The University of Tehran Press

Pollution

https://jpoll.ut.ac.ir/

Print ISSN: 2383-451X
Online ISSN: 2383-4501

Life Cycle Analysis of Polypropylene Product in Industry Petrochemicals in Iran

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Article Info

Article type:
Research Article

Article history:
Received: 19 April 2024
Revised: 9 June 2024
Accepted: 28 August 2024

Keywords:
Environmental Impacts;
Life Cycle Assessment;
Petrochemical Industry;
Polypropylene

ABSTRACT

Polypropylene (PP) is a widely used polymer representing over 25% of global polymer demand. However, its production is associated with significant environmental repercussions. This article presents a comprehensive life cycle assessment (LCA) aimed at evaluating the environmental ramifications associated with polypropylene production within a petrochemical complex situated in Iran. The chosen functional unit is one metric ton of PP. Employing the Impact 2002+ methodology within the OpenLCA software, the analysis meticulously computes emissions of various pollutants such as carbon and sulfur oxides, particulates, and others throughout the entire manufacturing process. The findings indicate that PP production is notably energy and fossil resource-intensive, making significant contributions to climate change and human toxicity impacts. The approximated carbon dioxide emissions surpass 12,700 kg CO2 per tonne of PP, accompanied by 86 kg of non-methane volatile organic compounds and 6.58 kg of sulfur dioxide emissions per tonne of PP. Predominantly, the most substantial impacts emanate from the feed and olefin production phases. While acknowledging the potential variability in LCA data and methodologies across diverse contexts, these initial assessments posit that the integration of renewable energy sources and lower-carbon technologies holds promise for mitigating emissions and operational costs within this particular PP production facility. Subsequent research endeavors should seek to validate these projections and rigorously assess the trade-offs associated with proposed enhancements.

Cite this article: Safi Jahanshahi, S., Sharafati, A., Vahidi, H., & Hosseini, S. A. (2024). Life Cycle Analysis of Polypropylene Product in Industry Petrochemicals in Iran. *Pollution*, 10 (4), 1019-1031.
https://doi.org/10.22059/poll.2024.375323.2344

DOI: https://doi.org/10.22059/poll.2024.375323.2344

INTRODUCTION

In the vast polymer industry, Polypropylene (PP) emerges as a dominant market, representing over 25% of global polymer demand (Horne *et al*., 2009). Its extensive production, however, is associated with notable environmental repercussions (Roes *et al*., 2007). Recent times have seen environmental experts place a premium on gathering definitive, quantitative data concerning atmospheric pollutants and their industrial impact. This trend bolsters more effective governance, routine industrial performance evaluations, and strategic actions designed to mitigate environmental damage resulting from these operations.

Nations that extract oil tend to establish an extensive array of petrochemical plants to diversify their economic portfolios and complete their industrial value chains (Li *et al*., 2021). Indeed, over 51 such facilities in Iran are contributing an aggregate nominal output amounting to 56 million tons per annum (Bahri & Nekoumanesh, 2016). Of the country's propylene output,

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which totals 1,115,000 tons annually, a vast majority (95%) is redirected towards PP production, with the remainder (5%) being processed into diethylhexanol (Azadi & Yarmohammad, 2011; Noorollahi *et al*., 2021; Pashakolaie *et al*., 2015).

Within the petrochemical industry, the PP unit serves as a linchpin, extensively threading into various phases of the industrial cycle. The synthesis of PP involves the polymerization of propylene—a process conducted under controlled conditions of temperature and pressure, facilitated by the well-known Ziegler-Natta catalyst (Malpass & Band, 2012). This catalyst induces the formation of an isotactic polymer capable of achieving crystallinity at rates as high as 90%. Universally utilized, PP's thermoplastic properties render it indispensable across multiple applications. It surfaces in products such as films, textiles, diverse packaging materials, medical devices, pipes, as well as construction and automotive parts (Phung *et al*., 2021).

The method of life cycle assessment (LCA) serves as an analytical framework that captures the environmental footprint across the full spectrum of a product's or process's life span. It relies on in-depth and precise evaluations backed by extensive global data repositories (Garcia-Garcia *et al*., 2021). The method ensures comprehensive identification and quantification of both direct and ancillary consumption of energy and resources, as well as an assessment of the ensuing waste and pollution.

