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Energy, economic and ecological problems of waste management

Kwiatkowski M.
Wydział Energetyki i Paliw, Akademia Górniczo-Hutnicza im. Stanisława Staszica
Al. Mickiewicza 30, 30-059 Kraków, tel.0 12 617 41 73, e-mail: kwiatkow@agh.edu.pl

Abstract

The aim of this work was to present energy, economic and ecological problems connected with municipal waste management in Poland. In recent years, avoidance, minimizing waste generation and recycling have been given high priority in recognition of the fact that on the one hand waste may represent a valuable resource, while on the other, inappropriate management and disposal of waste may have a negative impact on the environment and on social health conditions. Minimization of space requirements for landfill and developing recycling methods play very important roles in waste management at present. Prevention and minimization of the municipal waste generation and recycling are given high priority by the European Union waste policy, as the most desirable methods of the waste treatment. Recycling of municipal solid waste has been offered in this article as an alternative to traditional forms of waste disposal, such as landfill, and very expensive and controversial ones, such as incineration.

Streszczenie

Energetyczne, ekonomiczne i ekologiczne problemy gospodarki odpadami komunalnymi

Celem niniejszej pracy było przedstawienie energetycznych, ekonomicznych i ekologicznych problemów związanych z gospodarką odpadami komunalnymi w Polsce. W ostatnich latach unikanie i minimalizacja wytwarzania odpadów oraz ich recykling mają wysoki priorytet z związku z faktem, że z jednej strony odpady mogą być cennymi surowcami, a z drugiej strony niewłaściwa gospodarka i usuwanie odpadów mają negatywne oddziaływanie na środowisko i stan zdrowia społeczeństwa. Minimalizacja obszarów składowisk i rozwój metod recyklingu odgrywają aktualnie bardzo ważną rolę w gospodarce odpadami komunalnymi. Zapobieganie i minimalizacja generowania odpadów komunalnych oraz recykling mają także wysoki priorytet w polityce Unii Europejskiej, jako najbardziej pożądane metody postępowania z odpadami. Recykling stałych odpadów komunalnych zaproponowano w niniejszym artykule jako alternatywę do tradycyjnych metod postępowania z odpadami, takich jak składowanie oraz bardzo drogiej i kontrowersyjnej metody termicznej utylizacji.

1. Introduction

Parallel to the progressing economic growth and gradually improving quality of life, the amounts of municipal waste produced by societies increase as well, while their removal and disposal has become one of the major problems faced by the present civilization. The issue of neutralizing and proper management of waste is also inseparably linked to other problems, such as running out of the resources of fossil fuels and the propagation of the greenhouse effect, as well as the increasing pollution of natural environment [1].

In many countries, including Poland, outdated solutions based on landfill are still predominant. Yet this method of waste disposal has been criticized with increasing emphasis as the least effective form of neutralizing waste [2,3]. Plenty of valuable materials contained in waste and suitable for recycling are lost irretrievably at landfill sites, which also occupy large areas and pose a threat to natural environment and to people. Yet positive changes in the attitude towards the problem of municipal waste are seen increasingly often, represented by abandoning the primitive method of landfill for the sake of combined and rational waste management, based on the premises behind the economic, ecological and energy calculi, compliant with the rules of Sustainable Development, defined in Article 3 of the Environmental Protection Act of April 27, 2001 as 'such socioeconomic development which involves the process of integrating political, economic and social activities without disturbing natural equilibrium and the integrity of basic natural processes in order to guarantee for particular societies and individual citizens in both present and future generations the possibility to fulfil their basic demands'.

Therefore sustainable development is based on rational formation of the environment and adequate management of its resources in order to develop such conditions that will enable fulfilment of the present requirements of the society for raw materials and power, taking into account the demands and safety of future generations. The following basic rules were drawn up which must be observed to maintain sustainable development:

- the rule of using state-of-the-art environment-friendly technologies with regard to maintaining profitability in economic terms;
- the rule of preventing pollution or neutralizing the sources of pollutants;
- the rule of responsibility for damages on the part of the polluter;
- the rule of forethought, i.e. the demand to stop such actions whose results cannot be foreseen,
- the rule of prudence, according to which not even the least threat to natural environment and human health can be disregarded.

