Evaluating Environmental Impacts in Mixed Plastic Waste Powder Recycling: A Comparative Study of Solar Photovoltaic and Natural Gas Alternatives

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Abstract: - The objective of this study is to assess the environmental impacts (EIs) of mixed plastic waste (MPW). According to the results, MPW powder, a blend of polyethylene (PE) and polypropylene (PP), significantly reduces climate change (CC) impacts when compared with industry standards. Furthermore, solar photovoltaic (PV) technology is assessed as an alternative to natural gas for producing MPW. When compared to natural gas, PV reduces the effect of MPW on climate change from 1.11 kg CO_2 eq to 0.94 kg CO_2 eq. Therefore, this research demonstrates how the use of PV technology in MPW powder production can reduce emissions by integrating renewable energy into the recycling process.

Key-Words: - Solar Photovoltaic; Natural Gas; Carbon Footprints; Embodied Energy; Mixed Plastic Waste; Environmental Impacts; Polyethylene; Polypropylene.

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1 Introduction

Oil and gas reserves in the Middle East make this region a major player in the global plastics industry, [1]. According to the Gulf Petrochemicals and Chemicals Association (GPCA), the petrochemical sector in the Gulf has grown by 5.9% annually until 2020, reaching 108 billion USD, [2]. It illustrates how plastic waste plays a significant role in global supply chains and environmental impact (EI) assessments, making it particularly relevant to life cycle assessment (LCA) studies of plastic waste.

Plastic waste is largely incinerated or disposed of in landfills, with less than 10% recycled, posing serious environmental and health risks, [3]. Plastic production is growing rapidly, which has led to issues such as harmful emissions, carbon footprints, fossil fuel depletion, and microplastics in food chains, [4]. The accumulation of plastic waste in landfills also contributes to long-term soil degradation, resulting in further ecological damage. This has necessitated the development of effective recycling and waste management strategies.

Although many studies on plastic recycling focus on its use in construction, such as in concrete, these solutions do not often produce high-value-added products, [5], [6], [7], [8]. Several alternative applications have been explored for plastic waste, including porous oil sorption materials for water treatment, [9]. Mechanical and chemical recycling processes, however, require energy and chemicals, which can reduce economic and environmental efficiency, [10]. To determine whether these recycling methods are truly beneficial to the environment or if they simply shift the burden to other stages, a comprehensive sustainability assessment is imperative.

LCA is used to evaluate the environmental impacts (EI) of a product or system from raw material extraction to disposal or recycling. Researchers apply LCA to evaluate the environmental footprint of various materials and processes, [11]. One study found that incorporating recycled polypropylene (PP) fibers into concrete footpaths could lower carbon emissions by up to 93% and reduce water consumption by 99% compared to steel wire mesh, [12]. Another investigation revealed that using low-density polyethylene (LDPE) as an aggregate in concrete could lead to a reduction of more than 7% in concrete and steel usage, [13]. Additionally, research demonstrated that blending recycled plastics with fly ash in concrete could decrease carbon emissions by approximately 13% compared to traditional methods, [14].

Almost 60% of all plastic wastage comprises polyethylene (PE) and PP, [15]. These plastics are frequently thrown away as waste after being utilized for single-use purposes. Separating or blending these polymers is highly challenging due to their immiscibility, similar densities, and lack of compatibility, [16]. Thus, recycling the mixture from plastic waste without segregation would be easier and more efficient. The present study was focused on evaluating the environmental impacts in terms of embodied energy and carbon footprints for production via plastic waste recycling. A commercial LCA tool, i.e. Gabi by Sphera, was used for this work.

This research presents an LCA for producing 1 kg of powdered material per batch from MPW. Using real experimental data, the study offers an accurate evaluation of the EI associated with this process. The results highlight key factors that influence the feasibility of this production method for effectively managing MPW.

2 Materials and Methods

MPW recycling involves collecting plastic waste, separation, and shredding. The shredded plastics were dissolved in xylene, which was later recovered using a vacuum and condenser system. The final powder was produced with electricity as the primary energy source. Water was reused to minimize energy demand and carbon emissions, which are higher in Qatar due to desalination. Figure 1 (Appendix) represents the steps for the production of MPW powder.

The LCA assesses the EI of a system or product throughout the course of its full life cycle, from the extraction of raw materials to disposal or recycling. The LCA methodology consists of four steps, as shown in Figure 2.

