INCORPORATING AGILE LIFE CYCLE ASSESSMENT AND MACHINE LEARNING TO PREDICT ENVIRONMENTAL IMPACTS FOR CHEMICAL RECYCLING OF STATE-WISE LANDFILL PLASTIC WASTE

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Abstract

The increasing consumption of fossil-based plastics and the current linear approach combined with inefficient plastic waste handling are the main reasons behind the accumulation of plastic waste. The conventional way of disposing of plastic is through landfilling. About 86% of the plastic waste was landfilled in 2019; over the years, a significant fraction of plastics have been deposited in landfills. National Renewable Energy Laboratory (NREL) and the United States Environmental Protection Agency (US EPA) estimate the figure to be around 32.2 to 44 million metric tons with an average market value of $7.5 billion. Therefore, shifting towards a circular plastic economy through developing new recycling techniques is imperative. Chemical recycling of plastic, a promising solution, has the potential to fully utilize the waste by producing plastic monomers as well as high-value chemicals. Life cycle assessment (LCA) and other sustainability indices help determine whether chemical recycling is a viable alternative to current plastic waste management. In this study, we present an agile modeling framework that predicts greenhouse gas (GHG) emissions based on a given product distribution to evaluate energy demand and environmental implications of the chemical recycling of plastics. A data-driven machine-learned model was developed using the published literature data on oil yields by chemical recycling of plastic waste. Predicted oil yields from the machine-learned model at different reaction conditions and plastic waste fractions were then used as the primary product yield for the LCA model. The study assessed the chemical recycling of plastic waste landfilled annually for each U.S. state, considering different plastic types and conversion temperatures. This study elucidated the influence of varying waste composition, temperature, and utilities specific to each U.S. state. We identified that GHG emissions can vary up to 3-fold among the U.S. states, even when the same recycling process is followed. GHG emissions depend significantly on the state-specific grid characteristics and plastic waste composition; for example, waste with higher low-density polyethylene (LDPE) and polystyrene (PS) fractions and lower high-density polyethylene (HDPE) and polypropylene (PP) fractions had lower emissions than waste with comparatively high HDPE fractions. Moreover, suitable state-specific co-product handling pathways (e.g., fuel gas-to-electricity vs. fuel gas sold directly as an energy product) were also identified depending on the primary energy sources for electricity generation.

1. Introduction and Motivation

Plastics are present in our everyday products because of their desired physical and chemical properties and low manufacturing costs. It has been estimated that total annual plastic production may increase to 1606 Mt globally by 2050 (Zheng and Suh, 2019). Rapid growth in plastic use and waste mismanagement result in large-scale plastic waste accumulation, most of which is landfilled. In 2018, the USA generated about 35 million tons of waste plastics, with around 8.4% recycled, 76% sent to landfills, and 15.6% incinerated for energy recovery (US EPA, 2024). Around 99% of the globally produced plastics are derived from fossil fuel-based chemicals (Ali et al., 2023). Consequently, when plastic waste is sent to landfills, its potential energy is effectively wasted. Canada's plastic waste management system estimates that nearly $8 bn is lost due to discarding 86% of plastic waste to landfills (Bio-Tec Environmental, 2023). NREL estimates that the energy value lost in 2019 due to landfilled plastic waste could supply 5.5% of the power used by the industrial sector in the U.S. (NREL, 2022).

Plastic pollution is a global challenge. The current linear approach of 'take-make-use-dispose' for plastics is not sustainable. Through sustainable plastic waste management approaches, we can switch to a circular plastic economy that will ensure economic and environmental benefits. It has been estimated that a circular plastic economy can reduce GHG emissions by 25% and generate savings of $200 bn per year by 2040 (Reddy et al., 2020). Conventional ways of treating waste plastics, such as landfilling and incineration with energy recovery, do not fully utilize the potential of waste plastics and have a pollution risk. Mechanical and chemical recycling can enable the circular plastic economy by transforming waste into reusable resources.