Municipal waste management has also been of interest to politicians on both international and local level, which is reflected in a number of Directives of the European Commission, as well as national legal acts and resolutions passed by local self-governments. The Framework Directive of the EC, which serves as the fundamental regulation in the European Union in the area of waste management is Directive 75/442/EC on waste with the amendments laid down in Directive 91/156/EC, which provides for the basic tasks to be tackled with regard to municipal waste management. The waste management strategy as provided for in that Directive assumes undertaking actions in five general directions, i.e.: preventing creation of waste; recycling and reusing; optimizing and selecting methods of final disposal; transport regulations; and possible reparatory measures. According to the Directives mentioned above, the main orientation of modern waste management should be the measures targeted at preventing creation of waste and adequate production of goods, so that their reuse or utilization had minimum effect on the natural environment. The discussed Directive also emphasizes the necessity to apply the ‘polluter pays’ principle and to use substitutes for the traditionally used raw materials, promote returnable packages and recycle raw materials or energy from municipal waste. The Directive points to the requirement to adequately regulate the matter of transporting municipal waste, emphasizing the fact that the waste originating within the EU should not be utilized outside the EU, and in particular it should not be exported to the third world countries. The Polish Act on packaging and packaging waste of May 11, 2001, based on Directive 94/62/EC, also underlines the demand to reduce the amount of materials used in packaging and the number of packages used during the production and distribution of goods.

2. Thermal utilization of municipal waste

Due to the growing volumes of waste caused by rapid industrialization and development of towns, the concept of utilizing waste by way of incineration in the suitably adjusted systems emerged in the second half of the 19th century [4,5], while in the early 20th century the technology of thermal utilization of municipal waste became popular in Europe and the United States. Yet the significant development of thermal waste utilization plants was observed in the 1970s, triggered mainly by the worldwide fuel crisis and the increase in the energy value of waste. At present, in the EU countries there are some 370 operating plants which process thermally some 46 million tonnes of municipal waste each year. Currently in Poland there is one small waste incineration facility, owned by the solid municipal waste neutralization plant in Warsaw and situated in the city’s district of Targówek.

Both the costs of building thermal municipal waste utilization plants and their operating costs are relatively high as compared to other methods of managing waste, and they are growing constantly due to the increasingly severe requirements for thermal waste utilization systems in terms of environmental protection. In a modern waste incineration plant, where all required fumes treatment processes are applied and where the secondary waste produced during incineration is utilized and the sewage treated accordingly, as much as 80% of the costs of the investment are the costs of the treatment of fumes, secondary waste utilization and sewage treatment systems [6].

High costs of the waste utilization technology result not only from the costs of the systems themselves, but also from low energy efficiency of the process [7] Estimated costs of building a modern incineration plant in Poland may be comparable to the parallel costs in the countries in the West or higher, which is mainly due to the requirement to import the majority of technologies and equipment and to lower profits from producing heat energy caused by lower energy value of Polish waste and the necessity to deliver them from larger areas as compared to highly developed countries. The building costs must also include the possible costs of developing a special waste landfill site used to deposit dust obtained during the treatment of fumes, as well as ashes, while the actual volume of waste reduced when utilized in an incineration plant is only within 40 - 70% [8]

The process of thermal utilization of municipal waste causes producing toxic waste, both solid and liquid, as well as discharging harmful substances to the atmosphere which cannot be wholly eliminated despite using the increasingly effective environmental protection measures in the systems [6]. Among these substances, the most dangerous to human health are dioxins and furans, as well as other durable organic pollutants produced during the incineration of materials containing chlorine [9-16]. Dioxins and furans, even when resolved at a very high temperature [min. 1200^{o}C] in an incineration chamber provided that they remain in that chamber at least for ca. 3 seconds, may undergo a *de-novo* reaction and become resynthesized in the process of cooling fumes in the components of the exhaust system [6]. It should also be emphasized that under the conditions described above [1200°C, 3 sec.] it is possible to eliminate only some 30% of dioxins and furans, while another 30÷40% are adsorbed on active carbons, and the remaining part of the compounds contained in the fumes is discharged into the atmosphere [6]. The modern installations are often fitted with the system of rapid cooling of fumes, where the intensity of the process of recombination of dioxins and furans decreases owing to lowering the temperature of fumes below 200°C, and yet this does not solve the problem of these health-hazardous compounds.

