Life Cycle Environmental Impacts of Plastics: A Review

12/08/2022

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Who Is VitalMetrics?

VitalMetrics is a CDP accredited solutions provider, and our data is recognized by the Greenhouse Gas Protocol as a data source for calculating Scope 3 GHG emissions.

In operation for over 20 years, VitalMetrics has worked with Fortune 100 companies, our data is used by leading management and consulting firms, and thousands of people use our data and tools every single month.

VitalMetrics has three lines of service: our GHG emissions database (CEDA Global), GHG accounting, and life cycle assessment.

CEDA is a listed data source on the Greenhouse Gas Protocol website.

VitalMetrics is a CDP accredited solutions provider.

Dr. Sangwon Suh
Founder & Chief Scientist

VitalMetrics was founded by Dr. Sangwon Suh, a leading industrial ecologist and LCA expert. Dr. Suh has contributed to ISO GHG standards, the GHG Protocol, and International Panel on Climate Change reports. He leads VitalMetrics' content and product development with his pioneering approach to GHG emissions data, calculations, and stepwise approach to sustainability maturity. Dr. Suh has worked with leading organizations like Microsoft, Kellog's, Virgin Atlantic, top consulting firms, and multiple Fortune 100 companies. Dr. Suh is also a professor at UCSB Bren School and Leiden University.

