage recycling since 2012.

An example of how the LandGEM model works is shown in figure 1. The data about Krasnoyarsk LHWs from Krasnoyarsk officials [15] was used. In 2012 waste input to LHW was reduced from 280000 tons/year to 200000 tons/year due to starts of garbage recycling. As can we seen from figure 2, in scenario with no garbage recycling LHW may produce 220000 tons of landfill gases in contrast to 165000 tons in scenario with garbage recycling.

The LandGEM model is widely used in PBW modeling in various countries [11-12;14;16-18]. In the context of this work, it is particularly worth noting the work [14] in which 35 landfills in Canada were successfully modeled using the LandGEM model, which means that the model is fundamentally applicable in Siberia.

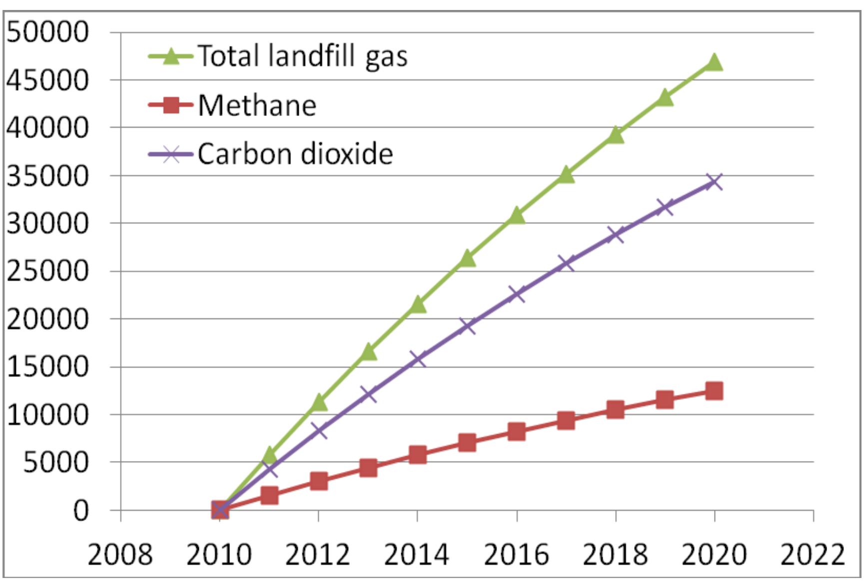

Fig. 2. Example of calculating the total amount (tons) of landfill gases, methane and carbon dioxide in the LandGEM v 3.02 model produced by Krasnoyarsk LHWs. Scenario without garbage recycling.

The EPER-Germany model.

The EPER-Germany model was created and is used in Germany and is the so-called zero-order model. This is a simple balance equation that describes only the current landfill, but not the landfill that has stopped working. Model equation:

$$Q = M * DOC * DOCf * F * D \quad (2)$$

Where Q and M correspond to model (1), DOC is the share of carbon-containing waste in the total mass, $DOCf$ is the share of DOC available to methane-synthesizing bacteria, F is the share of methane in landfill gas, and D is the efficiency of gas collection (for incineration). The model's fitting parameters $DOCf$. DOC, F and D can be measured.

The EPER-Germany model is also widely used for modeling landfills [14;19-20]. In [14], an attempt was made to use the model to describe landfills in Canada, but the result was significantly worse than that of LandGEM.

The TNO Model.

The TNO model is similar to the LandGEM model, but instead of a discrete equation, a differential equation is used. This model is used in Denmark. The model equation has the form:

$$Q = 1.87 * M * DOC * DOCf * k * \exp(-kt_{ij}) \quad (3)$$

The designations are identical to (1) and (2). The difference from the LandGEM model is the use of explicit parameters for the proportion of carbon in total biomass and the proportion of carbon available for decomposition instead of the maximum decomposition rate.

3 Results and Discussion

The authors of the three main modern models of gas formation at solid waste landfills minimized the number of adjustment parameters. In the EPER-Germany model, it is only one – the fraction of degradable carbon. However, this is achieved at the cost of refusing to describe the closed dump. The LandGEM and TNO models use two adjustment parameters each.

As can be seen from (1) and (3), the LandGEM and TNO models actually differ in the name of the parameters and the level of sampling. Indeed, it is easy to get (1) from (3) by replacing $1.87 * DOC * DOCf$ to $L_0/10$. Thus, when choosing between LandGEM and TNO, the choice is actually reduced to the availability of a ready-made implementation in the public domain, available to LandGEM, but not to TNO.

The simplicity and number of fitting parameters for EPER-Germany are achieved at the cost of describing only the stationary case. In the case of Siberia, it is not landfill gas collection that is relevant, but landfill remediation, and the ability to model the case of a decrease in the gas production intensity after the landfill is closed is important, which the EPER model lacks.

4 Conclusion

The LandGEM model seems to be a fairly effective modeling tool tested on a large number of landfills in conditions close to the Siberian region. Having a ready-made implementation of the open source model simplifies both the use of the model and its refinement if necessary.

In the course of the work, the presence of an isomorphism between the LandGEM and TNO models of gas formation at landfills was shown. These models can be used in assessing greenhouse gas emissions at landfills in the Siberian region with the aim of further developing technologies for the utilization of these gases and land reclamation on the basis of closed artificial ecosystems.

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