Mechanical recycling of post-consumer plastic wastes is difficult due to variations in plastic types and the presence of contaminants, such as inks, pigments, and adhesives, in the feed stream. On the other hand, chemical or feedstock recycling is less sensitive to the variation in waste plastic feed. Through chemical recycling, valuable chemicals and fuels can be recovered from the waste plastics, and, as a result, chemical recycling can close the loop for plastic circularity. Various technologies, including pyrolysis (Alston and Arnold, 2011; Evangelopoulos et al., 2015), gasification (Arena et al., 2010), and hydrolysis (Ügdüler et al., 2020) are applied to recycle waste plastics to their petrochemical constituents chemically. LCA of waste plastic management on different technologies enables the quantification of the environmental footprint associated with each technology and finding the environmental impact hotspots. Among the technologies, pyrolysis can convert a wide range of plastic waste and has reached commercial-scale maturity (Solis and Silveira, 2020). Also, the GHG emission for pyrolysis is 50% lower than the conventional energy recovery options (Jeswani et al., 2021). However, most LCA studies on waste plastic pyrolysis are based on static assumptions. The LCA does not incorporate the varying operational or temporal parameters that may influence the outcome (Lueddeckens et al., 2020). Nevertheless, the distribution of the final pyrolysis product is influenced by feedstock changes, reactor geometry, pyrolysis temperature, heating rate, residence duration, secondary reactions, and the presence of foreign components inside the reactor that can act as catalysts. (Hájeková and Bajus, 2005; Hernández et al., 2007; Karaduman, 2002; Onwudili et al., 2009). To incorporate the influence of varying pyrolysis operational parameters, we propose an agile LCA model that uses known product distribution to predict the overall environmental impact. In the process, the model can calculate changes in the environmental footprint due to the variation in feed compositions and temperature by incorporating the corresponding product distribution. A data-driven machine-learned model was developed to predict oil yields from chemical recycling of landfill plastic waste with varying feedstock compositions at different temperatures. Predicted oil yields were then used as the primary product yields for the LCA model. Thus, our data-driven ML-aided LCA model can generate a landscape of GHG emission scenarios for informed decision-making.

2. Review of Related Work

Chemical recycling of plastic waste through pyrolysis yields hydrocarbons that can be used as fuels, valuable chemicals, or monomers for plastics. Numerous small-scale facilities are operational, and corporations like Honeywell are developing large-capacity plastic-to-fuel recycling operations (Schneider 2022). LCA can quantify the carbon footprint of such processes. Recent LCA studies on pyrolysis showed that plastic pyrolysis had lower environmental implications on impact categories like fossil fuel depletion, climate change, and human toxicity than landfill disposal (Xayachak et al., 2023). Hermans *et al.* studied the environmental impact of sorted plastic waste pyrolysis. The study showed that the global warming impact for pyrolysis was 0.81 kg CO_2 -eq. / kg sorted plastic waste, 73% lower than incineration with an energy recovery pathway (Hermanns et al., 2023). Arena *et al.* found that, compared to energy recovery through gasification, the plastic-to-fuel pathway via pyrolysis had lower impacts on climate change, acidification, and fossil resource use categories (Arena et al., 2023). However, most LCA studies on waste plastic pyrolysis are based on static assumptions/data; temporal or operational variations are not included in the LCA (Lueddeckens et al., 2020). For example, plastic composition and energy consumption values were static in the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET ™) model, giving the environmental footprint value for the chemical recycling of waste plastics only for a fixed waste plastic composition (Benavides et al., 2017). LCA studies should incorporate scenarios addressing varying operating conditions to support decision-making abilities. Ou and Cai developed a dynamic LCA model that incorporated emission change due to changes in feedstock moisture and particle size for a fast pyrolysis process (Ou and Cai, 2020). The variation in moisture content and particle size gave insightful information on fast pyrolysis. Similarly, our work proposes an agile LCA framework for plastic-to-fuel pathways that quantifies GHG emissions using product distribution. The product distribution was obtained through machine learning (ML) algorithms.

ML can predict the amount of pyrolysis oil, gas, and char yield and their characteristics using less time and expense compared to experimentally finding out the kinetics behind the pyrolysis procedure for each varying condition. Neural Network (NN), Support Vector Regression (SVR), Decision Tree (DT), and eXtreme Gradient Boosting (XGBoost) models are often used for forecasting the product distribution from pyrolysis (Paavani et al., 2025). Pan *et al.* developed a hybrid NN-genetic algorithm that could predict oil production from polyethylene (PE) and PS co-pyrolysis with an error percentage of less than 8% (Pan et al., 2022). Another study used the XGBoost model to predict the oil yield from the co-pyrolysis of biomass and plastic waste with a prediction accuracy regarding the R^2 value of 0.86 to 0.9 (Prasertpong et al., 2023).