GREENHOUSE GAS PROTOCOL ISO ipcc WORLD RESOURCES INSTITUTE

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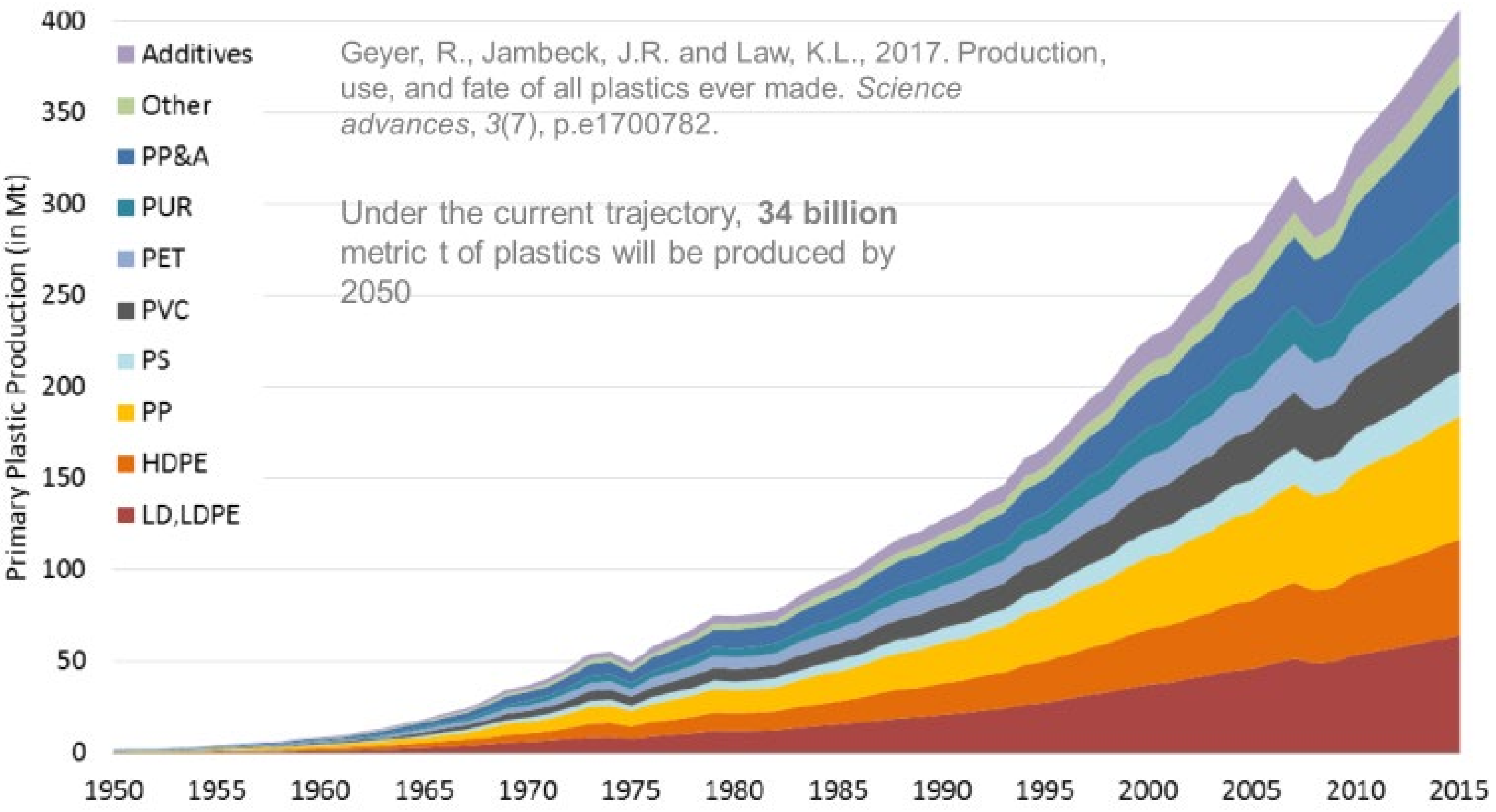
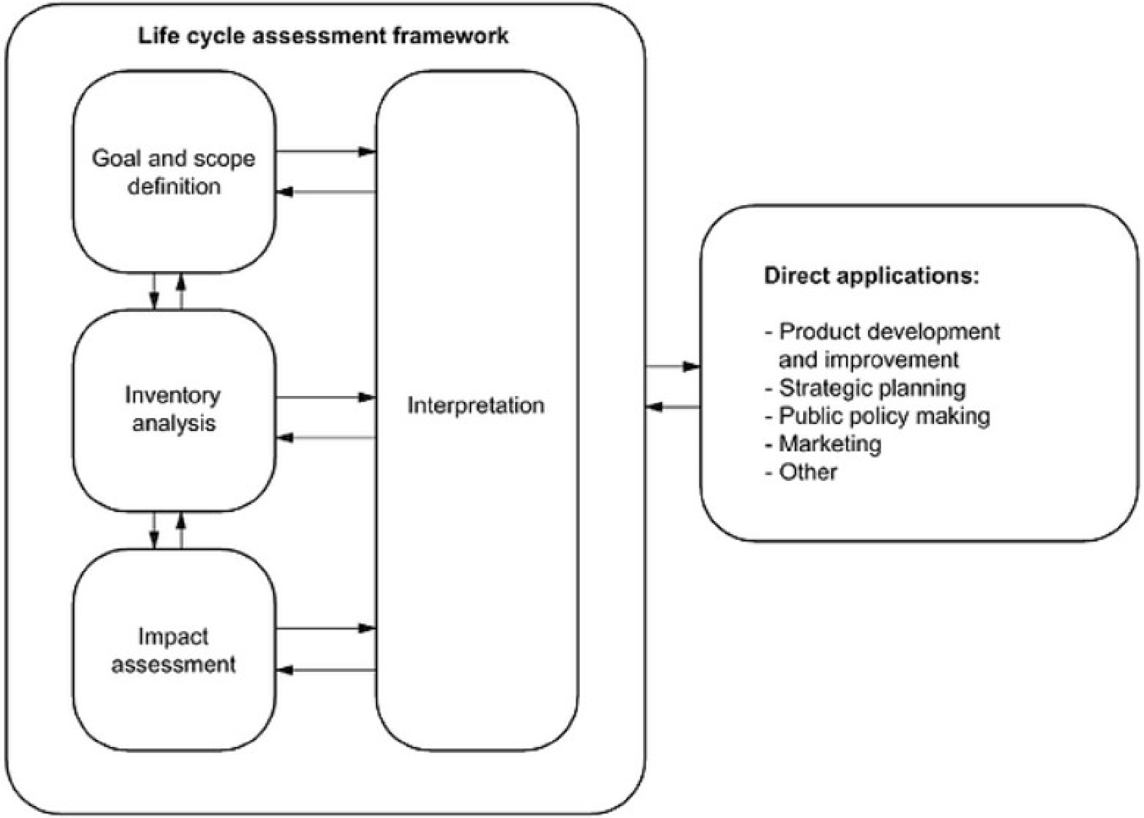


Primary Plastic Production (in Mt)
400
350
300
250
200
150
100
50
0
Additives
Other
PP&A
PUR
PET
PVC
PS
PP
HDPE
LD,LDPE
Geyer, R., Jambeck, J.R. and Law, K.L., 2017. Production, use, and fate of all plastics ever made. *Science advances*, *3*(7), p.e1700782.
Under the current trajectory, **34 billion** metric t of plastics will be produced by 2050
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

