Mitigating greenhouse gases emissions in processing fossil carbon containing industrial waste

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Abstract. The article assesses the Best Available Techniques for the methods of reduction of greenhouse gases (GHG) emissions in the waste treatment sector, that includes oil, plastic and rubber materials. The certain GHG emissions sources were shown and an attention is paid to the economic feasibility of specified methods in different places. It was shown, that for GHG mitigation policy, waste-management should be complied with the product life-cycle optimization, while recycling is considered as initially the best available method. The article is based on methods of scaling and statistical generalization. The data was obtained from official resources, including Reference Documents on the Best Available Techniques, National Inventory of GHG and from scientific publications. It was intended with full agreement, that resource efficiency enhancement relevantly should be in top priority of environmental and economic regulation.

1 Introduction

Nowadays, the humanity faces so called triple planetary crisis; this term refers to the three main interrelated issues: climate change, pollution and waste origin and biodiversity loss. Mitigating the effects of climate change means reducing the input of GHG to the atmosphere. It means cutting emissions from power plants, industry, transport, agriculture and waste. The ‘cap and trade’ principle is used to stimulate mitigation activities in several countries [1]. A cap is a limit set on the total amount of GHG that can be emitted by the installations covered by the definite system (regional, national etc.). Normally, the cap is gradually according to the national or local environmental targets. The cap is expressed in emission allowances system, where one unit gives the right to emit one tonne of carbon dioxide equivalent (CO_2-eq). In the European Union, for each year, enterprises must surrender (or purchase) enough allowances to square up their GHG emissions in order to avoid heavy fines.

Operational since 2005, the European Union Emissions Trading System is the oldest one: first voluntary climate projects were implemented within the framework of the Kyoto

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Protocol back in 2008-2012. Climate projects lay a ground for the national voluntary carbon unit's market; one of the pilots has been started on Sakhalin Island. It is assumed that possible buyers for this derivative are the companies, which consider themselves as undoubtedly carbon positive, and financial institutes which aim to comply with voluntary agreements on climate mitigation. The participant of Emissions Trading System in the Sakhalin Island Pilot (that was established in 2022) controls its impact via carbon market [2]. All issued carbon units in the project's boundaries are included in the national Registry of Carbon Units.

Despite there is no participation in the second commitment period, a sufficient number of Joint Implementation Project proposals were submitted and approved by Russia in compliance with Article 6 of the Kyoto Protocol during the first commitment period [3].

Waste-processing industries implement climate projects within the framework of the Kyoto Protocol along with other carbon-intensive industries, such as oil and gas or metallurgy ones. Concerning Waste Section of Intergovernmental Panel on Climate Change Guidelines, relevant sections of projects should cover energy transition to an application of biomass (timber harvesting waste and wastewater sludge incineration) instead of fossil fuels combustion, plus manufacturing of fuel pellets from wood waste.

National system for climate projects and carbon units' registration has been functioning since 2022, however, project proposals for the waste management sector are yet to be worked out. Present classification of GHG emissions and absorption is based on the following:

- Impact of individual technological processes (for example waste management) can be assessed at the regional level and then integrated to the state level (e.g., to the National GHG Inventory).
- Impact of individual entities under Scope 1 (direct emissions) can be evaluated via assuming of GHG emissions and absorption from all activities and processes controlled by a single enterprise (e.g., corporate reports).
- Impact of individual entities covering also indirect emissions (Scopes 2 and 3) is assessed as GHG emissions and absorption from certain enterprise (direct emissions) and that occurs at sources located outside this enterprise (indirect emissions).
- Carbon footprint of the product life cycle is assessed considering both direct and indirect GHG emissions and absorption along the whole product useful life, from its manufacturing to recycling or disposal. it involves various techniques and sites that can be located at a considerable distance from each other.

This research considers specific contribution of the organic chemicals waste management, e.g., oil, rubber and plastic scrap, to GHG emissions and discusses available opportunities for their reduction.

2 Materials and methods

In the context of this study, industrial waste management is considered as the integral part of product life-cycle. We assessed projects and programmes implemented in waste-management industry from the point of view of resource efficiency and existing standards of the waste processing.

At first part, in order to find most promising GHG reduction opportunities, we evaluated characteristics of waste generation sources and estimated waste processing techniques.

Next, each group of waste was considered as a headspring of recycled material and energy resources as a result of modern technological process. An identification of the most carbon-intensive life-cycle stage for each type of waste was carried out, and corresponding methods for GHG emissions reduction were suggested.

