

Assessment of carbon emission potential of polyvinyl chloride plastics

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Abstract. Plastic pollution has become a global concern, and research has shown that carbon emissions during the lifecycle of plastics are rapidly consuming global carbon credits. This study focuses on the effective assessment of carbon emissions from polyvinyl chloride (PVC) plastics using a life cycle assessment (LCA) method during the production and recycling stages. The greenhouse gas emission potential is evaluated using 1kg PVC plastic as a functional unit. Research has shown that the total carbon emissions during the production stage of PVC plastic are 7.83kg CO₂-eq. The carbon emissions during the production stage of hydrochloric acid, acetylene, electricity, and water vapor are 2.340 kg CO₂-eq, 4.900 kg CO₂-eq, 0.117 kg CO₂-eq, and 0.468 kg CO₂-eq, respectively. During the recycling phase, the carbon emissions from the power consumption zone are 0.184 kg CO₂-eq, followed by 0.156 kg CO₂-eq from natural gas. Research has shown that fossil materials contribute the largest carbon emissions during the production stage of PVC plastics. Therefore, how to effectively reduce the use of fossil fuels or seek alternative raw materials can effectively reduce carbon emissions.

1. Introduction

Plastics are multifunctional, durable, and cost-effective materials used in a wide range of strategic fields, including packaging, construction, automotive manufacturing, electronics, and agricultural production [1]. Over the past 70 years, plastic production has continued to grow, from 1.5 million tons in the 1950s to 359 million tons in 2018 [2]. Due to the difficulty of natural decomposition of plastics, they have accumulated in land, freshwater, and oceans for decades. In 2010 alone, an estimated 4 million to 12 million tons of plastic waste generated on land entered the marine environment [3]. There are also increasing reports of pollution in freshwater systems and terrestrial habitats, as well as the pollution of synthetic fibers to the environment [4]. After physical, chemical, and/or biological interactions, large blocks of plastic will be decomposed into microplastics (MP) (1–5 mm) or nanoplastics (NPs) (< 1000 nm)[5].

At present, there are more than 300 types of plastics produced, of which more than 60 are commonly used and can be divided into ordinary plastics and engineering plastics according to their uses. Polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), polyurethane (PU), and phenolic resin are the main general-purpose plastics, among which PP and PE are the most commonly used polymers in daily plastic products. In Europe, 40% of plastic is used for packaging. The large-scale production of plastics will inevitably lead to a large amount of waste generation. Currently, the main disposal methods include incineration,

landfill, and recycling, among which recycling can minimize environmental pollution. At present, the biggest difficulty faced by plastic recycling is that the cost of collection and treatment is lower than the value of secondary materials. Unfortunately, the economic benefits of plastic recycling are poor. Landfill is the lowest cost method of all treatments, with most waste plastics directly entering the landfill site.

When microplastics enter the marine environment, marine organisms will ingest a certain amount of microplastics and enter higher-level organisms along the biological chain, posing unpredictable hazards. The harm caused by plastics to aquatic organisms mainly includes plastic additives, physical blockages caused by ingestion, and other issues. Plastic additives and pollutants can cause behavioral changes, metabolic processes, and endocrine disruptions. The types of harm caused by ingestion include internal damage to aquatic organisms, suffocation and entanglement, reduced growth and photosynthesis of primary producers in the food chain such as algae, and their impact on the reproduction and development of crustacean.

All plastics used before, including resins, fibers, and additives, were processed from fossil fuels. The molecules or monomers used to manufacture plastics, such as ethylene and propylene, also come from fossil fuels. Plastics require a large amount of resources and energy input during the production stage, which can only be used in plastic production after being processed. The energy and material input during the processing further exacerbates the carbon emissions brought by the plastic

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industry during the production stage. Research has shown that the primary production stage of synthetic resins contributes the highest carbon emissions, accounting for 69% to 86% of the total carbon emissions during their lifecycle. In the case of different fossil raw materials, the carbon emissions generated vary significantly, with coal to olefin producing the highest carbon emissions.