Basics of Life Cycle Assessment (LCA)

Source: Life Cycle Initiative

LCA Process (ISO 14040)



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Objectives

1	Review existing research and activities related to LCA in plastic material and plastic -based products
2	Identify the challenges and gaps in current studies, standards, tools, and other resources
3	Discuss the current research gaps that are being filled by ongoing initiatives and those yet to be addressed

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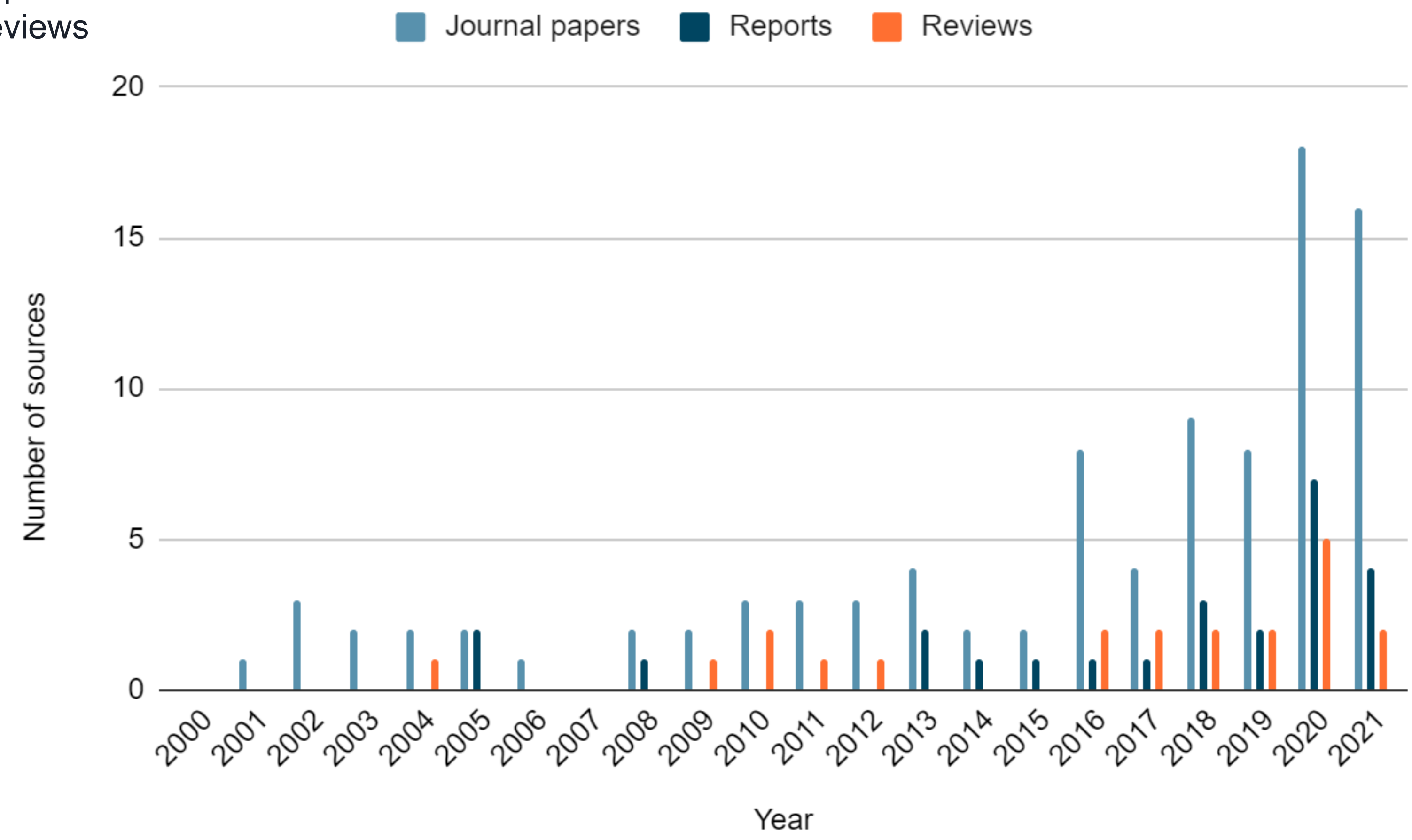
Total: 144 total sources reviewed