3. Technology Approach

In this study, we assessed the GHG emissions from the pyrolysis of landfill plastic waste for each state of the USA. Instead of conducting a case-specific LCA with static data, we advocate for an agile Excel-based LCA framework based on the GREET model (Wang et al. 2022). This model can produce a landscape of scenarios for the GHG emissions of gate-to-gate plastic-to-fuel processes. It is easily adjustable to quickly evaluate the impact of decision variables and technology parameters on GHG emissions. The evaluation of environmental impact for scenarios such as pyrolysis energy requirements for varying feedstock composition, temperature and residence time, different fuel types used for pyrolysis (electricity vs. natural gas), variations in electricity generation efficiency, grid electricity characteristics, and co-product handling can be performed using this model. The ML model was trained and validated with a dataset containing 325 individual data points obtained from 39 open literature. Random Forest was chosen as the machine learning model based on mean absolute error. The classification of the polymer feed was done based on the elemental composition of the polymer and the molecular weight of the monomer. Rapid scenario assessments using this ML-based LCA model will inform the early-stage process and accelerate technology development. This LCA study aims to assess the quantitative impacts of operating parameters, electricity sources, co-product handling and crediting methods, and electricity conversion efficiencies on GHG emissions for landfill plastic pyrolysis.

3.1 System Boundary and Functional Unit

The LCA system boundary (Figure 1) encompasses the transportation of curbside municipal solid waste (MSW) to the sorting facility, pyrolysis, and the transport and distribution of the main product, pyrolysis oil (Py Oil). The boundary defined in this paper is a modified version of that taken from the GREET model (Benavides et al. 2017). The process starts with transporting the collected curbside MSW to the material recovery facility (MRF) for sorting. The sorted non-recycled plastic (NRP) is then sent to a plastic pyrolysis plant. Py Oil is the main product, and the co-product is fuel gas.

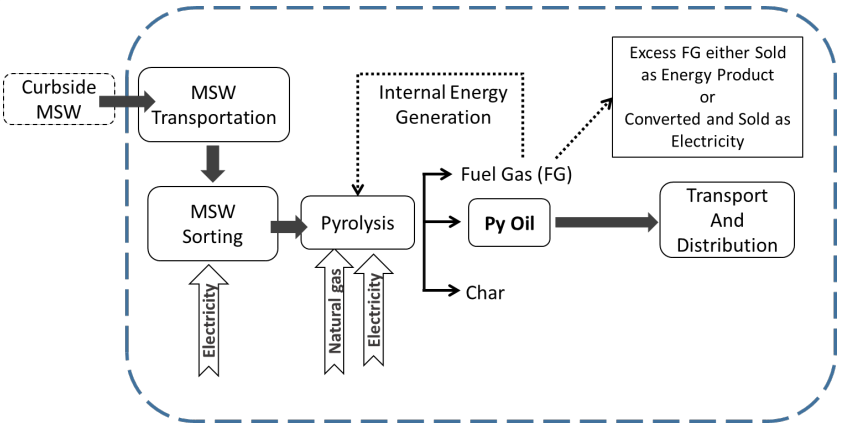

Figure 1. System Boundary flow chart for the plastic-to-fuel pathway

The functional unit is considered 1 megajoule (MJ) of energy obtained using the lower heating value of Py Oil. Table 1 explains the two scenarios for handling the co-product, fuel gas, similar to the GREET model (Benavides et al., 2017). In the first scenario, fuel gas from pyrolysis was burned to meet the process's internal heating energy demand. The rest of the fuel gas is sold as an energy product. For the second scenario, the fuel gas is combusted to generate internal heating, similar to scenario one, and the remaining fuel gas is combusted to generate electricity at 34% efficiency. The generated electricity is used for internal electricity demand, and excess electricity is sold to the grid. In general, for a multiproduct process, the environmental burdens can be partitioned among the co-products, or the

co-products can be credited as alternatives to other market products. For this process, fuel gas or electricity produced is credited via energy allocation or displacement. In energy allocation, the environmental burden is partitioned based on the energy contents of the product (Py Oil) and co-product (fuel gas). In displacement or system expansion method, co-produced electricity is credited via displacing grid electricity. Char or residues are landfilled. The impact due to the transportation of the coke to the landfill site is assumed negligible. Emissions from the transportation and distribution of Py Oil is not considered when comparing scenarios.

3.2 Life Cycle Inventory and Impact Assessment Methodology

The inventory inputs were obtained from the GREET module for MSW transportation to MRF facility separation. Fuel properties such as carbon content, heating value, product transport, and distribution were also obtained from GREET. Product distributions of mixed waste plastic pyrolysis at varying process conditions were obtained using the ML model. Since the ML part is not within the scope of this paper, we only focus on the LCA part. Characterization factors and emission factors for GHG emissions were taken from the Intergovernmental Panel on Climate Change (IPCC) and the GREET model.