Plastic not only exists in our environment, but also accumulates as it enters people's bodies along the food chain. Amidst this growing concern, there is another largely hidden aspect of the plastic crisis: the impact of plastics on global greenhouse gas emissions and climate change. At the current level, greenhouse gas emissions from the plastic lifecycle threaten the goal of maintaining global temperature increases below 1.5 °C. As the petrochemical and plastic industries plan to expand production on a large scale, this problem may become even more severe. Almost every piece of plastic starts with fossil fuels and emits greenhouse gases at every stage of its lifecycle: 1) the extraction and transportation of fossil fuels, 2) the extraction and manufacturing of plastics, and 3) the management of plastic waste. If the production and use of plastics continue to grow according to current plans, these emissions could reach 1.34 billion tons CO₂ per year by 2030- equivalent to over 295 new 500 MW coal-fired power plants. By 2050, the cumulative greenhouse gas emissions from these plastics may exceed 56 billion tons, accounting for 10–13% of the entire remaining carbon budget[6]. Among all plastics, polyvinyl chloride (PVC) is the most consumed plastic, and the production stage is the main stage of greenhouse gas emissions from plastics.

All plastics currently used, including resins, fibers, and additives, are processed from fossil fuels. The molecules or monomers used to manufacture plastics, such as ethylene and propylene, also come from fossil fuels. Plastics require a large amount of resources and energy input during the production stage, which can only be used in plastic production after being processed. The energy and material input during the processing further exacerbates the carbon emissions brought by the plastic industry during the production stage. Research has shown that the primary production stage of synthetic resins contributes the highest carbon emissions, accounting for 69% to 86% of the total carbon emissions during their lifecycle. In the case of different fossil raw materials, the carbon emissions generated vary significantly, and the carbon emissions from coal to olefins are the highest

It is necessary to explore the key carbon emission sources within this stage. Recycling is currently considered the most user-friendly disposal option, but there is little exploration of greenhouse gas emissions at this stage. Therefore, it is necessary to explore these two stages.

2. Life cycle assessment tools and methods

2.1. Assessment instrument

The tool for conducting life cycle assessment (LCA) of PVC plastics in this study selected Simapro, a professional

operational software for LCA developed by PR é Consultant in the Netherlands. The software includes: (a) a lifecycle unit process database, and (b) an impact assessment database [7]. Users can establish different types of lifecycle units and system processes within the software as needed, and adjust the process allocation ratio according to actual needs.

Life Cycle Assessment (LCA) is an assessment method for preventive environmental protection, which mainly identifies and quantifies the potential environmental impacts of energy and material utilization, as well as waste; By identifying and quantifying the environmental impacts of energy and material consumption and pollutant release throughout the entire lifecycle stage. The concept of LCA originated in the 1960s, when environmental degradation, especially limited access to resources, began to become a concern. After experiencing a low point in the 1970s and 1980s, the concept of LCA was first proposed by the International Conference on Environmental Toxicology and Chemistry (SETAC) in 1990, and subsequent academic discussions were held to explore the theory and methods of LCA.

2.2. Evaluation method

The LCA method includes four parts: research objectives and scope, system boundaries, data sources and inventory analysis, and results and explanations. (a) The goal and scope are the starting points for determining the conduct of LCA; (b) The system boundary is 1kg PVC plastic production and recycling, which is consistent with the current mainstream domestic processes; (c) Data source and inventory analysis include input output material flow and energy demand of unit process; (d) In the results and interpretation stage, analyze the results of the early stages of LCA to determine the most important issues for the environment. Based on the results obtained, specific conclusions or recommendations should be given.