- 98 peer-reviewed journal papers
- 25 reports
- 21 reviews

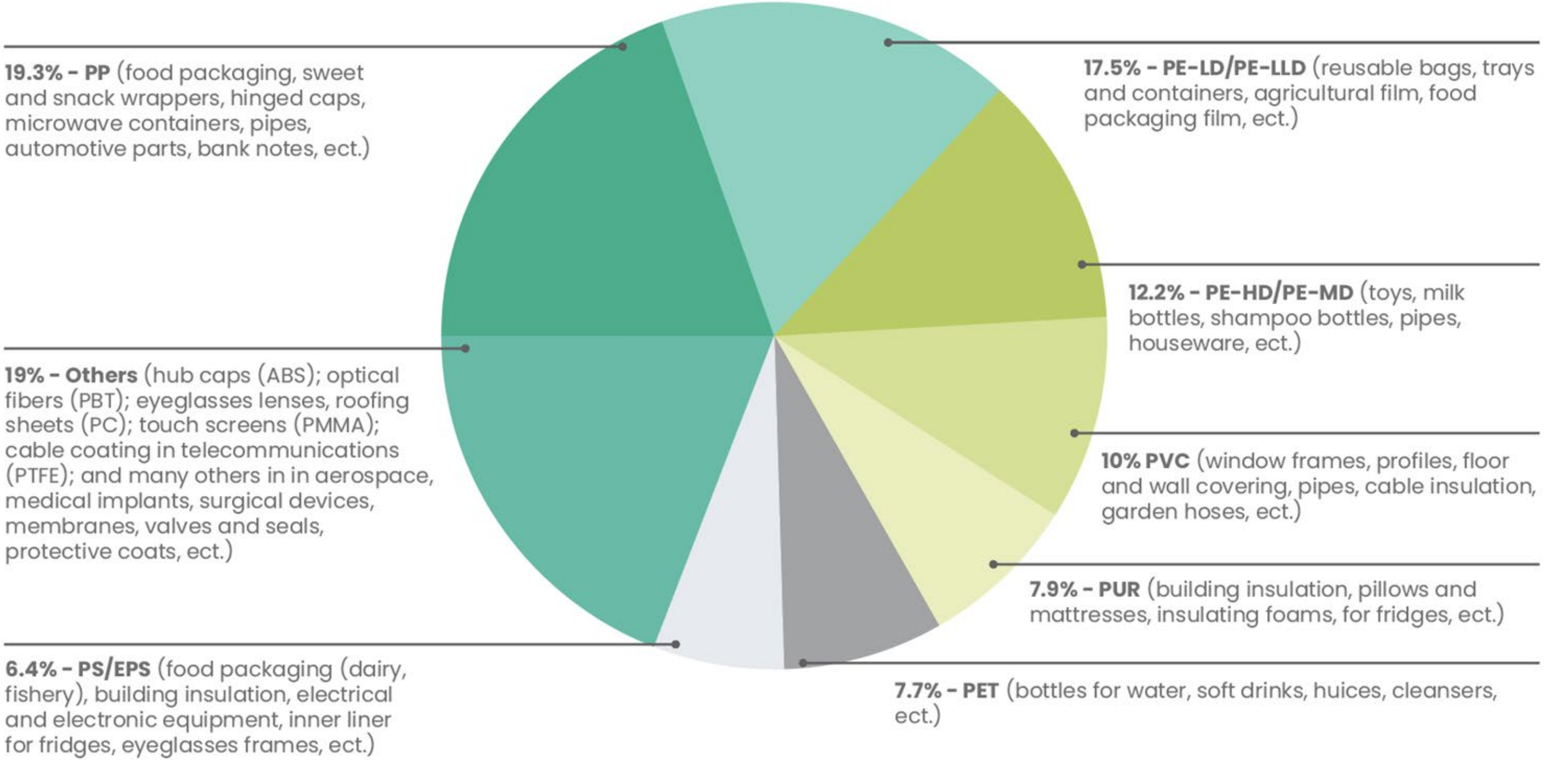


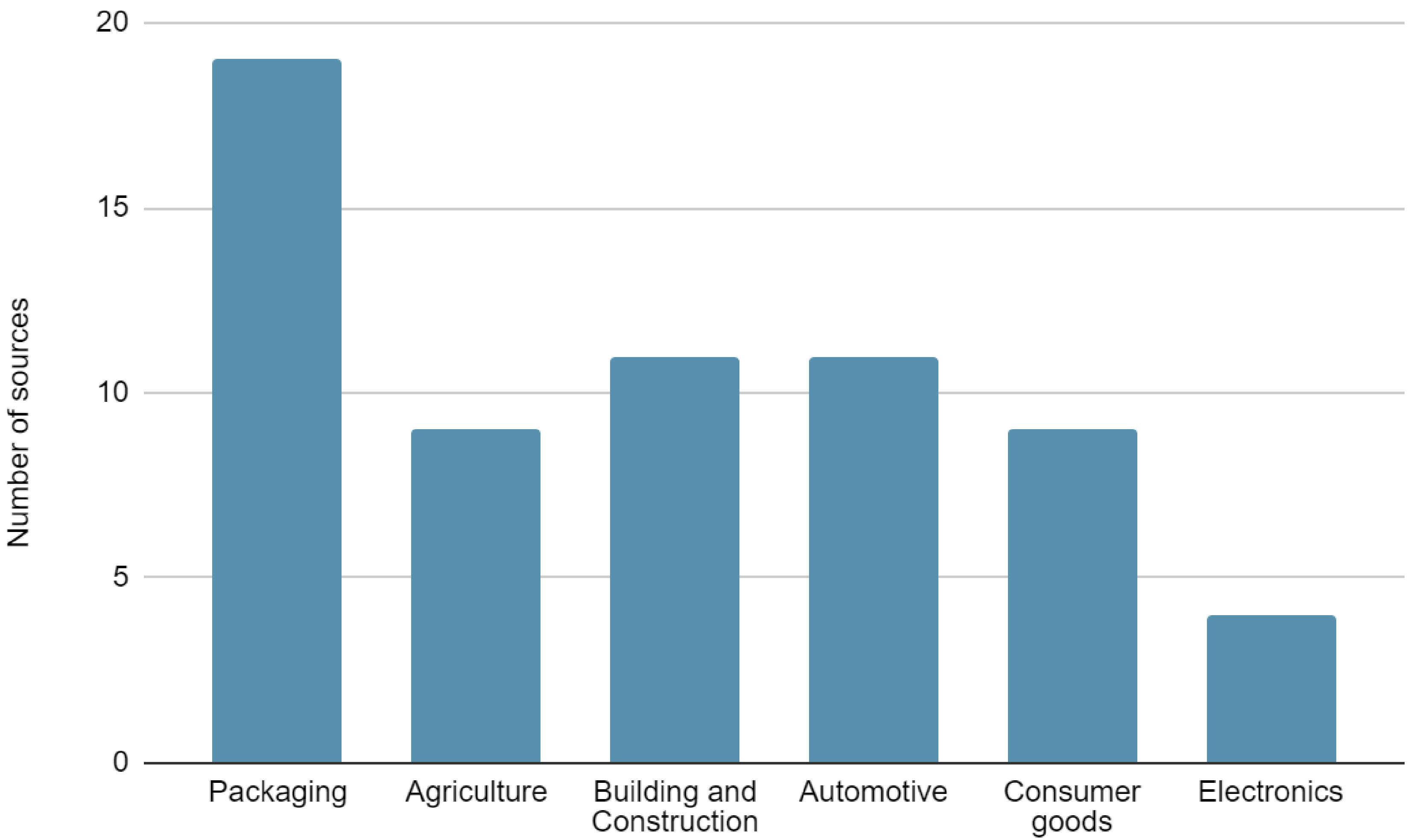
Source of Data	Description
US LCI database	National Renewable Energy Laboratory (NREL) created the US Life Cycle Inventory Database to provide gate-to-gate, cradle-to-gate, and cradle-to-grave accounting for plastic environmental impacts
Ecoinvent	Life cycle inventory database encompassing around 18,000 processes including energy supply, agriculture, transport, chemicals, construction, and waste treatment.
Plastics Europe	Association of plastic manufacturers in the European plastic industry.
Gabi Plastics Extension Database	Gabi provides life-cycle inventory data on mass plastics (e.g. PE with various densities, PP, PS), vinyl polymers (e.g. PVC, PVAL), technical plastics (e.g. ABS, PMMA, PTFE), polyamide (e.g. PA 6, PA 6.6, PA 6.12), special plastics (e.g. PPS, PEEK, SMA)
USEEIO database	The Environmental Protection Agency (EPA) provides an LCA database on US products and services. This database includes datasets for multiple plastic products (e.g. plastic bottles).
Comprehensive Environmental Data Archive (CEDA)	CEDA is an extensively peer-reviewed suite of environmentally extended input-output databases first launched in 2000. These are designed to assist various environmental systems analyses including life cycle assessments (LCA), carbon, energy, water, waste, and toxic impact assessment throughout the supply chain.
CarbonMinds	CarbonMinds has developed a CM.CHEMICAL database from a regionalized model of the global chemical industry, built from plant-level. The database provides life cycle inventory datasets for national averages of consumption, production and per technology.
The GREET Model	The GREET model is developed by the Argonne National Laboratory to address the life-cycle emissions of various fuel-vehicle combinations. Since plastic is widely used in automobile manufacturing, this model includes LCA data for plastic resins and products.