Table 1: Co-product handling scenarios considered in this study

Scenarios	Treatment of fuel gas as a co-product in LCA modeling
Scenario 1	Co-produced fuel gas is combusted to meet internal heating energy demand only. The remaining fuel gas is sold as an energy product
Scenario 2	Co-produced fuel gas is used to produce both heating energy and electricity. After meeting the internal heating energy demand, the remaining fuel gas is converted to electricity. Extra electricity is sold to the grid.

3.3 Energy Calculation for Plastic-to-Fuel Conversion

The energy required to pyrolyze landfill plastic waste was calculated at varying temperatures (400° C to 700° C). Polyethylene terephthalate (PET) and polyvinyl chloride (PVC) were assumed to be separated from the waste plastic feed before pyrolysis, as PET is more favored for mechanical recycling. At the same time, the presence of PVC is often problematic for thermal degradation techniques. The pyrolysis feed comprised the remaining HDPE, LDPE, PP, and PS resin types. We first listed the resulting product components from pyrolyzing each resin type at the corresponding temperatures. Then, the resulting pyrolysis products were lumped into gas, oil, and residues. The average heat of formation, specific heat capacity, and molecular weight for the lumped categories were used to calculate the enthalpy change. The remaining wax/char or unreacted plastics were negligible and were not considered in the process.

4. Discussion

As stated, the LCA for landfill plastic waste pyrolysis for all 50 states was performed under two co-product handling scenarios. A detailed discussion follows.

4.1 Scenario 1: Fuel Gas is Combusted to Meet Internal Heating Energy Only

4.1.1 Impact of Temperature

For scenario 1, the fuel gas was combusted to meet the internal heating demand only. The electricity demand for the pyrolysis process was assumed to be met from the grid. The emissions for electricity use were calculated considering that grid electricity was generated considering the US average grid electricity mix. Figure 2 shows that the net emissions for plastic pyrolysis are the lowest at 600 °C and highest at 400 °C among the three temperatures because the oil yields for all states were the highest at 600 °C and lowest at 400 °C. Since the environmental footprint assessment is based on Py Oil energy as the main product, higher oil yield reduced environmental impacts. For example, Texas has the highest oil yields (57.5% at 400 °C) and, consequently, the lowest GHG emissions.

We plotted the percentage of oil produced and GHG emissions from waste plastic pyrolysis at varying temperatures to identify the impact of oil yield on the GHG emissions. Fifty U.S. states were represented as ranges in Figure 3. When plotted over a range of temperatures (from 400°C to 700°C), it was seen that the emissions trend changed inversely to the Py Oil yield (Figure 3(a) and (b)). The observed oil yield trend is in line with the other studies on the effect of temperature on pyrolysis oil yield. Generally, oil yield increases with temperature up to a certain point and then decreases as higher temperature facilitates the breakdown of larger oil molecules into gases (Riesco-Avila et al. 2022). For scenario 1, the overall emissions from waste plastic pyrolysis can be lowered by increasing the oil yield.