In the context of petrochemical operations, PP's production is a significant environmental focus due to its substantial and growing volume—propelled by ever-increasing market demands (Mannheim & Simenfalvi, 2020). A granular and factual exploration of the PP production pipeline, inclusive of each operative phase, resource, and catalytic agent used, is vital. It paves the way for actionable intelligence that could potentially propel remedial measures aimed at ecological amelioration (Mannheim & Simenfalvi, 2020). Pioneering work such as the inquiry by Alsabri *et al*. (2022) highlights the tripartite implications of PP manufacturing, waste recycling, and environmental stewardship (Alsabri *et al*., 2022). The collective insights amassed from various LCA investigations are critical instruments for gauging the environmental ramifications of PP processing.

Broad evaluations of product and process life cycles that hinge on PP can direct the industry toward more environmentally favorable practices (Mannheim & Simenfalvi, 2020). Recognized as pivotal, LCA tools are extensively employed to appraise the ecological aspects of energy, water, resource depletion, waste production, and emission of pollutants in industrial contexts (Al-Khori *et al*., 2021; Jelti *et al*., 2021). Their efficacy is substantiated in the orchestration and oversight of circular economies and industrial ecology frameworks, garnering recognition in many national sustainability initiatives (Gerber *et al*., 2013; Palazzo *et al*., 2020; Schwarz *et al*., 2021; Walker *et al*., 2021). At a time when plastic production and diverse recycling techniques are on the rise, LCA is heralded as a pragmatic approach to curtailing ecological degradation (Kousemaker *et al*., 2021). Discourses such as Alzoubi's 2022 analysis of agricultural material packaging (Alzubi *et al*., 2022) and Khoshnava *et al*.'s 2018 appraisal using the ReCiPe methodology in SimaPro (Khoshnava *et al*., 2018), underscore the decision-making prowess endowed by LCA.

Conversely, there is a research lacuna focused explicitly on the LCA of PP production processes within the refining sector, with extant studies primarily assessing the life cycles of goods with PP as a central component. A noteworthy study by Alsabri *et al*. (2021) scrutinized the life cycle of PP within the Persian Gulf's petrochemical sphere (Alsabri *et al*., 2021). It compared the environmental cost of various polymers and underscored the high pollutant quotient tied to PP's production, amounting to an estimated 1.58 kg CO2 emissions per kilogram of PP.

The production of propylene flags formidable concerns vis-à-vis climatic impact, resource depletion, toxicity, acidification, and petrochemical oxidant emissions. A more region-specific analysis by the Gulf Petrochemicals and Chemicals Association (GPCA) posits PP's carbon emissions at 1.95 kg CO2 eq. for each kilogram produced (Association, 2018). This contrasts with Narita *et al.*'s earlier findings from a Japanese perspective, presenting a slightly lower carbon emission rate of 1.4 kg CO2 eq. per kilogram of PP (Narita *et al.*, 2002).

Confronting the environmental nuances concealed within processes akin to PP production requires acute awareness and exacting research. Precise knowledge of pollutants, coupled with an understanding of the ecological strains of production, is imperative for shaping intelligent, environmentally-sound reforms. Foremost is the rigorous life cycle evaluation of products—a measure that can reveal industrially viable choices that lessen ecological impacts. Notably, such an investigation into the life cycle of PP is currently underway for the first time in a national petrochemical plant.

MATERIALS AND METHODS

Polypropylene production process

Olefin plant processes

The feedstock is first preheated to 150-430°C in a convection section heat exchanger by recovering heat from the hot cracked gas stream. Steam is added as a diluent, typically at a 0.4 ratio to the feed. The steam lowers hydrocarbon partial pressures and reduces coking. The feed/steam mixture is preheated to 560-650°C before entering the cracking furnaces.

The preheated feed enters the radiant section of 8-12 vertically oriented furnace coils. Here, it is rapidly heated to severe cracking temperatures of 800-875°C to initiate thermal cracking reactions. Each coil has multiple passes for extended exposure time. Temperatures steadily increase down the coil length. Cracking reactions occur within 0.1-0.5 seconds.

The furnace burners provide the extreme temperatures required, fuelled by refinery gas, natural gas, or oil. Furnace operation is complicated by coke formation on the coils which reduces heat transfer. Periodic steam air decoking is required after 3-4 months. Higher steam dilution minimizes coking but also reduces yield.

The cracked gas leaves the furnace coils at 700-850°C. Primary fractionation towers immediately separate heavy liquids including tar, fuel oil, and pyrolysis gasoline at 350-450°C. Rapid quenching to 200-300°C follows in transfer line exchangers using oil, boiler feed water, or recycled oil. Quenching halts the cracking reactions.

The first stage compressor raises the quenched gas pressure from 2 to 35 bar. Water scrubbing then removes soluble contaminants. Caustic scrubbing follows to absorb acidic gases like CO2 and H2S at 40-70°C. This prevents downstream corrosion and equipment fouling. The compressed gas also undergoes drying and chilling steps between compression stages.