Relevant LCA databases

- These databases provide LCIs of several hundred plastic materials
- Temporal and spatial system boundaries vary
- The level of aggregation / resolution also varies
- Overall, Europe is better represented
- Limited coverage in additives and bio-based plastics

Distribution of plastic demand by resin types





Number of sources
20
15
10
5
0
Packaging
Agriculture
Building and Construction
Automotive
Consumer goods
Electronics

Packaging

- Largest portion of primary non-fiber plastic production (**42% in 2015**)
- Short product life-time: mostly less than 1 year
- **Common uses**: bags, bottles, take-away food containers
- **Materials**: HDPE, PET, PP, PS, PLA, PE, cotton, paper
- **Important factors on environmental impact**: Use pattern, weight, geographical context and waste management practices

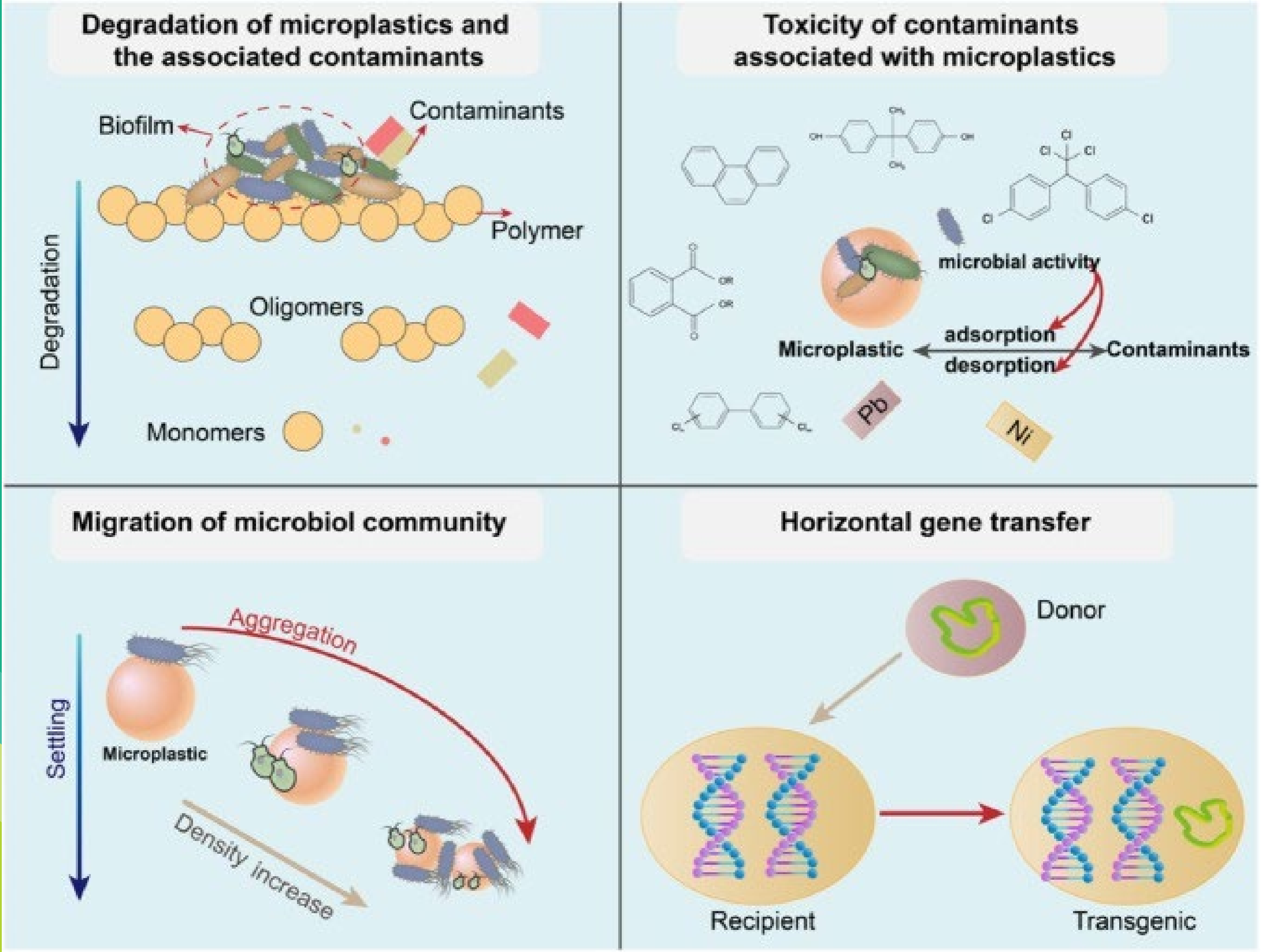
Packaging cont.

