Potential for the regional energy supply system optimization through recycling waste into energy

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Abstract. The use of renewable energy sources is becoming a general trend for optimizing energy supply and achieving low-carbon development goals in various regions of the world. In Russia, in connection with the introduction and implementation of government support measures for solar, wind, bioenergy, starting in 2013, a large-scale introduction of energy-generating facilities began. This factor, as well as the need to solve the problem of recycling waste from the municipal sector, agriculture and forestry, makes it necessary to use local renewable energy resources, including waste. This approach helps to optimize the regional energy system, even if they are grid connected. The paper discusses the methods and potential for optimizing energy supply in the regions of southern Russia, which has a high population density, a significant deficit in energy balance, and problems in the field of solid waste processing. The basis for this work is the use of municipal sector waste as an energy resource, with an assessment of the economic and environmental efficiency of this process. The use of geoinformation technologies provides a spatial analysis of the resource potential, a comparative analysis of the distribution of energy production and consumption within the region, as well as helps to assess the availability of territories for the optimal placement of solid municipal waste processing facilities.

1 Introduction

The renewable energy sector is actively developing in many countries. Especially high growth rates are observed in solar and wind energy. Bioenergy lags behind, although biomass and biogas plants produce a predictable amount of energy (unlike solar and wind power plants), since their operation does not depend on climatic conditions. Especially the great potential of bioenergy in solving climatic, environmental and energy problems is highlighted by a number of EU Horizon 2020 program projects (uP_Running [1], AgroBioHeat [2] projects), which work on research and implementation of energy generating enterprises based on agrobiomass. These projects prove that agrobiomass is a large, under-exploited local resource that can be used for energy purposes to help solve energy and climate problems while contributing to rural development.

In most cases, the raw material for bioenergy are wastes from other industries [3]. A stable supply of raw materials is required for the operation of bioenergy plants. Ensuring such supplies, choosing the location of the processing factory, developing efficient logistics schemes for short and reliable supplies of biomass are logistical tasks, on the effective solution of which the success of the enterprise depends.

Logistics solutions include harvesting, transporting and storing agricultural waste. The energy use of agrobiomass is expected to have a positive social impact on the regions, where it creates additional jobs on the ground and prevent the outflow of youth from rural areas. Finally, the projects are designed to promote the dissemination of affordable modern technical solutions for heating systems that use...
agrobiomass with high efficiency instead of traditional fuel, thereby reducing the level of harmful emissions and improving the ecological situation in the regions [4].

In the Republic of Kazakhstan, agriculture is one of the basic industries, which makes it possible to practically completely ensure food security, as well as to export significant volumes of agricultural products abroad. At the same time, the processing of organic waste is practically not developed. At the same time, due to the sufficient amount of animal and crop waste, the country has a great potential for producing biogas, heat and electricity using biogas plants and thermal power plants using waste biomass.

2 Methodology

The research methodology is based on the approaches that were developed in the work of the European Institute for Energy Research at the KIT [5]. The methodology allows to assess the potential for using bioenergy resources, taking into account the spatial distribution of raw materials, as well as to select the most optimal sites for placing biogas power plants (BGPP) within a given area. Spatial analysis carried out using GIS tools, in addition to economic feasibility, takes into account environmental constraints and infrastructural factors (proximity to gas distribution and electric networks, roads, etc.). To achieve these goals, the mathematical functions of ArcGIS [6] are used, which, based on the initial data sets, allow a feasibility study. Fig. 1 shows the algorithm of the proposed methodology.

Figure 1. Algorithm of the methodology for the selection of sites for the installation of high potential BGP using ArcGIS [5]

One of the key stages in the analysis of the territory in order to select and justify the site that is most optimal for the construction of a station for processing livestock waste is to determine the transport accessibility and availability of sources of raw materials (animal and crop waste).

The sequence is as follows:
1) pre-selection of the zones suitable for biogas development with respect to the exclusive and selective criteria;
2) geocoding of the animal farms data and assessing its spatial density to identify optimal sites within those pre-selected zones;
3) mapping the arable land within certain distances from biogas plant sites to assess the share of required land for biogas dedicated crop planting in the total arable land (similar spatial analyses is carried out for selected crops);
4) assessing the costs of transporting waste to potential sites for biogas plants, the amount of waste processed and other characteristics, a technical and economic analysis, as a result of which the technical potential of biogas production from the processing of agricultural waste and its cost are determined.