With their accumulation capacity, dioxins are deposited in the fatty tissue of live organisms, and having penetrated into human body they lower the effectiveness of the immune system, impede growth processes, impair reproductive abilities, cause neurological and hormonal disorders and damage to kidney and liver, and have significant effect on the development of malignant tumours [17-19]. According to the latest regulations on the acceptable volumes of toxic substances discharged by thermal waste utilization plants, the acceptable amount of discharged dioxins is I-TEQ 0.1ng/Nm^3. The supporters of developing thermal waste utilization plants point out that such acceptable discharge levels are small, yet it must be remembered that the main source of dioxins are waste incineration plants, and when potential analyses are carried out, the total volume of these substances discharged throughout the period of operating given incineration plant must be taken into account [8]. Huang and Beukens [20] emphasized also that gas discharges are but a small fraction of the total volume of dioxins which penetrate into the environment in the process of incinerating municipal waste – the remaining amount is transferred to the environment through other streams generated in the incineration process. For instance, some of the toxic substances contained in the ashes and slag produced during the waste incineration process and deposited afterwards may penetrate into the ecosystem [20,21].

When a modern municipal waste incineration plant is built, it is also required to develop suitable lab facilities provided with costly specialist analytical and measurement instruments, operated by adequately trained personnel. Yet attention is also drawn to possible errors in the assessment of current discharge levels, caused by the changeability of the process determined by the current morphological composition, and therefore variable fuel value, diversity of the process kinetics and impossibility to constantly control the discharge of such compounds as dioxins and furans due to technical and economic reasons [23].

For municipal waste to be suitable for the process of thermal utilization, it must have adequate energy value; the economically reasonable value outside Poland is 5000 kJ/kg, and having regard to the economically advisable use of heat from the incineration process for heating purposes in the plant or in the local heating system, the modern systems should be designed to perform incineration of municipal waste of the energy value above 7000 kJ/kg [8]. However, despite the increasingly popular use of the thermal energy produced in the process of thermal utilization of waste for heating purposes, it is possible to recover only small portion of the energy contained originally in the waste [7,24]. The volume of that portion oscillates between 15 and 30%, depending on the content of waste material and its moistness [7,8]. Attention is also drawn to the fact that the volume of waste deposited at the landfill is almost the same throughout the year, while the demand for thermal energy differs considerably depending on the season and ambient temperature.

The volume of municipal waste produced by one person in Poland ranges between 60 and 300 kg in a year, which is much less than in the western countries. Considering the above, a thermal waste utilization plant would have to operate on an area which is at least two times larger than in a country in Western Europe to obtain equivalent daily efficiency, which would result in a considerable increase in transportation costs. Also, the process of thermal utilization of waste induces discharge of carbon dioxide, the main greenhouse gas responsible for the propagation of global warming, as well as nitrogen and sulphur oxides [24].

Discussions have been currently under way throughout Poland, Krakow included, about the legitimacy to build thermal waste processing plants. One of the arguments is the requirement to meet the EU accession obligations in terms of waste management, including the reduction of biodegradable waste. The demand to build thermal waste processing installations within the Polish municipal waste management systems was accounted for in the National Waste Management Plan adopted by the Council of Ministers in 2002. The plan involves building eight large municipal waste incineration plants to complement the systems of managing waste produced in large cities [25,26].

