PRACTICAL APPROACH FOR JOINT EU UTILIZATION OF ANIMAL WASTE TOWARDS ENERGY AND INDUSTRIAL APPLICATIONS

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The climate change combat requires continuous efforts in diversification of the energy sources and increasing the energy effectiveness of the human society. Some of the possible measures in this direction are vital only when put on large-scale basis, like on regional or European Union level. The practical approach for joint EU utilization of animal waste towards energy and industrial applications is one such a measure. It suggests the efficient use of the biowaste as an energy source, as well as some industrial/agricultural applications of the process residues. The necessary actions for achieving its goals are discussed in the paper. The expected outcome of such measure is justified. The common EU environmental objectives, set up in the green Taxonomy that could be met by such action are defined. Important aid to the sustainable development on regional and EU level is expected after the implementation of the discussed measures.

INTRODUCTION

The ever-increasing energy consumption worldwide necessitates the construction of new power generation facilities whose operating characteristics must meet modern environmental requirements. This fact, in turn, calls for the development of conceptually new solutions to simultaneously meeting the energy demand and reducing the harmful anthropogenic and technogenic impact on the environment. A well-known technology in this respect, which is also implemented within the context of the circular economy, is the utilization of animal and plant waste for the production of biogas fuel applicable in thermal and electric power generation systems. Despite being a well-known technology [1] in terms of the process of methanisation of organic waste through anaerobic digestion, the production of biogas from animal manure and plant waste has a strongly determined local character, the type and quality of the end product depending on multiple factors of a variable nature. Therefore it is clear that a joint effort between the EU countries will easily overcome this issue. Such effort will foster the achievement of the EU's short-term and long-term goals and ambitions related to the production of thermal and electric power with zero CO_2 emissions, the realization of a circular economy through the utilization of waste from one technology as raw material in another, conservation of natural resources and reduction of those types of industrial production which leave an environmental footprint by substituting the raw material they are supplied with for restructured waste material. At the same time, along with addressing these ideologies, the sustainable biowaste utilization is indirectly aimed at the preservation of biodiversity and the restoration of local ecosystems in the EU countries involved in its implementation, by replacing large-scale power generation facilities which use conventional fossil fuels as the primary energy source, with smaller power-generation facilities which exploit renewable fuels. In order to achieve the defined objectives, as well as to ensure the maximum and optimum accomplishment of the objectives for sustainable development of the European economy and ecology, this approach provides for an implementation methodology at several levels: local, for each member state, large-scale – at the EU-level, as well as a blended approach involving the combination of local production and subsequent distribution of raw materials and materials on the European market. In order to achieve these goals a state-of-the-art approach in the production of biogas, biochar and an improvement of both technologies through the utilization of additional waste materials will be needed for the practical implementation of anaerobic digestion and gasification processes.

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Extensive experimental and computational studies need to be conducted on the potential for realization of a circular economic cycle in the EU countries through the energy utilization of the organic waste from regional rural farms.

The experimental research work provides for the implementation of familiar biogas production technologies [2] on various kinds of animal and plant waste materials from the European agricultural sector and the determination of optimal ratios for their co-utilization through analytical characterization of the end products. The waste to be studied should be selected on a regional principle. The first methodological step has to be to carry out analytical investigation based on available statistical data on the existing potential in the different geographical regions of the member states, with a view to the subsequent local utilization of the waste under economically viable conditions, with minimized transport costs – both of the waste material from its source of origin to the utilization site, and of the resultant energy product to the final consumer. The approach adopted here has to be individual for each partner country. The discretization of geographical areas will not be undertaken on the basis of their administrative division, but, instead, will take into account such factors as: the area covered, topography, available infrastructure (including rail), the possibility of centralized construction of an energy source at a relatively equal distance from all producers of animal and plant residue, population density with respect to identification of the social component, climate features of the region, etc. The identification of the available waste raw materials by region has to be followed by laboratory testing in order to determine experimentally the energy and resource potential of specific samples collected from the local agricultural production. In the first part of the experimental activities, two main waste utilization technologies should be implemented: anaerobic digestion and gasification. Both technologies are well-known in the scientific field and industry, but by the current moment, the main challenge they face is obtaining a positive economic effect from their implementation, justified by the improvement of the technological parameters of the processes. To overcome this flaw, improved methodological sequence under which the research has to be conducted for both technologies is foreseen, including: analytical determination of the macro-component composition of the animal and plant waste, treatment of the waste at different process parameters, analytical determination of the characteristics of the end products, identification of the influence of initial and boundary conditions on the end products and derivation of correlation dependencies, optimization of the processes through modification of the experimental conditions.