Cracked gas separation involves several cryogenic distillation towers for pure olefin recovery. Before separation, trace acetylene is selectively hydrogenated to ethylene to prevent polymer formation. Demethanizers operate at -35°C and 10 bar to remove methane and hydrogen. Deethanizers then separate ethane at -27°C and 21 bar. C2 splitters further purify the ethylene stream. Depropanizers (-2°C, 17 bar) and debutanizers (42°C, 3 bar) subsequently extract propane and butane products. Off-gas recycles improve separation efficiency. Liquid phases from the distillation towers are also recycled. Throughout separation, chillers and condensers maintain the required cryogenic temperatures using propylene, ethylene, and propane refrigeration loops.

Hydrogen from the demethanizers is further purified to 99.9%+ purity for recycling via pressure swing adsorption. Propane and butylene streams undergo selective hydrogenation to remove diolefins and acetylenes to prevent polymerization in downstream units. All products are finally dried and sent to storage or derivative plants. The complex arrangement of reaction furnaces, quench, and compression systems, distillation towers, recycles, and purification units enable high yield production of high-purity olefins from various feedstocks. Careful monitoring of temperatures, pressures, and feed conditions is necessary for optimal operation.

Polypropylene production process

Polypropylene is produced from the polymerization of propylene monomer. This occurs in the polymerization reactor using a Ziegler-Natta or metallocene catalyst system. The catalyst helps control the reaction and the properties of the polymer produced. In the reactor, liquid propylene feed is mixed with hydrogen gas and contacted with the solid catalyst particles under carefully controlled temperature and pressure conditions. The propylene monomers link together in chains to form solid polypropylene powder with a high molecular weight. Factors like catalyst type, reactor temperature, monomer concentration, and hydrogen ratio impact the polymerization rate, yield, and polymer properties like molecular weight distribution, crystallinity, and tacticity. The polymerization reaction is highly exothermic so temperature control is critical.

The polymerized polypropylene powder is first compounded by intensive mixing with stabilizers and other additives. This enhances the physical properties of the final product. The compounded polymer is then extruded and pelletized for downstream processing. Extrusion involves feeding the polymer powder into the extruder feed hopper. It is conveyed forwards by a rotating screw inside a heated barrel and fully melted by the time it reaches the die. The molten polymer is forced through the die orifice and emerges as a continuous profile shape which is cooled into a solid form. The profile is then pelletized into small beads for shipment. Extrusion conditions like temperature, screw speed and die design impact the pellet properties and quality.

In summary, polypropylene is produced through catalyst-driven polymerization of propylene monomer followed by extrusion and pelletizing to make a material suitable for further plastics processing.

Life Cycle Assessment

Environmental life cycle assessment (E-LCA) is a comprehensive technique to evaluate the total environmental impacts of a product or system over its entire life cycle. LCA considers all impacts from raw material extraction, manufacturing, transportation, use phase, and end-of-life disposal, following a "cradle-to-grave" approach.

This study conducted the LCA according to the International Organization for Standardization (ISO) 14040 standards, which provide technical guidance on LCA methodology.

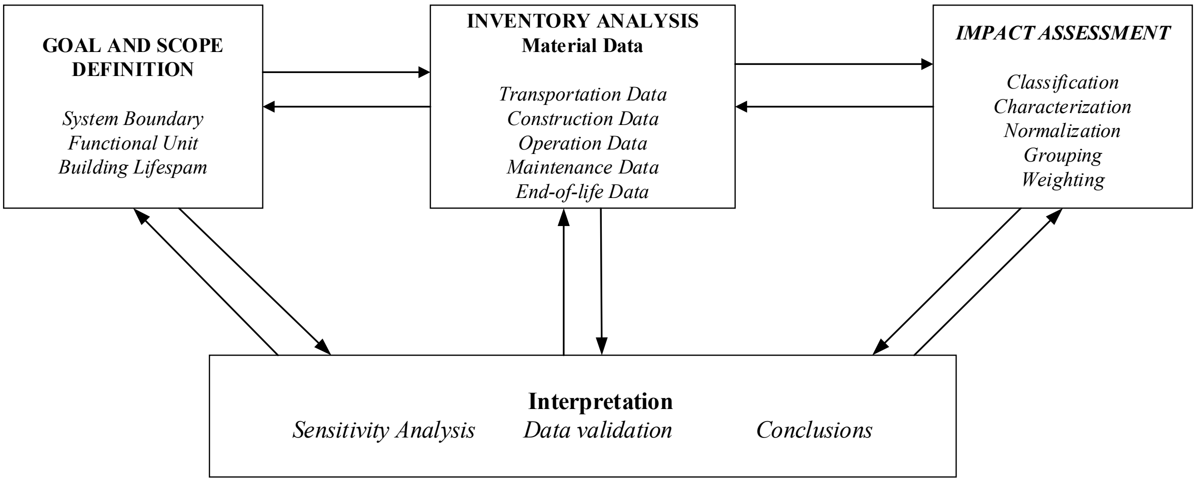

Fig. 1. The four main stages of life cycle assessment studies (Arvanitoyannis, 2008)