Obviously building thermal waste utilization plants cannot be avoided, yet they should be merely an element of the process of utilizing the waste, which could not have been managed by way of recycling; incineration of waste should by no means become the only or predominant method of managing municipal waste. Developing a thermal waste processing plant cannot rule out the requirement to provide a landfill or perform selective collection of municipal waste and recycling [24]. It should be emphasized that the demand to achieve adequate recycling levels and the implementation of the technologies of clean production and reducing the amount of generated waste will consequently lead to considerable reduction of the fuel value of municipal waste. Moreover, it must be noted that the majority of plastics are produced on the basis of petroleum-derivative half-finished products, which in the light of the alarming forecasts about the depletion of the deposits of petroleum is another argument for the rational system, based in particular on reducing the production of waste, thoroughly selective collection of the waste which could not have been avoided, and its further recycling.

Incautious and widespread development of municipal waste incineration plants may add to maintaining energy-consuming and ineffective utilization of natural resources and further penetration of pollutants into the environment. In some ways municipal waste incineration approves of ‘dirty’ production processes and the production of growing amounts of impermanent and disposable goods, such as packaging products. Proper functioning of a waste incineration plant requires ongoing delivery of the specified volume of municipal waste, and thus less interest, and consequently less funds may be paid to support the measures intended to reduce the amount of waste at their sources of origin, reuse and recycle waste material, as well as implement clean technologies, in which waste is either not generated or non-toxic and can be processed easily. The funds spent on thermal waste processing plants, or at least part of them, can be devoted successfully to developing a modern and effective system of selective collection and recycling of waste, as well as implementing the methods of efficient utilization of energy and, above all, the solutions, which would prevent from producing further waste.

It is emphasized that considerable significance for further functioning of the existing incineration plants in Europe and the planned facilities in Poland may be attributable to the decisions made by the European Court of Justice and the European Commission in 2003, according to which incineration cannot be considered a form of recycling, but it is a form of waste disposal. As a consequence, incineration plants cannot receive the funds from such sources as packaging management systems; the recycling levels will not include the weight of incinerated packaging, hence obviously reducing profitability of a number of thermal waste utilization installations [8]. Therefore any investment to such a scale as a large incineration plant should be preceded with careful and reliable analyses in the context of the overall waste management in its economic, environmental and energy-related aspects [27].

A promising direction in municipal waste management is utilizing waste as fuel in rotary furnaces used to produce clinker. Inside such furnaces, which can be even 240 m in length, the fumes remain for some 8.5 to 10 seconds, while the temperature ranges approximately from 1600°C to 1750°C, which means that the conditions for the decomposition of dioxins and furans are met [6,28]. Still the possibilities to use this method are limited for technological reasons, i.e. the demand to maintain adequate parameters of clinker and the fact that the rotary furnaces are not commonly available.

Works have been under way to develop the methods to destroy dioxins and furans under the conditions of plasma, where temperatures are within the range from less than ten thousand up to fifteen or so thousand degrees centigrade, yet very high power consumption in plasma reactors prevents their common use. Another promising method for thermal utilization of waste is pyrolysis, which proves definitely much more effective in a number of aspects than incineration.

3. Minimizing waste

As it was already mentioned above, the main orientation for the rational management of municipal waste in line with the rules of sustainable development in terms of energy is preventing the origination of waste, e.g. by promoting multiple use packaging as provided for in Directive 94/62/EC and utilizing recyclable materials to produce new goods. One of the methods to minimize the generation of municipal waste is implementing the principle of the producer's extended responsibility for the manufactured goods, according to which the producer is responsible for the effects of his product on the environment and which imposes the obligation to manage the product accordingly when it is no longer in use. The rule has it that the producer obliged to utilize his products will be interested to a sufficient extent in taking the environmental requirements into account at the stage of designing and manufacturing the products. An example of this approach is the 'take-back' principle according to which the products are returned to the producer as soon as they are out of use [8].

Producer's responsibility for his products can be either physical, when the producer is directly engaged in managing the products out of use, or economic, when the producer incurs partial or whole costs of managing the waste left when the products are no longer in use. According to the 'polluter pays' principle, the producer may also be charged with the costs of environmental pollution due to using the product and its utilization. The principle of responsibility for products undermines the legitimacy of producing disposable goods containing toxic materials, and it also forces the producers to use the maximum possible amounts of reusable materials in their products.