The assessment of technical and economic potential in this work was carried out for energy production with combined heat and power technologies as well as the bio-methane feeding into the natural gas grid.

Thus, in the process of research, such ArcGIS tools as Geocoding, FocalStatistic-sum, MapAlgebra, Buffering, Extract, Overlay, Proximity, Selection were used. Corine Land Cover and Open Street Map were used as sources of digital data for mapping factors.
3 Results and discussion

The Akmola region of Kazakhstan, which is included in the group of agricultural regions with significant industrial potential, was chosen as a region for testing the methodology. The main direction of agricultural production in this region is the cultivation of cereals, vegetables, as well as meat and dairy farming (Fig. 2). In connection with the large amount of waste generation and environmental problems that may grow up as a result of waste storage (especially storage of animal waste), the problem shows necessity of processing them into energy.

In accordance with the methods presented above, an assessment of animal breeding waste energy potential was carried out, taking into account the type of livestock and poultry, its age, and housing conditions. In this case, only waste generated in large farms where it is possible to organize collection, transportation and disposal of waste (available gross waste potential) was considered (Fig. 3). It turned out that poultry farming (large poultry farms) provides the main contribution to the formation of animal breeding waste energy potential in the Akmola region.

Assuming that animal breeding waste can be processed at biogas stations and further processed into heat and electric energy, the task was to find the optimal sites for the placement of these stations, taking into account a number of natural, infrastructural and socio-economic factors of the territory and using mapping and geoinformatics tools (ArcGIS). Baseline information is the location of large livestock farms, the capacity of waste generation and their energy potential, as well as cartographic information, including hydrographic and road transport networks; boundaries of protected areas; settlements, forests, power lines and electrical substations. The result of combining these datasets is cartographic layers that reflect both favorable and limiting to the construction and operation of agricultural waste processing facilities factors (Tab. 1).

| Favorable factors                      | Limiting factors                                      |
|---------------------------------------|-------------------------------------------------------|
| Road transport network                | Nature protected areas                                |
| Power lines                           | Forests                                               |
| Low voltage power substations         | Swamps                                                |
|                                       | Rivers and water protection zones                      |
|                                       | Territories of cities and villages                     |

To take into account the spatial distribution of waste biomass sources, the "density" of waste generation was calculated within a circle with a radius not exceeding the distance of cost-effective transportation of animal waste (40 km). Density "is considered here as a conventional value equal to the ratio of the waste source capacity (tons of waste per year) to the area of a circle of the corresponding radius. Then closely located livestock farms - as a result of addition - provided a higher spatial "density" of waste (Fig. 4).
Figure 4. Cumulative waste density within 40 km zones around animal breeding farms

In addition to the size of the resource, the main factor in choosing a territory for the location of biogas stations (BGPP) is transport accessibility (logistics). Using ArcGIS tools, we created a map showing the maximum distance for waste transportation from each livestock enterprise (40 km) (Fig. 5). Then, the most suitable, taking into account resource availability and transport accessibility, for the placement of BGS were determined as polygons built at the extreme points of the road network no longer than 40 km. The map (Fig. 5) shows these landfills and highlights the most productive sites in terms of resources (animal waste).

Figure 5. Road network within zones with high animal waste energy potential

To increase the yield of biogas, it is necessary to add plant raw materials to animal waste in order to achieve a ratio of carbon to nitrogen concentration of the order of C/N=10-20. On the territory of the Akmola region, wheat accounts for 83% of the total harvest of livestock products, therefore, the potential for using wheat straw collected within no more than 20/40 km from large livestock farms was assessed to achieve the specified ratio. The calculation results, assuming a uniform distribution of arable land over the territory, show that the need for straw can be fully satisfied with crop waste collected within 20 km from livestock and poultry enterprises.