Goal and Scope Definition

Life Cycle Impact Assessment (LCIA), a pivotal component of LCA, initiates with the selection of impact categories—integral to the overarching environmental analysis. These categories should be established during the initial goal-setting and scope-defining phase to direct the later Life Cycle Inventory (LCI) data compilation. Post data collection, these selections may require reassessment due to their intrinsic association with potential human health and ecological impacts. The objective of conducting a life cycle assessment in the context of this study is to appraise the environmental impacts generated by the production of polypropylene at petrochemical facilities. Such an evaluation is instrumental in pinpointing those processes with the most substantial influence on ecosystems, human health, and resource conservation. Establishing a Functional Unit is indispensable for structuring and scrutinizing a product system within LCA. An FU articulates the utility of a product in measurable terms, serving as an anchor for all calculations related to impact assessment. This metric may encapsulate a variety of product qualities, encompassing efficiency, technical caliber, adjunctive services, and cost. In the parameters of our study, the FU is determined as the production of one ton of polypropylene.

The system boundary for an LCA is demarcated by the study's goals and scope. In this analysis, our objective is to assess the environmental repercussions attributable to the production operations at one specific petrochemical enterprise in Iran. Hence, the environmental impact under review is confined to the facility and its immediate vicinity. Our study employs a 'gate-to-gate' approach, explicitly omitting the broader 'cradle-to-grave' impacts. This delineation excludes the upstream processes like raw material extraction, transportation to the plant, and any precursor activities, as well as downstream processes comprising product distribution, utilization, further manufacturing, and eventual disposal. The focal point for our system boundary encompasses the feed's ingress to the petrochemical complex through to product