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The relevant data had been obtained from National GHG Inventory and by direct interviewing with company's representatives in charge of environmental protection and waste management.

A composition of industrial waste differs greatly between branches of economy. Degradable organic carbon and fossil carbon are presented both in industrial and municipal solid waste. The consolidated fossil carbon chemicals garbage list includes petroleum product waste, materials and things contaminated with petroleum products, rubber scrap (tires, tubes, footwear, etc.), polymer goods, which had lost their consumer properties, and organic solvents.

3 Results

From data analysis from the official open information sources [4] we determined prevailing types of fossil carbon containing waste that can be a potential source of GHG emissions: methane (CH_4), carbon dioxide (CO_2), nitrogen hemioxide (N_2O) (Figures 1-2).

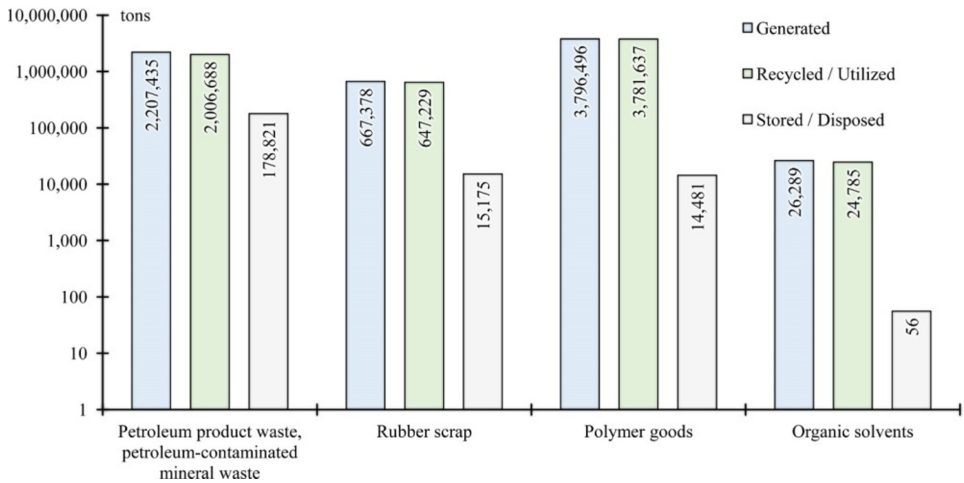

Fig. 1. Fossil carbon containing waste and its management in 2022, tonnes/year [4] (Source: composed by authors based on [4]).

As Figure 1 suggest, in terms of mass the primary sector of waste generation consists of polymer goods, which had lost their consumer properties, plus petroleum product waste, mineral waste (materials and things) contaminated with petroleum products, etc. Rubber scrap largely consists of used tires and is considered as a valuable product for recycling; the organic solvents waste tends to zero.

3.1 Petroleum product waste, mineral waste contaminated with petroleum products, etc

Petroleum product waste is generated from mineral petroleum-based products, which have lost their utility during storage or use. Mostly it contains used motor and industrial oils, transformer oils, lubricants and their mixtures. Petroleum product waste contaminate also ballast and flushing water from tankers of crude oil, petroleum products and liquified petroleum gas.

In terms of mass the leading share belongs to used engine oils, and currently the most common methods of specific waste management are recycling or combustion. Only a small part is assigned for disposal (Figure 2).

According to the official statistics, amount of petroleum product waste for the period 2016-2020 reached 300,000 tonnes, while amount of used engine oils remained in the range of 147,000 tonnes.

3.1.1 Recycling

There are two methods implemented for utilization of petroleum-based products: purely physical (settling, filtration, centrifugal separation) and physical-chemical (sorption, coagulation, thermo- and vacuum drying, selective dissolution). As a result, used petroleum chemicals are separated from impurities and water. Final products may be restored for the initial goods at the oil refineries.