At the final stage of the study, the amount of biogas and its cost were calculated using the example of three biogas stations (BGPP) for processing animal and poultry waste in the Akmola region. Moreover, each of the biogas plants processes waste from several livestock farms. It was assumed that the produced methane can act as an analogue of natural gas for the consumer. At present, after purification and upgrading, biogas produced at biogas stations and installations abroad is supplied to the consumer (if gas distribution systems are available) as an analogue of natural gas. Therefore, estimates
were made for the cost of the produced methane, taking into account the investment costs for the construction of biogas stations, the costs of transporting waste to the biogas plant, the current costs of operating the stations and repairs, cleaning (desulfurization of methane). To bring biomethane to the quality of natural gas supplied to the consumer, i.e. removal of hydrogen, sulphides due to their high corrosiveness and odors, water wash technology and pressure swing adsorption technology are currently used in European countries. At the same time, according to [3], these methods are used only in a few countries (Sweden, Germany), and it is difficult to estimate the average investment costs for the introduction of these technologies. As a result, when calculating the cost of biogas, the costs of the following operations were not taken into account:

- biomethane refining procedures;
- the cost of connecting BGPP to gas distribution networks;
- the cost of animal breeding waste (it was assumed that this waste is free and only the cost of transportation was estimated);
- the cost of crop waste (it was assumed that crop waste (straw), which goes to the bedding of livestock and is thus included in organic waste, increasing the biogas yield, is free and the cost of their delivery to livestock farms is zero).

When calculating the payback of biogas plants, it was assumed that a simple payback period was calculated (excluding the discount rate, capital is not borrowed).

An analysis of the typical results obtained for a plant operating on waste from several livestock farms showed that in the case when only methane is sold as a waste product, the simple payback period is 11.5 years. With the additional sale of biofertilizers (sludge), the payback period is reduced to 3.40 years. Since part of the energy produced by the biogas plant (in the form of methane in biogas) must be used for the needs of the plant itself, calculations of a simple payback period were also carried out on the assumption that only 30% of biomethane is sold to external consumers. In this case, the payback period rises slightly - up to 4.29 years, which is also a completely satisfactory result. Analysis of the cost structure shows that the maximum contribution is made by investment (capital) costs; transportation costs are only 6.2%. When constructing waste processing stations at each of the livestock enterprises, the simple payback period for BGPP projects without the sale of fertilizers is from 12.05 to 17.71 years. With the sale of 30% of biomethane and the total amount of fertilizers received to the consumer - from 3.56 to 5.24 years, which is higher than the results of calculating the payback period for the combined enterprise. This is due to a reduction in investment costs in the construction of a large enterprise in comparison with several small biogas plants and a relatively low share of waste transportation costs in the total cost structure. The results obtained can only be considered as "bottom-line estimates", since a simple payback period is calculated and capital and operating costs for a number of technological processes are not taken into account.

Evaluations of the efficiency of waste utilization of all livestock enterprises in the region showed that the total technical potential of electricity production is 54 243 MWh/year, and heat - 395,714 GJ/year. Savings of hydrocarbons (coal) in the processing of animal breeding waste by means of methane digestion followed by the use of methane in the Mini CHPP for the Akmola region of Kazakhstan amounted to: 10 848 t/year in the case of electricity generation at the CHP and 16 848 t/year in the case of heat energy production. When utilizing plant waste with energy production, it is assumed that net CO₂ emissions into the environment (which were absorbed by plants during growth) does not occur. In this regard, the prevention of CO₂ emissions in the event of biogas production from waste and its further use as fuel at a thermal power plant in the region will amount to 548 tons of CO₂ per year.

4 Conclusions
In the Republic of Kazakhstan, the development of the biogas industry is currently at an early stage, the government has introduced green tariffs to stimulate bioenergy, BGPP projects are being implemented within the framework of the Concept for Sustainable Development of the Republic of Kazakhstan until 2050. Spatial analysis tools allow us to search for optimal areas for the location of waste processing
facilities. The main selection criteria are: the presence of permanent sources of waste (poultry and cattle farms; crop farms), limiting (protected areas, water bodies, settlements) and favourable factors (power lines, roads, electrical substations) to the development of biogas production. Estimates of the simple payback period of biogas plants in the Akmola region showed that the most optimal is the centralized collection and processing of waste from several farms, taking into account the costs of transportation. At the same time, the payback period is reduced by 0.5-6 years compared to BGPP at each farm. The total technical potential of electricity production from waste of large livestock enterprises in Akmola region is about 54 000 MWh/year, heat energy – 395 000 GJ/year. This can provide fuel (coal) savings of more than 10 000 tons/year in the production of electrical energy and 16 000 tons/year - of thermal energy, as well as obtaining more than 35 000 thousand tons/year of valuable organic fertilizers. When utilizing crop waste, CO₂ emissions can be reduced by about 550 t/year.

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