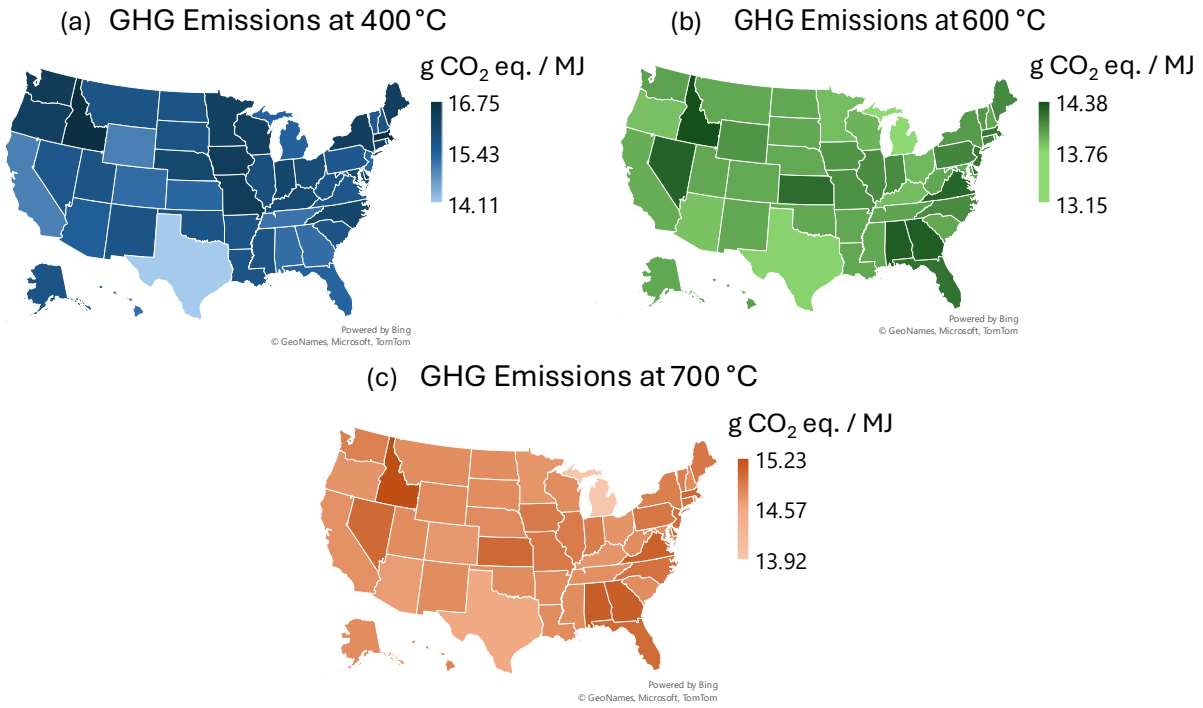

Figure 2. State-wise GHG emissions for the pyrolysis of landfill plastic waste at varying temperatures ((a) at 400°C, (b) at 600°C and (c) at 700°C). In this case, part of the fuel gas was combusted to meet the internal heating demand of the pyrolysis plant, and the remaining fuel gas was sold as an energy product (credited via the energy allocation method). The emissions for electricity use were calculated considering the grid electricity was generated following the average grid electricity mix.

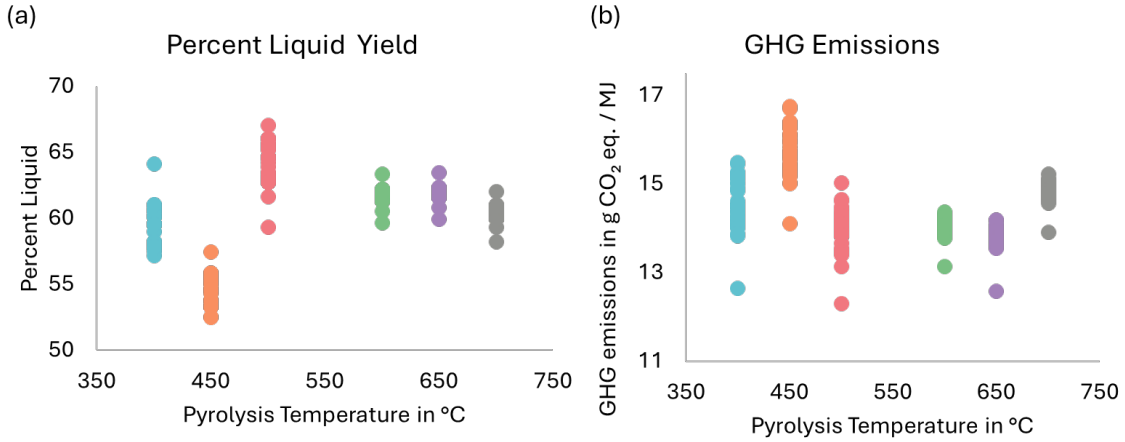

Figure 3. Variation in oil yield (a) and GHG emissions (b) at different pyrolysis temperatures. The ranges depict all fifty US states.

4.1.2 Impact of Feed Composition

Further analysis of variation in oil yield among the states indicated that higher LDPE and PS fractions in the waste plastic feed increased the oil yield. PS has the highest oil yield (97%) when pyrolyzed. As a result, pyrolysis of the landfilled plastic waste yielded the highest oil in Texas because of high PS fraction (15.91%). Among the polyolefin plastics, LDPE has a comparatively higher oil yield. (Sharuddin et al., 2018). Fractions of HDPE and PP present in the composition impacted the total energy required to pyrolyze, ultimately impacting the total GHG emissions. It was also observed that the higher HDPE fraction in waste plastic required more energy, while waste with a higher PP fraction required less energy for pyrolysis resulting in higher and lower GHG emissions, respectively. For example, states such as Alabama, Delaware, Georgia, and Nevada have high HDPE and low PP fractions in landfill plastic waste compositions, resulting in high GHG emissions (Figure 2). Even though some states yielded higher oil from pyrolysis, for example, Alabama, the high energy requirement due to high HDPE fractions increased the overall GHG emissions. Therefore, pyrolysis of plastic waste with high PS and LDPE fractions and low HDPE fractions is environmentally more favorable.