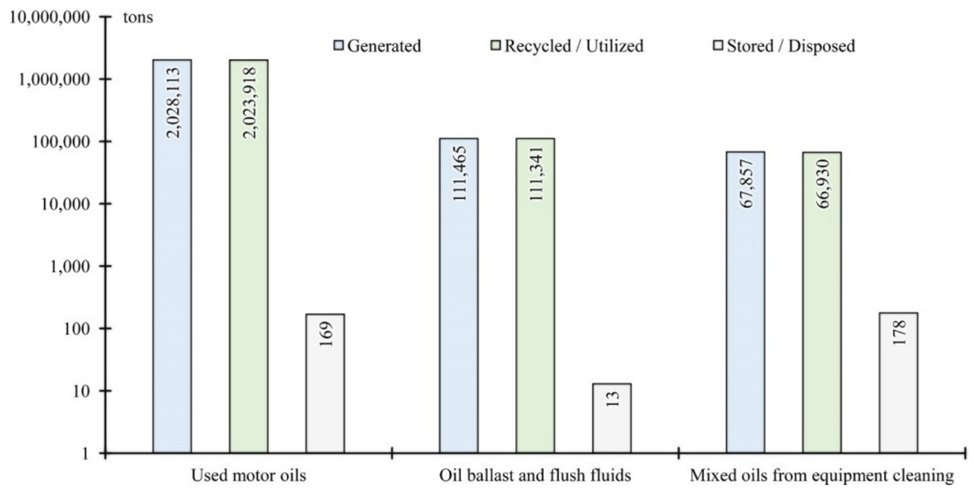

Fig. 2. Oil products waste ways of origin and its management in 2022, tonnes/year [4] (Source: composed by authors based on [4]).

3.1.2 Waste-to-Energy

Both combustion and pyrolysis of petroleum product waste, as well as oil-contaminated materials, allow for the significant reduction of its amount together with the generation of heat (waste-to-energy approach) [5]. However, this method demands the investments in flue gases treatment, and forms a significant source of GHG emissions.

3.2 Rubber scrap – tires, tubes, footwear, other rubber products

For this type of waste, the main share (in terms of mass) belongs to used pneumatic tubes and used ply tires (Figure 3). Modern waste management approaches include both recycling and combustion. Since 2017, these wares must be invariantly recycled for valuable components and disposal at landfills of that is prohibited by national law, which determined the list of resources for circular economy.

3.2.1 Recycling

Recycling of waste tires and tubes provides with a wide range of goods and materials: road, floor, sports coverings; rubber pellets, bitumen-concrete mixtures; metal and textile cord [6-7]. It is based on mechanical methods and no additional GHG emissions should be expected at Scope 1. There are some recycling facilities with capacity up to 30,000 tonnes of tires per year; waste tires are converted to rubber pellets for asphalt modifier and cord [8].

3.2.2 Waste-to-Energy

Within the framework of the circular economy, a number of projects have been implemented on the application of Refuse-Derived-Fuel in industrial processes to replace a part of fossil fuel [9]. For example, in cement manufacturing, GHG emissions originate both from fuel burning (energy-based, 30-40%) and from lime stone decarbonizing (technology-based, 60-70%), so the potential for mitigation is considerably limited by the share of energy. However, an incineration of rubber waste is accompanied by the release of various highly toxic underoxidized carbon-containing substances, that’s why it cannot be considered as a method of waste management.

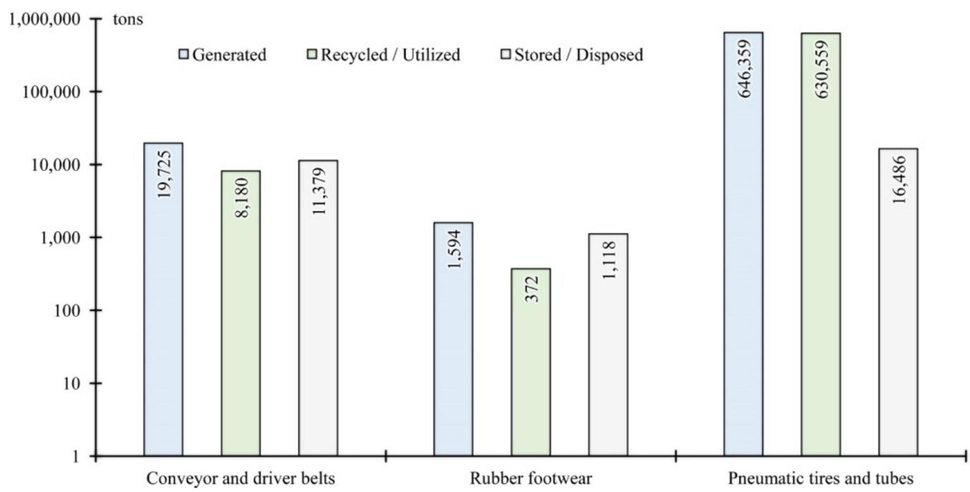

Fig. 3. Rubber scrap ways of origin and its management in 2022, tons/year [4] (Source: composed by authors based on [4]).