The objective was to assess the embodied energy and carbon emissions from waste collection to production. The transportation of waste back to the dumpster was excluded, and only electricity, xylene, and water were considered as inputs. The study focused on the operational phase, excluding the embodied energy and emissions from the equipment. For consistency, one kg of powder was used as the functional unit. Unit production data is provided in Table 1. Calculations were carried out using the GaBi software by Sphera. Net energy calculations are summarized in Table 2. All data were sourced from experiments and the GaBi database.

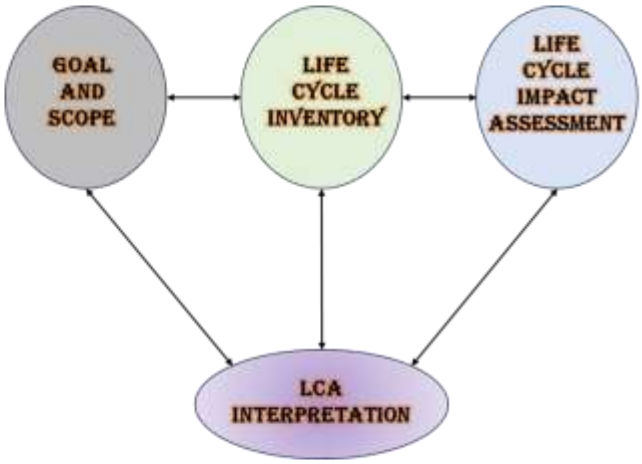

Fig. 2: Four phases of the LCA

Table 1. Inputs required for MPW powder production

Input	Value
Wastage	1.67 kg
Water	2.08 L
Electrical Energy	0.3688 kWh
Xylene	0.71 L

Table 2. Energy calculation for the inputs

Input	Energy (MJ)
Electricity	1.48
Xylene	47.60
Water	0.92

3 Results and Discussion

Figure 3 illustrates the CC and net energy results for MPW powder, virgin PE, and PP pellets, using PE as the baseline for normalization. The normalized climate change values are 1 for PE, 0.905 for PP, and 0.622 for MPW, while the normalized net energy values are 1 for PE, 0.957 for PP, and 0.647 for MPW. The actual unnormalized values are 1.79 kg CO_2 eq. for PE, 1.62 kg CO_2 eq. for PP, and 1.11 kg CO_2 eq. for MPW, along with 81.5 MJ for PE, 78 MJ for PP, and 52.74 MJ for MPW.

The reduced carbon emissions and net energy for MPW can be attributed to its use of recycled plastics, which require significantly less energy compared to producing new materials. The production of virgin PE and PP, derived from crude oil and natural gas, involves energy-intensive processes from raw material extraction to manufacturing. This results in higher energy consumption and carbon emissions for virgin PE and PP. In contrast, recycling MPW helps conserve energy and reduces overall EI, making it a more sustainable choice compared to virgin plastics.

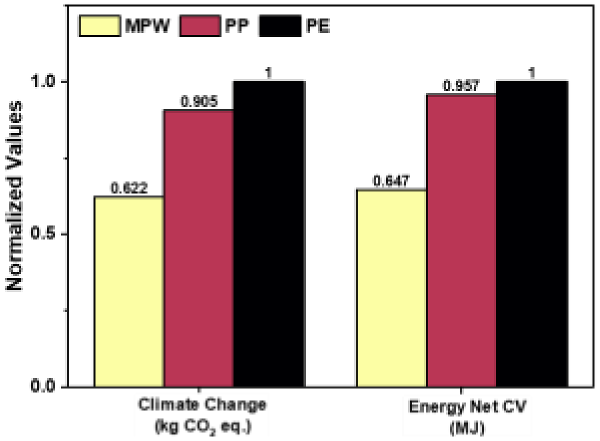

Fig. 3: Comparison of the normalized values: MPW vs. PE vs. PP

The choice of fuel significantly impacts both emissions and net energy. The results presented are based on electricity from natural gas for production, but using solar photovoltaic (PV) technology as an alternative would lead to different outcomes. Figure 4 compares the normalized CC for MPW produced using PV technology versus natural gas, along with PP and PE. When MPW is produced with natural gas, the carbon emissions are 1 kg CO_2 eq. per kg of MPW, while using PV technology reduces emissions to 0.85 kg CO_2 eq. This demonstrates the environmental advantages of PV technology, which results in significantly lower carbon emissions compared to natural gas. Additionally, MPW produced with PV technology has a lower carbon footprint than both PP and PE, highlighting the substantial environmental benefit of using PV technology in MPW production.