Extending the life of a product or reusing it results in considerable savings on raw materials and energy, reducing the volume of waste, and consequently also reducing the environmental costs related to the extraction of raw materials and fuels without effect on decreasing the consumption quality level. Currently this can be achieved with the modern technologies at hand, and its crucial determinant is applying suitable policy and relevant support mechanisms.

4. Recycling

The most useful method to reuse raw materials and energy contained in municipal waste the generation of which could not have been avoided is recycling, i.e. reprocessing used products, post-production waste and consumer waste into recyclable materials which can be further used to manufacture new products whose properties and purpose will be either similar to or different from that of the original products [29].

Recycling raw materials is a method to save the almost exhausted natural resources [30]. Moreover, it increases energy efficiency of the production process, which results in reducing pollution of the natural environment [2,3]. Yet it must be emphasized that recycling waste should not legitimize the existence of 'dirty' technologies and excessive production of waste, and neither should it generate hardly reusable products itself, as exemplified by the production of multi-material packaging based on reusable materials though much more difficult for further processing or utilization.

Recycling can be divided into original recycling, where the reclaimed materials are used to manufacture the products with the same properties, and secondary recycling, where the reclaimed materials are used to manufacture new products for which high purity and homogeneity of the raw material is not required [31]. Another division of recycling is into material recycling, based on reprocessing waste material, and chemical recycling, where the original material is reclaimed, degraded into original or derivative compounds and reused to produce the same or other product, although this type of recycling is usually highly expensive. In material recycling, an important aspect is the requirement to introduce packaging marks which would inform about the type of the material used to produce given packaging and its recyclable properties, as well as to maintain homogeneity of packaging, including avoidance of laminates.

Organic recycling, also known as composting, is the technological process based on processing organic substances of biological origin contained in waste material into compost, i.e. the manure whose properties are similar to humus containing up to 50% [31]. The waste useful for composting is garden and kitchen waste. When composted accordingly, biological waste makes an excellent manure which can successfully replace artificial fertilizers. Home composts are particularly recommended to eliminate the problem of compost disposal and the requirement to transport compost from the neighbourhood.

Energy savings resulting from recycling can be achieved on condition that the total energy used to collect, segregate and treat municipal waste, further processing included, will be lower than the energy used to produce the original material [32-34]. The maximum energy savings can be achieved in the process of recycling aluminium, since the energy consumed to produce aluminium is incomparably higher than the energy used to recycle it, including the transport at the particular technological stages. Reusing aluminium enables obtaining considerable energy savings at the level of ca. 222 GJ/t as compared to its production from original raw materials [35,36].

Considerable savings are also achieved in the process of recycling plastics, though these savings are still much smaller as compared to recycling aluminium [35,36]. A growth has been observed in Poland for the past several years in implementing the processes of reclaiming and recycling municipal waste in line with EU Directives. As a consequence, the volumes of reclaimed and recycled materials have been increasing year by year. Nonetheless, the basic determinant of successful recycling is implementing the adequate system of selective collection of waste.

5. Selective collection of waste

For the past several decades, suitable measures have been undertaken in many countries to minimize the volumes of municipal waste in landfill; the particularly important directions for development are the methods of reducing generation of waste and recycling waste, combined with a suitable system of selective collection of waste, which results in reducing the volume of waste intended for landfill, reducing harmful effects of the waste, and, above all, obtaining reusable materials with the least financial and energy outlays required. Selective collection of waste is the source of raw materials which can usually be reprocessed into usable products with much smaller outlays in terms of energy, raw materials etc. as compared to their production using original materials [33,37]. Unfortunately, it is still common in a number of countries, as well as in many regions in Poland, that waste is not segregated and all and the waste material ends up in one container to be carried away for landfill.