4.1.3 Impact of Electricity Grid

Each state has a specific grid electricity mix due to the varying primary energy sources used to produce electricity. When a state has more coal-fired power plants contributing to electricity generation, higher GHG emissions are associated with grid electricity use. States that use cleaner electricity harnessed from hydro or wind power have a low environmental footprint related to electricity generation. When state-specific electricity generation mixes were considered in the LCA (Figure 4), the lowest GHG-emitting state for landfill waste plastic pyrolysis changed from Texas to Vermont. According to the GREET inventory, Vermont's electricity generation mix includes 79% of hydro, wind, geothermal, and other energy sources, 20% from biomass power plants, and only 1% from natural gas-fired power plants (Wang et al., 2022). Consequently, emissions from electricity use for pyrolysis in Vermont had a low impact on the overall GHG emissions. States like West Virginia, Utah, Indiana, and Wyoming heavily depend on coal-fired power plants to generate electricity, resulting in large-scale environmental impacts. For West Virginia, 93% of energy generation is through coal-fired power plants. Using state-specific emissions also increased the GHG emission ranges among the states. The GHG emissions did not vary significantly among the states when the U.S. average electricity generation mix was considered (14.11 to 16.75 g CO_2 eq./ MJ at 400°C, Figure 2). However, using a state-specific electricity generation mix increased the GHG emission ranges among the states. The lower and the higher limit of the emissions varied significantly (8.15 to 26.26 g CO2 eq./ MJ at 400°C, Figure 4).

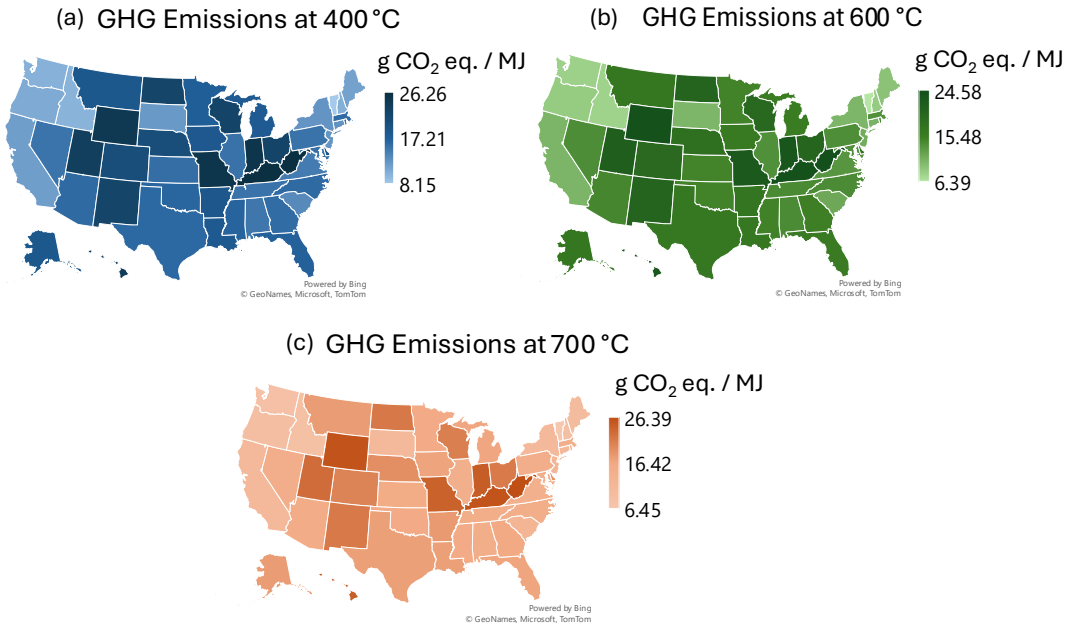

Figure 4. State-wise GHG emissions for pyrolysis of landfill plastic waste at varying temperatures (a) at 400 °C, (b) at 600°C and (c) at 700°C). State-specific electricity generation mixes were considered when calculating emissions from electricity use. In this case, part of the fuel gas was combusted to meet the internal heating demand, and the remaining fuel gas was sold as an energy product and was credited via the energy allocation method.

4.2 Scenario 2: Fuel Gas is Combusted to Meet Internal Heating Energy and Generate Electricity

4.2.1 Impact of Electricity Generation and Co-product Crediting Method

In this scenario, fuel gas was combusted fully to meet the internal heating and electricity demand, and excess electricity was sold to the grid (scenario 2). Since in scenario 2, all the fuel gas is combusted, the combustion process contributes to the overall emissions. States such as Texas, Vermont, and Alabama were found to produce lower fuel gas; therefore, the combustion burden on the overall environmental footprint for those states was low (Figure 5 (a) and (b)). High GHG emitting states, such as Michigan, were found to make a large quantity of fuel gas after pyrolysis.