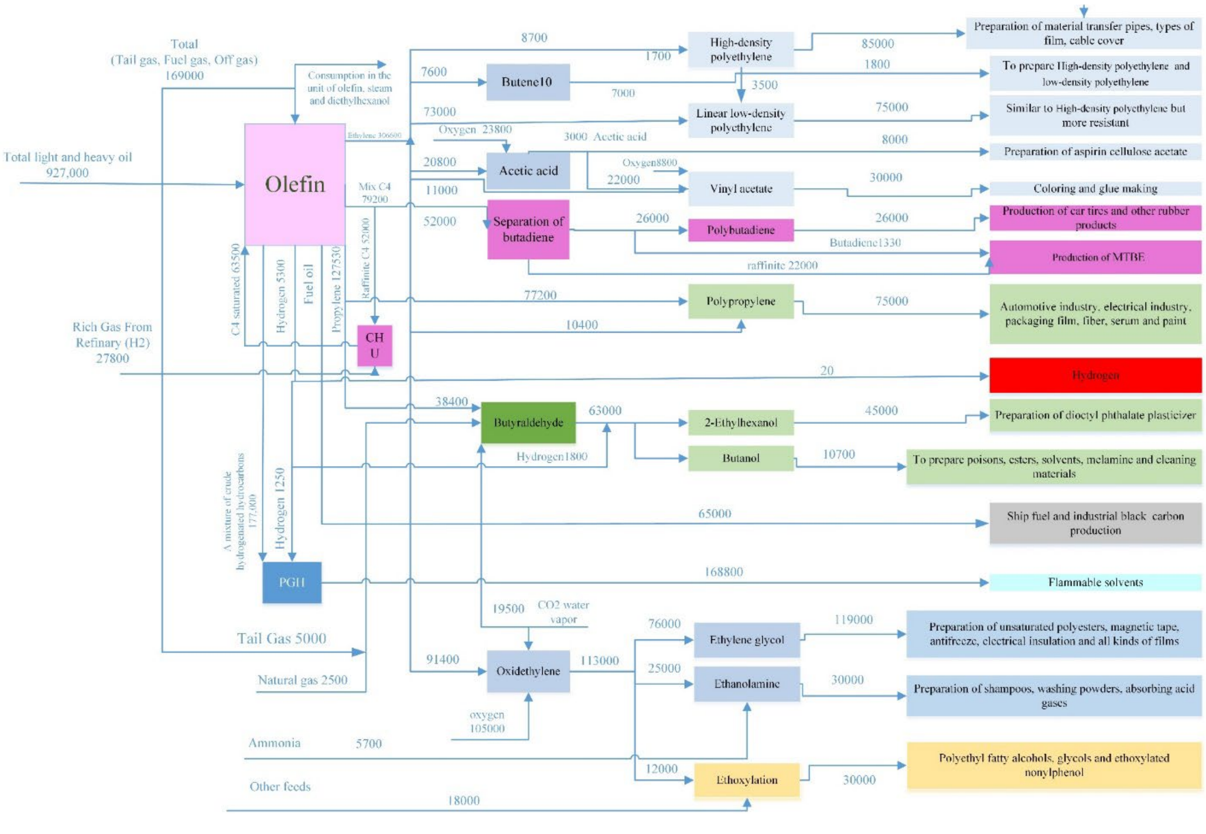

Fig. 2. System boundary in the life cycle evaluation study of the petrochemical complex

packaging alongside solid and liquid waste treatment, as illustrated in the accompanying figure. This boundary encapsulates specific units, including the olefin, power generation, and steam production sectors, which exclusively yield intermediary outcomes.

The current LCA model hinges on crucial variables such as all input materials, energy and water introduced into the polypropylene production process, and associated data—emissions, production and energy waste, effluent—considered dependent variables. These will be meticulously collected through on-site visits, sampling, testing, calculated assessments, and engineering judgment for integration into our principal model. The units involved in the production of polypropylene are Olefin unit (propylene and ethylene production), Polypropylene production, Packaging, Water vapor production, Power plant, Instrument air production, Waste incinerator and Sewage treatment unit.

Life cycle inventory

Data collection stands as one of the most arduous aspects of executing a LCA model. Although an abundance of secondary data can be sourced from the literature or databases such as ecoinvent, it is common to encounter specific processes or materials for which data is not readily available. The following are not included in the study:

Commonly, minute constituents such as catalysts, pigments, ancillary materials, or other additives, which cumulatively account for less than one percent of the net input by weight, are not considered in assessments. Excluding these elements narrows the study's scope and maintains focus. Although the production of some small-scale substances may be resource-intensive or carry the potential for toxic emissions, their impact is deemed significant only if disproportional to their mass. For the current study, materials or additives used that are of high toxicity or resource-intensive were not detected; consequently, it is unlikely that the environmental footprint of the resin is significantly understated due to these low-quantity substances.

The environmental footprint attributable to the construction of buildings, roads, pipelines, vehicles, and industrial equipment is not accounted for in this study. The energy and emissions tied to the production of capital goods and infrastructure tend to dilute over the lifespan of their output, rendering them inconsequential when averaged across the provided products or services' lifetimes.

The energy consumed for heating, cooling, and lighting in manufacturing environments is typically excluded from the study calculations wherever practicable. In industrial settings with significant thermal processing or high energy use, the energy attributed to space conditioning is minimal by comparison. The data collection methodology employed directed contributors to exclude or specifically note energy devoted to space conditioning in their reports. Thus, for the resin system under inspection, energy dedicated to space conditioning and similar overhead activities is not anticipated to contribute meaningfully to the total energy expenditure.

This study does not account for the energy consumption and waste generation associated with the actions of research and development, sales, and administrative staff. Similar to space conditioning, the energy use and accompanying emissions from support personnel functions are presumed to be negligible.

Environmental life cycle impact assessment

The study employed the Impact 2002 + framework in evaluating the environmental impacts pertinent to the LCA. Where local data is unavailable, past research has recommended the use of Impact 2002 + v.2.15. Utilized midpoint categories for single scores included carcinogens, non-carcinogens, respiratory effects from inorganics and organics, terrestrial ecotoxicity, acidification/nutrification, land occupation, global warming, and non-renewable energy. Endpoint categories adopted for single scores were natural resources, climate change, ecosystem quality, and human health.