Three basic methods of selective collection of waste are distinguished:

- the method of collecting waste to be segregated in sorting plants; its main advantage is significant cleanliness of the finally segregated waste; the drawbacks are relatively high costs, the requirement to deliver considerable volumes of waste, as well as hazardous labour conditions for the personnel directly operating the sorting line;

- the take-out method, in which the segregated waste is collected at specified locations into special containers or facilities [31]. This is the most popular method of selective collection of municipal waste though it may imply polluting the segregated waste due to insufficient knowledge or low ecological culture of the locals; therefore relevant educational and information actions are required, which will determine to a large extent the profitability of this method. A complement to the take-out system can be the system in which the inhabitants segregate municipal waste into plastic bags and take them out to be collected by suitable municipal services. This system is relatively cost-effective, as it does not require investments in specialist containers and machinery to empty these containers; what is more, the contents of the bags can be controlled, since the bags are transparent. The discussed system can be used with success in small villages and estates of detached houses, at camp sites, as well as during mass events.

One of the easiest to implement systems of selective collection of waste is the double-container system (or the less expensive option, i.e. the double-bag system). The effectiveness of this system is within the range from 10 to 50%, yet it must be emphasized that for the double-container system to be effective as a recycling system it is required to develop a relatively expensive dry waste segregation plant, which considerably increases the costs of the venture. Another waste collection system based on the take-out method is the bag system based on providing each house with a stand with differently coloured plastic bags for different types of municipal waste. This system is particularly effective in estates of detached houses and in small villages. One of the mechanisms for promoting this system may be to exempt inhabitants from charges for purchasing plastic bags and collecting segregated waste. Yet local authorities must subsidize the system, since the profit from collected waste is often lower than the costs of transport and infrastructure.

A very popular system in a number of European countries, including Poland, is the system based on multiple containers, with its effectiveness ranging from 10 to 60%. The majority of containers used in this system are coloured accordingly and provided with suitable openings to serve the particular type of waste to be segregated, which should theoretically prevent from polluting the collected waste with other fractions. The degree of reclaiming raw materials in the discussed system increases proportionally to the growing density of the location of containers, which must result in a rise in the costs of reclaiming reusable materials. A flaw of the system, caused by the lack of sufficient monitoring system, is the problem of container overload and damaging them by scrap metal collectors and vandals.

The systems discussed above do not guarantee recycling the used packaging materials above the average level of 40%, hence the popularity of the recycling centres in highly developed countries, such as Japan, the United States of America, Germany, or Scandinavian countries. The locals walk, drive, and even bike to such centres with their waste and segregate it into suitable containers with the professional help of the staff. This solution enables highly precise segregation of municipal waste, while the material collected this way is characterized by its maximum cleanliness. Apart from collecting municipal waste, such centres may also collect hazardous waste, such as used batteries, remains of paints and solvents etc.

Automated recycling centres have been increasingly popular in highly developed countries as well. The automated centres are provided with equipment to collect, segregate and compact waste. The operating principle of such equipment is that after inserting a bottle or other waste packaging into the relevant opening the device recognizes its shape and the type of material used to produce that packaging and issues a coupon with the value of the inserted packaging which the customer may cash on the checkout. Next this recognized packaging is transported on a bucket conveyor to the relevant compacting section where it is pressed, cut, crushed or granulated into small fractions, which considerably reduces the volume of packaging, and consequently also the cost of its storage and transport. The devices for automated selective collection of waste can be installed in modules, which enables adjusting the system to the locally collected volume of given material. Each device is fitted with an LCD and an audio system, which enables communication between the centre and the customer by way of visual or voice messages. Owing to their user-friendliness and attractiveness, automated recycling centres become increasingly popular in many countries, especially near large shopping malls. Such recycling centres are often used to educate school children and kids; their walls are decorated with painted characters from fairy tales, and children can hear or watch interesting stories in return for used packaging [38]. Locating such recycling centre near a shopping centre may result in increasing the number of customers, who may be interested in disposing of their waste on the occasion of shopping and in return for payment or other type of bonus.