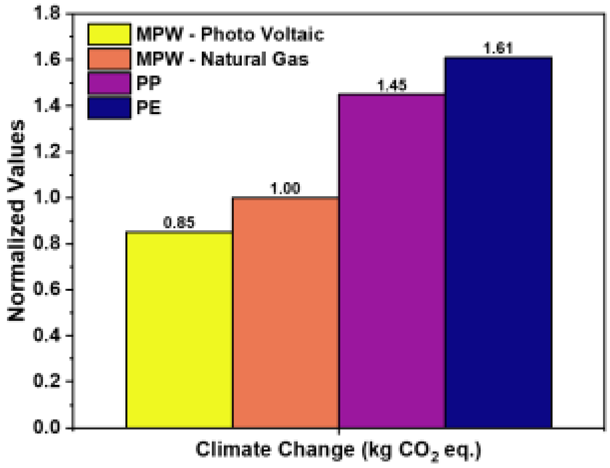

Fig. 4: Normalized climate change values

4 Conclusion

In summary, this study conducted an LCA of recycled plastic, assessing the EI across the entire life cycle, from waste plastic collection to production. The results showed that recycling plastic waste leads to reduced greenhouse gas emissions and energy usage. Additionally, incorporating renewable energy such as PV offers the potential for further reducing carbon emissions during powder production. By adopting renewable energy solutions, the sustainability of the production process can be significantly improved.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

The authors have no conflicts of interest to declare.

APPENDIX

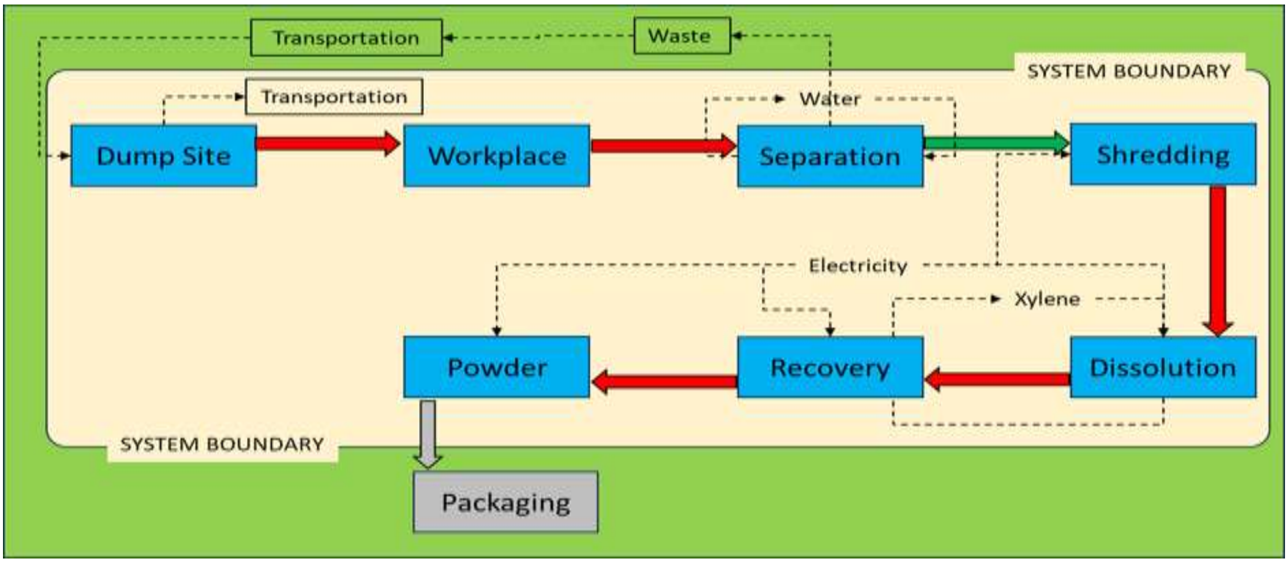

Fig. 1: Schematic representation of the steps for the production of MPW powder