Table 1. IMPACT 2002+ Life Cycle Impact Assessment Framework

Midpoint Categories	Endpoint Categories	Units
Carcinogens	Human health	DALY
Non-carcinogens		DALY
Respiratory inorganics		DALY
Ionizing radiation		DALY
Ozone layer depletion		DALY
Respiratory organics		DALY
Aquatic ecotoxicity	Ecosystem quality	PDF*m2yr
Terrestrial ecotoxicity		PDF*m2yr
Terrestrial acid/nutrification		PDF*m2yr
Land occupation		PDF*m2yr
Aquatic acidification		PDF*m2yr
Aquatic eutrophication		PDF*m2yr
Global warming	Climate change	kg CO2 eq
Non-renewable energy	Resources	MJ primary
Mineral extraction		MJ surplus

DALY = Disability Adjusted Life Years
PDF = Potentially Disappeared Fraction of species

RESULTS AND DISCUSSION

The polypropylene manufacturing process at the studied petrochemical complex significantly contributes to environmental pollution, as detailed by the LCA conducted using OpenLCA software. The selection of prevalent pollutants was guided by their associated impact categories, detailed in Table 2. This table also outlines the gross production of PP per ton and its environmental ramifications. Global Warming Potential (GWP) is quantified as the mass of CO2-equivalent emissions released. Annually, this facility in Iran produces approximately 95,000 tons of PP, corresponding with the emission of about 1,200 tons of CO2-equivalent gases. These emissions are anticipated to exert both immediate and enduring effects on the local environment and public health. On a per-unit basis—the functional unit being one ton of PP—the consequent carbon emissions are approximately 12,700 kg of CO2-equivalents. This figure reveals a stark contrast: the mass of the emissions surpasses the mass of the PP produced. Therefore, addressing these emissions is paramount and can be achieved through modifying current processes or adopting newer, more sustainable technologies. Sourcing the necessary thermal and electrical energy from renewable resources could notably diminish the overall GWP impact, potentially lowering production costs as renewable energy becomes increasingly cost-competitive against fossil-based alternatives. Further, captured CO2 could be opportunistically repurposed for polymer synthesis. Table 2 presents a comprehensive environmental impact assessment for the production of one ton of polypropylene, within the established categories of Carcinogens, Global Warming, Non-carcinogens, Non-renewable Energy, Respiratory Inorganics, Respiratory Organics, Terrestrial Acidification/Nutrification, and Terrestrial Ecotoxicity.

Land Acidification (LA), characterized by reduced fertility due to accumulation of nitrogen and sulfur-based acids such as NOx, SO2, and NH3, measures total environmental impact in SO2-equivalent mass. In the case of PP production, the annual output correlates to 5570 kg of SO2, translating to 58.6 kg per ton of produced PP pellets. Further, Petrochemical Oxidant Formation (POF) is accounted for by emissions of non-methane volatile organic compounds (NMVOCs), encompassing substances like formaldehyde, ethanol, benzene, cyclohexane, acetone, among others. NMVOCs facilitate the formation of ground-level ozone and aerosol

Table 2. Environmental impact assessment for the production of one ton of polypropylene

Indicator	Amount (per 1 ton production)	Unit
Carcinogens	6.76E+00	kg C2H3Cl eq
Global warming	1.27E+04	kg CO2 eq
Non-carcinogens	3.47E+01	kg C2H3Cl eq
Non-renewable energy	1.76E+07	MJ primary
Respiratory inorganics	1.47E+00	kg PM2.5 eq
Respiratory organics	3.42E-01	kg C2H4 eq
Terrestrial acid/nutri	5.86E+01	kg SO2 eq
Terrestrial ecotoxicity	3.24E+03	kg TEG soil

Table 3. Normalized and weighted results for the category of different effects

Impact category	Normalized	Weighted
Carcinogens	3.04575E-08	8.5281E-14
Global warming	28489755.48	28489755.48
Non-carcinogens	1.41269E-07	3.95553E-13
Non-renewable energy	5.81521E+11	5.81521E+11
Respiratory inorganics	1.53237E-06	1.07266E-09
Respiratory organics	1.17427E-09	2.5012E-15
Terrestrial Acidification/Nutrification	173307.2504	180239.5404
Terrestrial ecotoxicity	54541.42418	431.4226653

particulates, posing significant risks to human health, including cardiovascular and respiratory diseases, with certain NMVOCs also being recognized as carcinogens. Notably, the production of one ton of PP releases 4.24 kg of NMVOCs. Given that PP is a petrochemical derived from volatile organic compounds, such emissions during its production are to be expected.

Fossil resource depletion, indicative of the consumption of non-renewable fossil resources, is expressed as kilograms of oil equivalent. For the production of PP granules, 1.72 tons of oil are used per ton of PP produced. While the petrochemical nature of PP justifies this reliance on fossil resources, exploring alternative resources like biofuels could mitigate such an impact. Human Toxicity (HT) measures potential harm to human health, quantified in terms of 1,4-dichlorobenzene (DB) equivalent weight (kg 1,4-DB equivalent). The HT impact associated with manufacturing one ton of PP pellets is calculated at 77 kg 1,4-DB equivalent. Notably, HT and POF are considerable in assessing impacts relevant to human health. A significant proportion of the pollutants originate from the feedstock phase and the olefin production, with specific contributions from each phase detailed in the study. Throughout this stage, the propylene is purified before being processed in the PP production plant.