After meeting the internal energy demand, the remaining electricity was credited, following the energy allocation method (Figure 5(a)). When system expansion was followed (Figure 5(b)) to credit the co-product, electricity produced from fuel gas was displaced with the grid electricity sourced from the US-average electricity generation mix. Following the system expansion method, a higher credit was obtained from the co-product. For both co-product crediting methods, states with lower fuel gas and higher oil yield had comparatively lower GHG emissions.

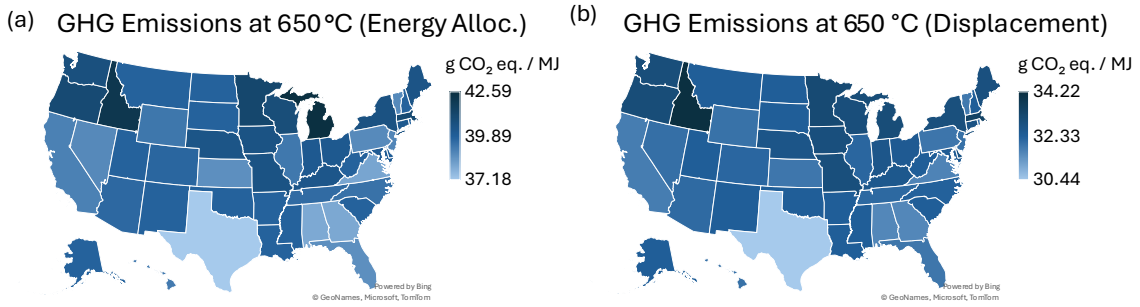

Figure 5. GHG emissions for pyrolysis of landfill plastic waste when fuel gas was fully combusted to meet the internal heating and electricity demand with excess electricity sold to the grid. Excess electricity was credited following (a) energy allocation method (b) displacement (system expansion) method. Both (a) and (b) emissions were calculated assuming grid electricity was generated following the average US electricity generation mix.

4.2.2 Impact of Electricity Grid and Conversion Efficiency

When state-specific electricity generation mix was considered for scenario 2 with system expansion (Figure 6 (a)), it was seen that the states with high coal-sourced electricity fraction in the generation mix had lower emissions compared to states that had cleaner primary energy sources for electricity generation. Higher credits were obtained for states with fossil-based electricity generation mixes when displacing the state grid electricity with the electricity produced from fuel gas. On the other hand, emissions from the states with electricity that have lower environmental footprints did not change significantly when the system expansion method of co-product crediting was applied (Figure 6(a)). This was because the emissions for electricity generation for such states are lower compared to states that generate electricity from fossil-based primary energy sources. Therefore, states such as Wyoming and West Virginia, in this case, showed lower emissions than Texas or Vermont (Figure 6(a) is compared with Figure 5(a)). The produced electricity credit is insufficient to significantly reduce the overall environmental emissions.

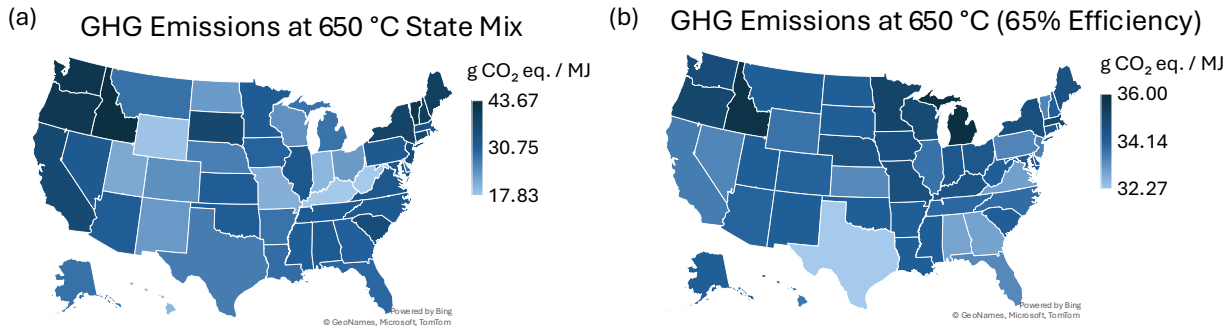

Figure 6. (a) GHG emissions for scenario 2 with state-specific electricity generation mix with system expansion as the co-product crediting method. GHG emissions for a 65% conversion efficiency from fuel gas to electricity instead of the conventional 34% are depicted in (b), with the energy allocation method used as co-product crediting

When considering electricity production from pyrolysis, the efficiency of converting fuel gas to electricity is another key factor to consider. Combined cycle electricity generation turbines with high conversion efficiency offset GHG emissions more than conventional boiler-type generators. We assessed the emissions for pyrolysis of landfill plastic waste feedstock at 650°C at 65% conversion efficiency (Figure 6(b)) with the energy allocation method used as co-product crediting. It was observed that the GHG emissions were significantly reduced when the conversion efficiency was high (Figure 5 (a) vs Figure 6 (b)). Currently, turbines with an efficiency of more than 64% are being introduced in electricity generation (Vandervort, 2018). With higher efficiency (>60%), on-site energy generation can become an environmentally viable option.