Due to the serious consequences of global warming, the International Organization for Standardization (ISO) has long established a series of standards for the accounting methods of product carbon footprints. Due to the many emissions that cause the greenhouse effect, the IPCC associates the radiative forcing of various carbon emissions with equal amounts of CO₂, resulting in a coefficient, Global Warming Potential (GWP). For different stages of carbon footprint calculation, the basic equations provided by IPCC are generally used The formula is as follows:

$$GWP = \frac{\int_0^T RE[1 - \exp(-T/\tau)] dt}{AGWP} \quad (1)$$

In the formula, RE represents the radiation efficiency of the target gas, representing the energy absorbed by the gas per unit area per unit time in the atmosphere, in W/(m² · kg); T is the time period taken for calculating the integral, usually taken as 20 years, 50 years, or 100 years. In this study, the value is 100 years; τ Is the atmospheric lifespan of a gas, in years; AGWP is the absolute global warming potential of CO₂ gas over 100 years.

2.3. Results and Interpretation

Interpretation is a stage of life cycle assessment where the results of other stages are comprehensively considered and analyzed based on the uncertainty of applied data and assumptions made and recorded throughout the research process. Based on the results obtained, specific conclusions or suggestions should be given, (1) respecting the intention of the goal definition and the limitations imposed on the research through the scope definition, and (2) considering the appropriateness of functional units and system boundaries. The interpretation should present the conclusions of LCA in an understandable manner. The purpose of the first element of life cycle interpretation is to analyze the results of the early stages of LCA, in order to determine the most important issues for the environment, namely those that may change the final outcome of LCA.

These important issues may be method selection and assumptions, inventory data of important lifecycle processes, characterization, standardization, or factors used in weighted impact assessments. Encourage practitioners to prepare a list of such choices during the actual implementation of LCA, defining goals and scope, product system modeling, and impact assessment, and provide reliable reports and recommendations. In this study, by determining the functional units, system boundaries, and inventory review of different plastics, and calculating the midpoint values of different plastics throughout the entire life cycle, specific greenhouse gas emissions brought by plastics and their contribution values at different stages and substances are obtained. At the same time, specific environmental impact sizes among different plastics should be given, and through these results, specific recommendations can be given. Provide specific reports on how to reduce environmental impacts for practitioners.

3. Results and Discussion

3.1. Assessment of carbon emission potential during the production stage of polyvinyl chloride plastics

The molecules or monomers used in the manufacturing of plastics, such as ethylene and propylene, all come from fossil hydrocarbons [4]. Research shows that plastic accounts for 70% of the total greenhouse gas emissions during the production stage. Research has shown that the primary production stage of synthetic resins contributes the highest greenhouse gas emissions, accounting for 69~86% of greenhouse gas emissions throughout their lifecycle [8]. This study combines the current mainstream PVC plastic production process to calculate the greenhouse gas emissions caused by materials and energy during the production stage, and identify key carbon emission sources.

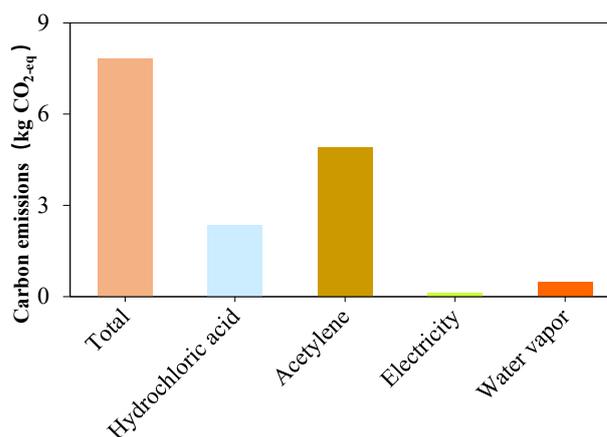


Figure 1. LCA of carbon emission potential in PVC plastic production process

The total greenhouse gas emissions of PVC plastic during the production stage are 7.83 kg CO₂-eq. The greenhouse gas emissions of hydrochloric acid, acetylene, electricity, and water vapor during the production stage are 2.34 kg CO₂-eq, 4.9 kg CO₂-eq, 0.117 kg CO₂-eq, and 0.468 kg CO₂-eq. Research has shown that acetylene contributes the largest greenhouse gas emissions during the production stage of PVC plastics, followed by hydrochloric acid. The consumption of electric energy contributes very little to greenhouse gas emissions during the production phase. Recycling of waste plastic recycling is regarded as an environmentally friendly approach. Recycling of plastics not only ensures the secondary utilization of waste plastics, but also reduces the consumption of fossil resources and greenhouse gas emissions, which is a very good decision for the secondary utilization of waste plastics in regions where fossil resources are scarce.