Each identified impact category reflects distinct stages within the PP production lifecycle, with varying emission profiles. For instance, the most substantial emissions are observed during the feedstock and treatment phase, succeeded by the reaction phase. In Table 3, the normalized and weighted assessments for different environmental impact categories are presented. The non-renewable energy category demonstrates the most substantial impact, with the Global

Table 4. Contribution of each of the units and processes involved in the production of one ton of polypropylene

Impact category	Reference unit	Polypropylene Plant	Compressed air Unit	DM-Water Production Unit	Incineration Unit	O2/N2 Production Unit	Olefin Plant	Power Plant	Steam Production Unit	Wastewater Treatment Unit
Carcinogens	kg C2H3Cl eq	0.0015083			2.04E-09			1.3912788	0.1386588	0.002306
Global warming	kg CO2 eq				1.6792486		2.6330105	2656.1547	216.99103	0.0072802
Non-carcinogens	kg C2H3Cl eq	0.030942		6.9285974	0.0052986			0.0385857	0.0127795	0.0976957
Non-renewable energy	MJ primary				7.8635896		41065.112	57419.174	3727913.8	
Respiratory inorganics	kg PM2.5 eq				3.12E-05		0.0439888	0.2547897	0.009772	8.15E-05
Respiratory organics	kg C2H4 eq							0.0736412	0.004092	4.92E-07
Terrestrial acid/nutri	kg SO2 eq				0.0013245		1.8915986	9.8841194	0.3829528	0.0048405
Terrestrial ecotoxicity	kg TEG soil	2.48E-12		7.67E-08	2.1869396			42.04567	0.4577046	458.66291
Terrestrial ecotoxicity	kg TEG soil	2.48E-12		7.67E-08	2.1869396			42.04567	0.4577046	458.66291

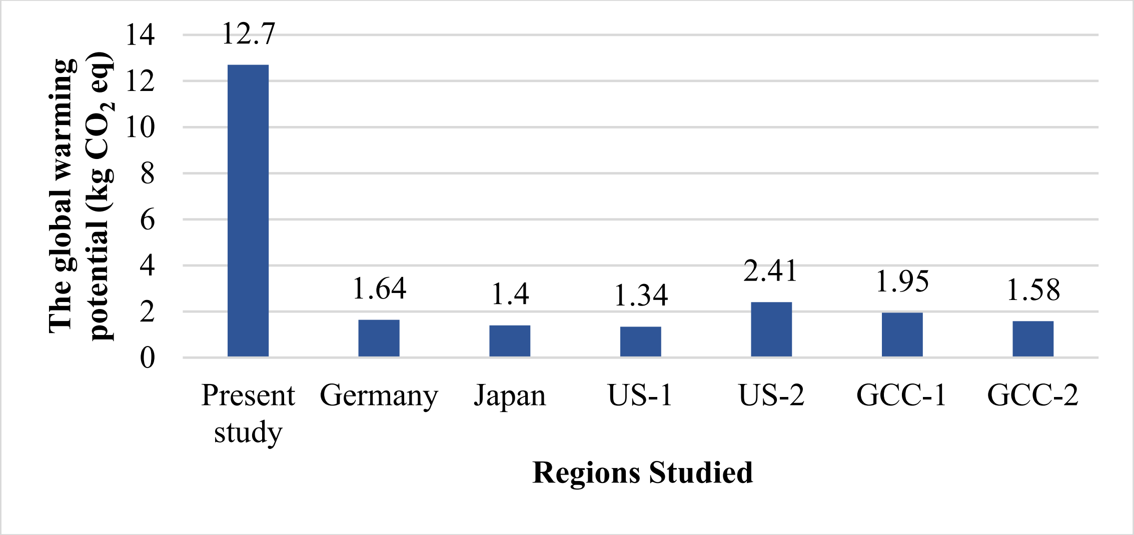

Fig. 3. The global warmi ng potential (GWP) for PP production in Japan (Narita et al., 2002), GCC (1 (Alsabri *et al.,* 2022) and 2 (Alsabri et al., 2021)), US (1 (Greene, 2011) and 2 (Thinkstep. GaBi [Computer Software])), Germany (Thinkstep. GaBi [Computer Software]), and the present study.

Warming and Terrestrial Acidification/Nutrification categories following closely, significantly influencing the environmental burden per ton of polypropylene produced.

The following table shows the contribution of each of the units and processes involved in the production of one ton of polypropylene. Steam and electricity production units and the production process of olefin products have the largest share in most of the impact categories. The reason for this is the consumption of fuel, raw materials, and exhaust gases from the chimneys of these units.