3.3 Polymer waste - goods, which have lost their consumer properties

Over 139,000,000 tonnes of single-use plastic waste have been generated worldwide in 2020 [10]. Plastics are manufactured from hydrocarbons, and it leads to the emission of approximately 450,000,000 tonnes of GHG annually [11]. There is a trend to ban the application of some types of single-use plastic ware; these laws are expected to come into force in 2024; in some regions, the turnover of such types of goods is already prohibited [12].

3.3.1 Recycling

Nowadays the petrochemical industry aims at improving its recycling techniques. A residue from the manufacturing of polymers (mostly after the thermal extrusion) is sent to mechanical processing, that doesn't add any GHG emissions, only small part is sent to chemical recycling so far. Plastic garbage is poorly collected for recycling (about 20%), while the largest part is either intended for a long-term service or is disposed of by landfills.

About 25% of polyethylene terephthalate (PET) is estimated to be collected and sent to processing. The amount of recycled plastic film and packages (highly likely a processable type of waste) lies below 5% of product in terms of mass, whereas its collection rate nears 80–90%. As for high-density polyethylene, e.g., for solid packaging, approximately 20% of its mass is recycled (less than 100,000 tonnes/year). The lowest recycling rate is for polypropylene (~10%), due to small demand in used material: it can be recycled few times without loss of its main properties and cannot be added generally to polyethylene goods. These types of plastic are processed mechanically in sufficient volume, the recycling rate for other types of plastic waste is insignificant [13-14].

An example of successful recycling is production of a new plastic bottle from a scrap one, a so-called 'bottle-to-bottle' process [14], that is implemented by Plarus polymer-processing plant (the Moscow region). The plant operates with recycled materials and consumes 1,500 tonnes/month of PET scrap with an output of PET preform, packaging ribbon, etc. Large-scale projects have been started already: EcoLine Group launched waste-processing at facilities in the Moscow region with total capacity of 1,700,000 tonnes per year, while RT-Invest Group installed a local complex for PET bottles scrap and low-density polyethylene recycling with an input up to 100,000 tonnes/year.

Condensation polymer is a process resulting in thermal decomposition of plastic to monomers with subsequent reassembling to new polymer. This method has yet to find a wide use in plastic waste recycling: equipment investments are considerably high, so a large-scale production is required [14]. Moreover, it leads to a specific problem, because monomers are highly toxic, so it contradicts with the principles of green chemistry manufacturing.

To contribute towards the circular economy principles, Sibur company has launched a number of recycling projects on mechanical and chemical polymer waste processing (Figure 4). Mechanical processing doesn't pay additional contribution to GHG emissions, minor ones are presented in chemical processing, depending on the employed technique. TotalCycle plastic package recycling plant (Russian-Indian EcoPartners Company Group) with capacity of 40,000 tonnes/year fabricates recycled materials (PET-flakes, polyethylene pellets, ready-made PET packaging ribbon) in the Tver' region. [15].

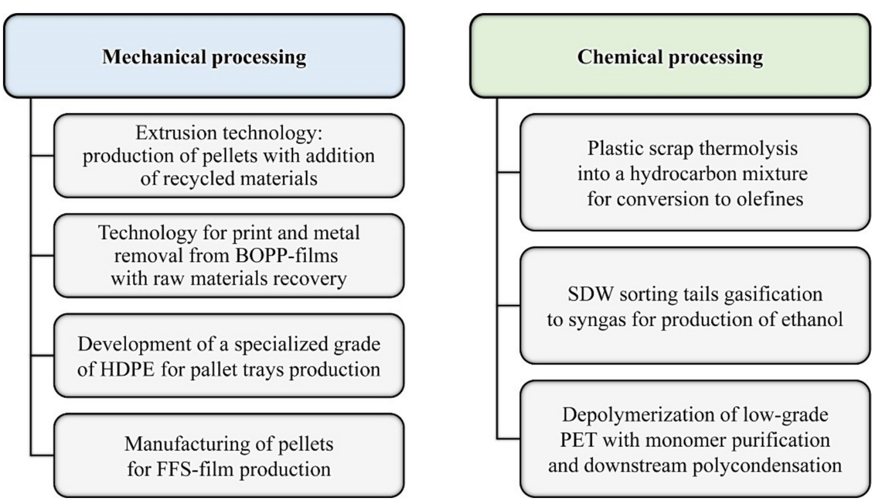

Fig. 4. Sibur projects in polymer recycling (Source: Sibur corporate report).