Acetylene, as a monomer in various chemical industry products, has received less attention in terms of greenhouse gas emissions caused by its processing and use. In addition, hydrochloric acid, as another important product in the chemical industry, not only makes significant contributions to greenhouse gas emissions in its production and processing, but also brings certain environmental pollution. These two monomers, as essential products for polyvinyl chloride production, make a relatively large contribution to greenhouse gas emissions. Developing new production processes or seeking other alternatives is an important way to reduce greenhouse gas emissions

3.2. Assessment of carbon emission potential in PVC plastic recycling stage

The greenhouse gas emissions in the recycling stage of PVC waste plastic recycling are 0.345 kg CO₂-eq, of which the carbon emissions of deionized water, electricity and natural gas are 0.004 kg CO₂-eq, 0.184 kg CO₂-eq and 0.156 kg CO₂-eq, respectively. The main greenhouse gas emissions during the recycling phase are electricity consumption, followed by natural gas. Energy consumption is the main source of greenhouse gas emissions in the plastic recycling stage.

The power consumption in the recovery phase is mainly used for the melting and extrusion of waste plastics. During this period, a large amount of heat energy will be generated, which will have a greater demand for electric energy and natural gas energy. At present, domestic power is still dominated by coal power generation. Therefore, the realization of clean energy can further reduce greenhouse gas emissions and make further contributions to the realization of carbon peak and carbon neutrality as soon as

possible.

Plastic recycling is the best way to dispose of plastic waste. It can realize the recycling of plastic waste and reduce the consumption of raw plastic and fossil energy, which can bring better environmental benefits at a certain level. For this reason, we should pay more attention to the recycling of plastic recycling and realize the closed-loop recycling of plastic.

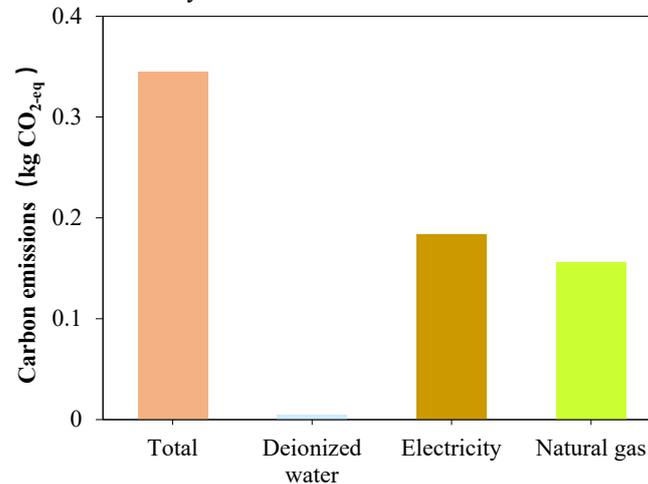


Figure 2. LCA of carbon emission potential in PVC plastic recycling stage

4. Conclusions

Life cycle assessment shows that the carbon emissions during the production process of polyvinyl chloride plastics are in the order of acetylene>hydrochloric acid>water vapor>electricity. The order of carbon emissions during the recycling phase is electricity>natural gas>deionized water. Research has shown that PVC plastics contribute the most to acetylene carbon emissions during the production process. The production stage mainly brings about greenhouse gas emissions through the consumption of energy and fossil fuels. The carbon emissions in the recovery phase are low. In the recycling stage, plastic is remanufactured into plastic particles, which can reduce the reproduction of original plastic. Therefore, the use of fossil materials and energy will also be reduced accordingly. In a sense, this is also a means to reduce greenhouse gas emissions at present. In addition, the recycled plastic can replace the original plastic reproduction, which can achieve a certain carbon emission reduction effect.

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