Figure 3 illustrates the carbon emissions equivalent for the production of 1 kg of polypropylene (PP) across different countries. The variance of global warming effects identified in LCA studies is largely contingent upon factors such as regional energy mix, energy and process efficiencies, types of processes employed, and recycling rates. This study incorporates a comprehensive scope that includes the production of PP from crude oil while accounting for associated power and steam production requirements, along with other necessary production elements.

The carbon emissions reported here exceed those detailed in analogous studies with a more truncated scope. Diverging from prior studies, this investigation has broadened the system boundary. Naphtha is included as an input in the ethylene production unit, with the carbon emissions from this process meticulously considered. Additionally, carbon outputs from essential power generation, steam production, incineration, and deionized water treatment have been meticulously calculated. As such, this research provides a more exhaustive exploration of the processes integral to polypropylene production, yielding findings of greater breadth and precision compared to studies with narrower system boundaries. Failing to account for ancillary processes such as energy generation, steam provision, wastewater treatment, and waste management would result in an incomplete appraisal of polypropylene production's environmental impact.

Figure 3 starkly highlights the importance of defining appropriate boundaries and scope in LCA studies. It underscores that a true and precise evaluation of environmental impacts mandates an all-encompassing approach, one that thoroughly considers the entire spectrum of processes contributing to pollution, as well as the consumption of energy, water, and raw materials. A study that restricts its focus to a singular aspect of the production chain will fail to deliver a holistic understanding of the environmental repercussions.

The carbon dioxide emissions data for PP production in Iran is juxtaposed with the findings from other LCA studies referenced in the literature, as well as against figures from the ecoinvent database representing Europe and other parts of the world. This particular LCA study diverges from preceding research in multiple aspects: the intricacies of the input processes, the efficiency of energy and processes implemented, the methodologies employed, and the reliability of the data sets utilized. The gross carbon dioxide emissions derived from this study are set against those from previous research, which are detailed in the table provided below.

The methodologies for computation and the selection of modeling software can vary across studies. For instance, the current LCA model is particularly comprehensive and meticulous owing to its focus on a specific polypropylene (PP) factory situated in Iran. Throughout the modeling and calculation stages, the vertical averaging technique was employed to derive optimal results. Variations in factors such as fuel types, energy mixes, production capacities, ages of facilities, energy and efficiency in processing, as well as types of processes, may contribute to elevated mean values of carbon emissions.

CONCLUSION

This LCA serves as an inaugural quantification of the environmental burdens entailed in PP production at a designated petrochemical facility in Iran. Given the resource-intensive nature of PP manufacturing, characterized by considerable material usage and emissions per tonne of the final product, it becomes evident that the process significantly contributes to the broader environmental landscape, particularly in terms of climate change impacts. The principal source of these impacts is identified during the refinement of feedstock and the synthesis of olefin to generate the propylene feedstock essential for polymerization.

In light of the substantial greenhouse gas and air emissions estimated on a per tonne basis, this study advocates for the exploration of avenues such as the incorporation of lower-carbon energy sources, technological advancements, enhanced efficiency measures, and the implementation of emissions control mechanisms to curtail the overall environmental footprint. The precise potentials for reduction and associated financial implications necessitate further scrutiny through systematic environmental and economic optimization.

Furthermore, with the ongoing expansion of PP production capacity in Iran, the absolute environmental impacts are poised to escalate without proactive intervention. While acknowledging the inherent uncertainties stemming from assumptions and data limitations in the model results, they nonetheless provide a rationale for prioritizing strategic actions geared toward fostering more sustainable production practices. The subsequent phases of research should encompass the collection of primary data, the evaluation of alternative scenarios, a comprehensive comparison of trade-offs, and the integration of the latest process simulations to fortify the reliability of impact estimates as the foundation for targeted interventions.

Future research should prioritize the collection of more localized data to enhance the accuracy and relevance of life cycle assessment `LCA) findings, particularly in diverse geographical contexts. Exploring alternative production processes, such as bio-based polypropylene (PP) and advanced recycling technologies, could reveal environmentally friendly pathways for PP manufacturing. Additionally, integrating emerging technologies like carbon capture and utilization (CCU), renewable energy sources, and solid oxide fuel cells (SOFCs) into petrochemical processes holds promise for significantly reducing emissions and improving energy efficiency. Rigorous comparative analyses of these technologies and processes will provide a strategic roadmap for industry stakeholders aiming to mitigate the environmental impacts of PP production.

GRANT SUPPORT DETAILS

The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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