The anaerobic digestion has to be conducted in bioreactors with a capacity ranging between 2 and 20 litres by placing different weight ratios of regionally selected waste at different constant temperatures, while ensuring homogenisation. At regular time intervals, quantities of the resultant gas has to be discharged, while determining its volumetric flow rate. The biogas has to be analyzed in terms of its composition and properties through gas chromatography technique, optical gas analyses and differential scanning calorimetry. The parameters which has to be subject to further optimization are related to the energy potential of the tested waste and include: a higher calorific value of biogas, a lower calorific value of biogas, quantity of biogas obtained. The main process characteristics, which represent the initial and boundary conditions for anaerobic digestion and which has to be modified in the experiments for optimization purposes, include: ratio of animal to plant waste, digestion temperature, operating pH in the reactor, presence of homogenization, stirring time and rate, retention time of the organic sample in the bioreactor. An important element of the production process of biogas from agricultural residue which has to be investigated, both as a stand-alone research component and within the context of the optimization task, is the influence of the seasons on the potential of the raw materials and biogas yield.

Along with the analysis of the dependencies obtained from the locally examined samples, a multivariate analysis of cross-referenced partner data has to be performed as well, in order to derive dependencies with potential applicability in a prognostic data generation system. Apart from the energy potential of the biogas produced in the anaerobic digestion process, another subject matter of investigation will also be the possibility for secondary utilization of waste material, namely, the solid residue produced in the bioreactor. Its composition has to be determined analytically for the experimental procedures which has to be selected as optimal for the energy purposes of the utilization. In subsequent studies, the secondary waste has to be analyzed in terms of its applicability to environmentally friendly technologies, such as: protein-rich filamentous fungi production, production of biological fertilizers, soil remediation systems, etc.

The second main technology for the utilization of agricultural waste, which should be experimentally investigated, is the gasification of materials. Similar to the anaerobic digestion testing, this technology will also be implemented on waste materials sampled from the identified regions. The gasification process has to be conducted in flow reactors through high temperature carbonization of the organic waste.

All results obtained from the laboratory-scale experimental activities and the subsequent analytical procedures should be allocated to a database structured in the following sequence: type of waste (animal/plant) – macro-component composition of the waste – appropriate combination with another type of waste (plant/animal) – macro-component composition of the waste – ratio of the two types of waste – process parameters of anaerobic digestion (temperature, homogenization, time) – quantity of the resultant biogas – quality of the resultant biogas – quantity of the secondary waste – macro-component composition of the secondary waste – potential applications of the secondary waste.

Based on the above the next stage of the laboratory-scale experimental studies should be related to determining the applicability of the products obtained from the gasification process in different technologies. From an energy point of view, the potential of the respective volatile components released in the process of carbonization has to be investigated. Part of their energy, generated during the partial oxidation with the oxygen from the substoichiometric amount of air, could be utilized to maintain the high-temperature regime of gasification, thus making the technology for the utilization of agricultural industry waste totally independent of external energy sources. The remaining energy potential (from unoxidised hydrocarbons and carbon monoxide) could be utilized in a secondary combustion system. The resultant flue gases, together with the flue gases from the gasifier, should be subjected to secondary utilization in a heat exchange system. The processes which can be fed with the resultant heat are: hot water production for heating and domestic hot water supply; drying installations; greenhouses for growing crops, etc. The specific approach for the secondary utilization of this energy potential has to be selected and investigated in compliance with the specific local needs according to the location of the biochar production facility.