- The impact categories evaluated in the LCA are important to the results and conclusions of the studies
    - PLA has lower global warming potential, fossil energy use, and human toxicity
    - PET has lower impact in acidification and eutrophication categories

Agriculture

- **Common uses** : Greenhouses, mulching, irrigation systems, crop transportation

- Mulch film makes up 41% of agricultural plastic use
  - Mechanic recycling is challenging due to contamination with soil, stones and biological waste
  - Biodegradable film 25-80% less impact depending on the impact categories and the end-of-life scenario compared to non biodegradable PE film



Source: Wang et al. (2021)

Building and Construction

Replacement materials for concrete : Fiber reinforced plastics (FRP), Polypropylene (PP) fiber

- Compared to traditional steel reinforcing mesh (SRM), recycled PP fiber consumed 99% and 91% less water and fossil fuel
- Produced 93% less CO_2 e and 97% less PO_4 e

Replacement for copper : polyethylene (PEX)

- Consumes 42% less CO_2 e and contains 47% less embodied energy

Building and Construction cont.

Replacement for flowing and sewer pipes : Polyvinyl chloride (PVC)

- Life-cycle energy consumption and GHG emissions from PVC are lower than similar materials
- There is also a higher rate of exposure to health hazards such as toxic mold growth, and heavy metals

Insulation material : Extruded polystyrene (XPS)

- 57% CO_2 e more than fiberglass, 2.8 times the CO_2 e of corkboard
- Produced 50% and 29% more SO_2 e than fiberglass and corkboard

Automotive

Plastics primarily used for reinforcements:

- Typical filler or reinforcement materials include talc, clay, natural fiber, carbon fiber, and glass fiber

- Reinforcement materials have different environmental impacts
    - Cotton reinforced PP has the worse environmental performance due to its cultivation process

- CFRP saves 17–25% energy with 65–70% weight savings

- High energy content carbon fibers- higher energy recovery in recycling

Consumer goods

- **Common uses** : Toothbrushes, wipes, nappies, feminine products, and other personal care products
- Johnson & Johnson toothbrush case study:
  - Pre-consumption plastic waste in toothbrushes
  - Lower environmental impacts and the production cost
- Drivers of environmental impact for single-use and reusable nappies and feminine products:
  - Single-use products: Production phase
  - Reusable products: Use phase
- Cultural context affects the adoption of alternative materials and user behavior

Electronics

- Additives in the composition make it difficult to recycle and reuse
  - Low recycling efficiency

- **Printer panels** : Additives are the biggest contributors to cradle-to-gate GHG emissions of a printer (up to 40%)

- **Laptops** : The recycled content of the product should be above a certain percentage depending on the metal, replacing the primary metal production for metals to be a better option than plastics

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Additives

- Categories: functional additives, colorants, reinforcements, and fillers

- Few LCA studies have incorporated additives, especially functional additives, into their scope

- Including additives into plastic LCA studies are challenging since:
  - There are a large number of potential substances
  - Some additives will alter the characteristics of the product, which requires more data for a comprehensive analysis
  - The impact of plastic additives also depends on the end of life (EOL) treatment for the product, which is also a blindspot in plastic LCA