4.3 Uncertainty Analysis

A Monte Carlo uncertainty analysis was performed for Texas for scenario 1 with energy allocation as the co-product crediting method. The base case GHG emissions calculated was 13.54, while the mean from the distribution was found to be 13.5. The resulting probability distribution function (PDF) followed the lognormal distribution. PDFs for uncertain parameters were obtained mainly from the GREET model and literature. The liquid yield was the most contributing parameter to the variance.

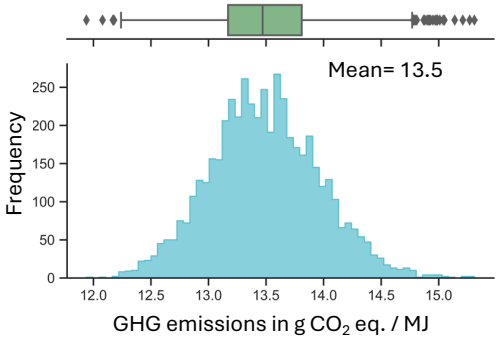

Figure 7. Frequency distribution for GHG emissions for Texas at 650 ℃ for scenario 1. In this case, part of the fuel gas was combusted to meet the internal heating demand of the pyrolysis plant, and the remaining fuel gas was sold as an energy product (credited via the energy allocation method). The emissions for electricity use were calculated considering the grid electricity was generated following the average grid electricity mix. Frequency data obtained from 5000 Monte Carlo simulation runs.

5. Conclusions & Recommendations

This work utilized an agile LCA approach to understand the change in GHG emissions for varying process conditions and assumptions such as product distribution, pyrolysis temperature, electricity emission factors, and fuel gas conversion efficiency at two different co-product handling and crediting methods. It was found that the types of plastics being handled in the pyrolysis process play a key role in product distribution. When fuel gas was combusted to meet internal heating demand and the remaining fuel gas was sold as an energy product (scenario 1), the GHG

emissions depended on the waste plastic feed composition. Landfill plastic waste with higher LDPE and PS yielded more pyrolysis oil, resulting in lower GHG emissions. On the other hand, higher HDPE fractions in the plastic waste composition increased pyrolysis energy requirement, resulting in higher GHG emissions. When all the fuel gas was combusted (scenario 2), the overall GHG emissions depended on the waste plastic compositions with the highest gas yields. This result is, however, subject to the assumptions considered when carrying out the LCA. When the state-specific electricity generation mix was considered, the lower GHG-emitting states changed from states with high oil yield to states with lower carbon footprint for electricity generation for scenario 1. When pyrolysis plants co-produce electricity, displacing the state grid electricity with the produced electricity, higher credits were obtained for states with fossil-based electricity generation mixes. This way, significantly lower GHG emissions were obtained for scenario 2. Electricity conversion efficiency is another important aspect that needs to be considered when deciding the use of fuel gas in a plant. Although producing in-house electricity from fuel gas can be capital-intensive, the emissions can be significantly reduced when using state-of-the-art turbines for electricity production, especially in states where the grid electricity still relies heavily on coal-based generation. Producing electricity using pyrolysis co-products for these states can bring a significant emission credit.

The plastic-to-fuel pathway still faces challenges that must be overcome to enable a circular economy. The waste plastic stream consists of different formulations of plastics, additives, colorants, and fillers, which can be challenging to separate to achieve the desired feedstock compositions for pyrolysis. Furthermore, contaminants such as additives and fillers complicate the pyrolysis process. Additionally, the fundamentals of plastic pyrolysis (such as the degradation pathway of plastics) are not fully identified. For example, the synergistic impacts on pyrolysis of mixed plastic waste and their reaction paths are not well known yet; therefore, this study can only give a ballpark estimation depending on the general product distribution of pyrolysis and the emissions thereof. The path forward should be identifying the reaction steps and developing a kinetic model that predicts the pyrolysis yield for large-scale platforms, considering both material and heat transfer occurring within the reactor. Such modeling will be able to predict the emissions more accurately and with confidence for real-life scenarios.

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7. Disclaimer

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