The selected approach for bio waste utilization envisages a wide-ranging study of the applicability of the resultant biochar in a large variety of ecological systems. Before undertaking the experimental activities, the samples identified as the most successful ones in terms of organic carbon content and specific surface area, should be subjected to further analytical assessment. Their morphology should be examined by means of Scanning Electron Microscopy [3], their macro- and micro-component composition – by means of Inductive Coupled Plasma – Mass Spectrometry and Atom Adsorption Spectrometry, and their thermophysical characteristics – by means of Differential Thermal Analysis. The presence of trace elements of the heavy metal type above standard values imposes certain limitations upon some of the secondary applications of biochar. Thermophysical characteristics assume crucial importance, both in determining the specific surface area of biochar and in its application in processes for the production of biocomposite materials, fuel cells, catalysts, etc.

The research on biochar [4] utilization has to be focused on three main directions: applications as soil conditioners, for the treatment of polluted water from heavy metals, as well as for the adsorption of carbon dioxide from industrial gas flows. The resultant biochar has to be investigated as soil conditioner both in its pure form and by adding different types of organic and inorganic components conducive to maintaining the nutritional values of soils when growing different kinds of crops. Within the context of the development of zero-waste technologies and the conservation of natural resources, when combining biochar with other materials, preference has to be given to those that are waste from a production process. An example of such combination is the utilization of the solid residue from the anaerobic digestion process by its mixing in biochar for production of biofertilizer characterized by high nutritional value, slow deposition of beneficial substances in the soil and the absence of synthetic products in it. Again, striving for the economically viable utilization of the materials, the experimental procedures should be carried out with locally produced biochar and residue, investigating the impact of the ratio of the two materials on different types of vegetable, cereal and fruit crops grown in the respective regions. Another approach for the application of biochar in a co-utilization system with waste from other production is the preparation of mixtures with ash obtained as inorganic mineral residue from the combustion of various types of biomass. A characteristic of some of these types of ash is the high calcium content bonded in a mineral structure, which could be applied as a pH regulator for acid soils.

The second environmental application of the produced biochar, which has to be investigated in detail on a laboratory scale, is related to systems for the removal of heavy metals from water flows. The load on the biosphere with heavy metals is growing strongly as the industry develops, and most often they could be detected in different water flows. The pollution of the aquatic ecosystem with heavy metals is mainly the result of the entry of industrial waste water containing increased quantities of them. The problem grows over the years because heavy metals generally have no self-cleaning mechanisms and they accumulate in the environment. Cadmium (Cd), lead (Pb) and mercury (Hg) are the subject of attention, given their proven highly toxic effect on ecosystems and organisms. The research activities has to be conducted using a standard methodology under equilibrium and dynamic conditions in order to determine the adsorption capacity of biochar with reference to heavy metals, as well as the kinetics of the occurring processes. For the purposes of experimental and analytical activities, techniques such as ICP and measurements with Ion Selective Electrode should be employed. The optimum operating range of the materials at different temperatures, pH and heavy metal saturations of solutions has to be determined. The data obtained from the experimental activities has to be analyzed by means of standardized modelling equations (e.g. Langmuir, Toth, Sips, First/Second Order Kinetics etc.) for the purpose of subsequent scaling-up of the technology to real scales.

Another possible application of biochar could be its use as an adsorption material in CO_2 capture systems. The nature of adsorption processes is rather complex and is described by means of a multitude of empirical constants which are experimentally determined for individual contact systems, such as the various biochar samples resultant from the gasification of animal and plant wastes and CO_2 as a component of the flue gas mixture from the combustion of conventional fuels. All this makes it mandatory to go through a stage of pilot studies of the gas-solid system before designing a real-scale installation. For the simulation calculation of adsorption installations, an essential parameter is not only the equilibrium adsorption capacity, but also the kinetics of the process, which is determined by the velocities of the following stages: transfer of molecules from the gas phase to the interfacial surface with the adsorbent (diffusion boundary layer); diffusion into the adsorbent particle; adsorption.