6. Deposit systems

The most advanced municipal waste management system is the deposit system, introduced already in a number of countries, such as Denmark, Norway, Sweden and Germany. In Denmark, the deposit system involves containers for carbonated drinks and beer, since selling them in disposable packaging is prohibited and such drinks are marketed in returnable bottles only. Each inhabitant of Denmark is obliged to pay waste tax in the amount depending on the methods of managing the waste produced by him. The highest fees are charged for landfill, incineration is slightly cheaper, while recycling is tax-free. The waste tax is paid in the form of rent, and therefore it is in the interest of the dwelling community to segregate waste with the utmost diligence, since they would not have to pay for having their segregated waste carried away [38]. The money obtained from waste tax supply the fund for supporting the development of modern municipal waste management. The fund is used in particular to subsidize all types of projects and measures targeted at reducing the harmful effects of waste on the natural environment, mostly such that support the development of waste-free technologies and promote clean technologies.

Currently the most effective system in which the highest recycling level has been achieved is the deposit system implemented in Germany. This waste management system is based on modern legislation and on the existence of institutions, which warrant supervision over the compliance of companies and inhabitants with their statutory obligations. All actions undertaken by the authorities are in line with EU Directives, with absolute observance of the 'polluter-pays' principle according to which the costs of polluting the natural environment are incurred by the polluter, be it a producer or a user of given product. As provided for in the German penal law, a polluter is treated equally with an arsonist or a thief, while the severity of penalties for polluting the environment effectively prevent any attempts at breaking the law in this aspect [38].

To solve the problem of the growing volume of packaging waste, the deposit system was introduced in Germany in 2006; in this system, purchasing drinks in either PET or aluminium containers requires paying a deposit, and all stores are obliged to accept bottles from consumers regardless of their place of purchase [38]. Additionally a special imprint on the labels was designed to enable easy identification of every bottle in order to specify the amount of paid deposit without problems.

Taking into consideration the obligation imposed on stores to accept bottles, the following two solutions were introduced: one solution is based on placing suitably signed cardboard boxes on the checkouts where checkout assistants place bottles and pay back the due deposits. The other solution is applied in larger stores, where automated collection machines are used. A bottle inserted into the machine is rotated until the sign from the label can be read or until the shape and type of that bottle is analyzed; next the machine displays the symbol of the inserted bottle and the amount of due deposit; the customer receives a coupon with bar code which can be cashed on the checkout [38].

Collecting and recycling municipal waste and scrap metal in Germany generates the annual savings in the amount of ca. 3.7 billion euro, where 2.3 billion euro is saved from using scrap metal in the steel production process, while approximately 700 million euro is obtained from reusing aluminium. According to the German Economic Research Institute, recycling enables saving 20% of the costs of providing raw materials and 3% of the costs of energy [38]. The funds saved this way can be used to further develop the system in small towns and to fulfil the statutory tasks in terms of waste management.

Some stores in Poland have already been provided with suitable equipment to perform selective collection of waste materials; such machines are installed in stores in the Kaufland, IKEA and Alma retail chains. However, due to the lack of adequate and general legislation, which would determine introducing the deposit system in Poland, the waste collection equipment is not popularized across the country. If such system was introduced in Poland along with the deposit system, considerable savings on energy and raw materials could be achieved and the problem of municipal waste would be partially solved.

7. Discussion

As was presented in this paper, the method for solving the problem of municipal waste which is most desired and favourable in economic, environmental and energy-related terms is to avoid their generation, mainly by way of changing the types and forms of packaging, changing the methods of distributing goods and using clean production technologies. Therefore one of the main priorities which accompany the development of municipal waste management strategy in line with the principles of sustainable development in terms of energy should be the measures targeted at reducing production of waste, extending product life and enabling their reuse in producing new goods, based on relevant legal and economic regulations. Excessive development of the infrastructure intended for thermal utilization and recycling of waste without introducing any mechanisms to reduce their generation will fuel environmentally harmful technologies, ineffective in terms of energy and raw materials, thus resulting in increasing the volumes of waste year by year.

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