3.3.2 Waste-to-Energy

Pyrolysis is considered one of the reasonable solutions for plastic waste recycling into fuel among the methods of thermochemical decomposition. Pyrolysis is typically carried out at 500–800°C, the final product is a mixture of various hydrocarbons [16].

Another widespread method for plastic waste utilization is incineration: by various estimates, currently up to 40 % of plastic waste is burned. Advantages of this method include reduced amount of waste and some generated heat (if stored). Disadvantages include a generation of secondary waste (ash) and flue gases that contain significant amounts of GHG and other harmful substances [17].

4 Discussion

We can assume that incineration is the main source of GHG emissions from petroleum garbage, that is a serious challenge for waste management. In the European Union, carbon capturing techniques are often being explored in response to climate concerns of incinerators, that release an average of around 1 tonne of CO_2 for every tonne of burned waste; it is making climate change worse and causes a cost to society that is not covered by such utilization [18].

For rubber and plastic scrap, waste-to-energy is possible for some cases, when recycling is not economically justified, but is recognized as the main source of GHG. The task is to optimize an incineration process and capturing of CO_2 during downstream treatment of flue gases.

Plastic waste processing is limited by local availabilities and demands. Recycled materials become so expensive, that the industry has no economic reasons to use them. A substantial part of recycled materials has not been claimed by processing sites and stored for months.

Russian government released a list of 28 categories of plastic ware intended for ban. It includes non-transparent and coloured PET bottles, cotton swabs, plastic substrates, single use plates, glasses, pipes, mixers, other tableware, foamed polystyrene egg containers, cup covers and other items that are difficult to recycle.

Special attention should be paid to composite materials, which contains plastic, e.g., widely used Tetra Pak. This type of package is very convenient for manufacturers, distributors and customers, but has no good technology for recycling.

The ways of increasing the recycle share for fossil carbon waste are: limited manufacturing and consumption of materials made from fossil fuels, widespread collection, sharing of recycled materials in customer products (by 2030 it should replace not less than 20% that made of fossil carbon), development of a new materials, that are matching the aims of sustainable development.

The problem is getting worse within the fact that recycling plants are mostly settled in the European part of Russia. Shipment distance for legal disposal by landfill may come up to 1,000 km, that incurs economic losses in waste management, especially in the Arctic territories.

It should be mentioned, that economic and environmental viable emerging techniques have been selected as Best Available Techniques and described in sectoral and inter-sectoral Reference Documents, e.g., “Waste Incineration” and “Waste Treatment”.

5 Conclusion

One of the cornerstone principles in waste management is high resource effectiveness and implementation of the Best Available Techniques.

Regarding for fossil carbon-containing industrial waste management, it should be noted, that it is strived towards recycling. Most of such waste can be considered as a valuable material, and their recycling means the sufficient conservation of natural resources. One tonne of recycled plastic saves about eight tonnes of crude oil.

Nevertheless, the combustion is still the most common method for its utilization. It happens because, from one side, the technologies of recycling to fine goods are sufficiently expensive for enterprises; from another side, the largest distances worldwide and extremely low density of waste accumulations make it initially unprofitable to collect and recycle.

Petroleum contaminated materials are usually burned because there are few credible ways of cleaning them from petroleum products. In Russian cold climate such waste serves as an additional heat source.

Waste-to-energy method leads to certain GHG emissions. There are approved carbon capturing technologies implemented already on large waste incineration installations, but millions of small ones are releasing GHG without any treatment.

Possible complications in waste recycling generally emerge at the waste collection and sorting stages. If solid waste is generated in industry, it is already purified (as usual).

For municipal waste, separate collection has only started to evolve and the rate of separation at waste processing facilities doesn’t overcome 20%. This results in poor economic results for sorting enterprises and rising in the price of recycled valuable components.

Accordingly, the strategy of mitigation of GHG emissions from fossil carbon industrial waste cannot be fulfilled without the carbon capturing, because waste-to energy sometimes is the only available method but the recycling should be widespread to correspond with principles of circular economy.

Carbon Units is an instrument for carbon-positive enterprise to comply with voluntary agreements on climate mitigation. Moreover, its price should be fair to attract the followers. Current experiments will obtain us with necessary data for more justification of GHG regulations.

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