The methodology for achieving the research objectives of this technology comprises conducting experimental and computational studies of CO_2 adsorption on the surface of biochar samples under dynamic conditions, including: determination of dynamic adsorption capacity $mgCO_2/g$; construction of a breakthrough curve for each system investigated; determination of optimum gas desorption parameters; testing the cyclicality of the processes of adsorption and desorption of CO_2; determination of the specific heat of adsorption (kJ/kg) by experimental measurement of the specific heat capacity at constant pressure of the investigated solid sample and the adsorption temperature; calculation of the experimental adsorption column parameters; validation of a digital LDF model for description of the process. The analytical techniques which has to be employed to perform the analyses described, include: Gas Chromatography Detection; Differential Thermal Analysis, Differential Scanning Calorimetry; Specific Temperature Measurements; Volumetric Gas Adsorption.

All the results obtained from the laboratory-scale experimental activities and the subsequent analytical procedures dedicated to the production of biochar from animal and plant waste should be allocated to a database structured in the following sequence: type of waste (animal/plant) – macro-component composition of the waste – appropriate combination with another type of waste (plant/animal) – macro-component composition of the waste – ratio of the two types of waste – process parameters of gasification (temperature, air quantity, residence time) – quantity of the resultant biochar – quality of the resultant biochar – quantity and energy potential of the flue gases – potential biochar application – specific experimental conditions for biochar application.

Both waste utilization technologies considered above, suffer from a significant drawback related to the lack of economic viability. The selection of local and compatible waste, as well as the optimisation of the process parameters with reference to the end products, represent one of the measures that could be adopted to overcome this drawback. Another measure is related to the inclusion of additional materials in the processes, for the purpose of improving biogas and biochar yields. The additives for improving or speeding up the processes are supplied in minimal quantities, which is a prerequisite for conducting a larger-scale research, not only within the framework of the respective regions. The focus in these research activities is in finding non-standard additives for the improvement of the processes which, in their nature, represent waste materials from a certain production. Materials which would replace standard catalysts, carriers, etc. has to be sought and investigated. In this way, another EU economic challenge will be addressed, related to so-called critical raw materials, which have been identified as economically and strategically important for the European economy but have a high-risk associated with their supply. Through this the preservation of natural resources will also be aimed. One of the investigated approaches for the improvement of digestion and gasification should be the addition of high porous zeolitic materials, neither natural nor artificial, but obtained by recrystallization of mineral waste material, such as fly ashes from coal combustion.

Important stage of the research is related to conducting computational studies on the implementation of the obtained biogas, on the basis of its determined energy potential, in thermal and electric power generation systems. An emphasis in the research should be placed on the development of potential scenarios for the replacement of existing Thermal Power Plants in the identified EU regions. Using specialized software products, calculations could be performed in order to determine the efficiency of different biogas utilization technologies, including: conventional combustion in a steam generator for production of super-heated steam which drives a steam turbine coupled to an electric generator; combustion in a gas turbine; combustion in an internal combustion engine, etc.

CONCLUSION

The foreseen approach for joint EU utilization of animal waste towards energy and industrial applications has a clearly defined interdisciplinary character. The accomplishment of the assigned tasks has to be performed by the effective and efficient interaction and collaboration of specialists coming from different scientific fields. The investigation of the anaerobic digestion processes has to be carried out by specialists with specific expertise in biology. The gasification process has to be executed by a team of power engineers, specialists in combustion processes. The determination and analysis of process parameters has to be conducted by chemical engineers. As the investigated processes are specific, there are no controllers available on the market to be installed on a pilot installation (and eventually on the real-scale installation). Therefore process engineers, and as well as specialists in automation systems, will also be involved in the set-up of the pilot installations. The construction of the different types of databases, as well as the geographical information system, has to be executed by specialists in computer science and computer engineers.

The discussed approach requires common effort on EU level from scientific, as well as from economic and societal point of view. The foreseen decision making process is presented on Figure 1.

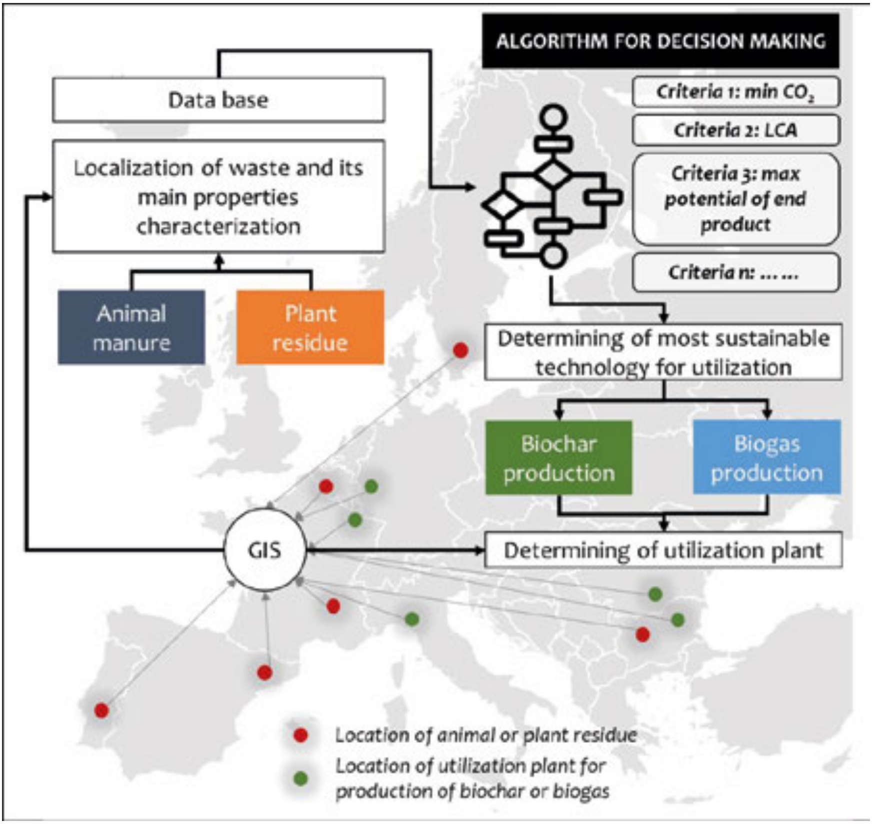

Fig 1. Proposal for joint waste utilization in european countries: technological sequence

With reference to the objectives set by The Taxonomy Regulation [5], the proposed approach addresses all the six identified environmental objectives, as follows:

Climate change mitigation: The utilization of animal waste in itself leads to a reduction in the free methane released in the natural decomposition processes of these residues, which, according to statistical data from OurWorldinData.org, accounts for 5.8 % of total greenhouse gas emissions in 2020. On the other hand, the planned applications of the resultant biogas in energy systems provide for the replacement of generating plants using conventional fuels, one of the main sources of CO_2 in the atmosphere.

Climate change adaptation: Carbon sequestration allows a negative carbon footprint for a farming operation by removing large quantities from the carbon cycle and storing them for thousands of years. Significant overall improvement of the greenhouse gas balance by avoiding methane emissions from rotting biomass and manure will be obtained.

The sustainable use and protection of water and marine resources: A focus in the analysed approach will be the application of the resultant biochar in systems for treatment of polluted water flows.

The transition to a circular economy: The overall concept of the proposed approach is dedicated to the realization of a circular economic cycle through the integration of waste materials in production processes for generation of power, high-value materials, fertilizers, additives, etc.

Pollution prevention and control: Environmental pollution prevention and control will be achieved at several levels. Firstly, waste material will be utilized in large quantities, after which the resultant products will be used in power generation systems where the carbon footprint is considered to be zero. Secondly, the application of utilized waste materials in water and gas flows treatment systems will also result in a direct impact on pollution prevention.

The protection and restoration of biodiversity and ecosystems: Under this indicator, the approach is expected to have an indirect impact. The replacement of conventional sources of electric power, mainly coal-fired thermal power plants, will result in clearance of land mass occupied by coal mining and ash storage systems. This will contribute to the recovery of animal and plant life at these locations. Treatment of water flows from heavy metals would also result in an indirect impact on this indicator by increasing the population of certain fish species.

Life cycle evaluation and life cycle sustainability assessment has to be performed by a team of specialists with proven experience in the respective field. And finally experts-sociologists has to be involved in the processes of assessment of public perceptions and attitudes towards the construction of the investigated installations at real scale in order to achieve a sustainable development in the selected regions as well as on EU level.

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