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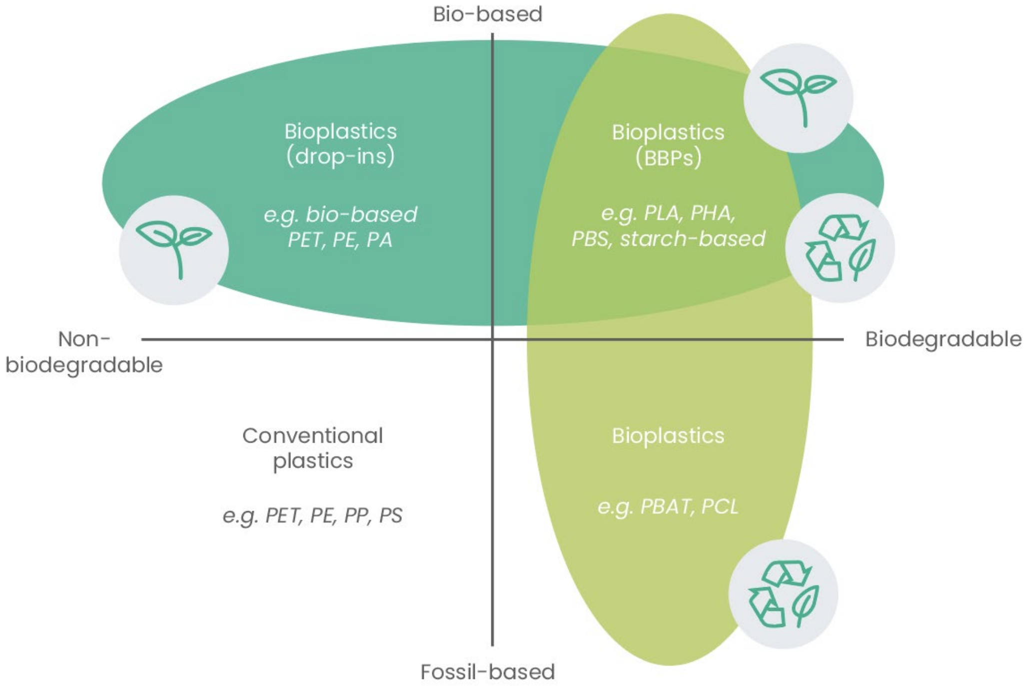
Bioplastics

Bioplastics is divided into three main groups:

1. Bio-based or partly bio-based, non-biodegradable plastics, such as bio-based PE, PP, or PET, and bio-based technical performance polymers such as PTT or TPC-ET;
1. Plastics that are both bio-based and biodegradable, such as PLA and PHA or PBS;
1. Plastics that are based on fossil resources and are biodegradable, such as PBAT.



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Bioplastics concerns

Using bioplastics may reduce climate impacts but may result in other environmental tradeoffs:

- Use of fossil-derived pesticides and fertilizers in large-scale agricultural products
- Feedstock of energy- and chemical-intensive crops
- Environmental impacts of land use change
- Ecosystem services damage due to excessive harvesting

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Challenges and gaps in plastics LCA

1. **Lack of reliable, high-quality regional data** on plastics
   - Asia has little LCI data is available
   - Region-specific emission factors are needed to accurately represent the background energy mix scenarios and EoL treatment options

1. Lack the assessment of impacts from **microplastics**

1. **Not all additives are well-studied** using an LCA approach

1. **No publicly available tool** with which manufacturers and researchers can assemble reliable LCIs of plastics

1. **Challenging to model of plastics' end-of-life** treatment
   - Waste collection rate, type and severity of contamination, and accessible recycling technologies vary widely across geographies and times

Conclusions

- LCA is well suited to evaluate plastics' life-cycle environmental impacts
- Further development in data and impact assessment is needed
  - Impact of plastics on marine and terrestrial ecosystems have been neither fully understood nor incorporated into LCIA
  - The fate, transport, and exposure of plastics in the environment including their degradation pathways are not fully understood
- Results are not directly comparable - differences in system boundaries, completeness of the study, assumptions made, and base years used, etc.
- Asia is the main production outlet, but existing LCIs focus on Europe
- LCI data on additives are scarce
- Representative LCAs for widely used plastics are scarce

Future outlook

- Harmonized and transparent LCA data that represent continents other than Europe is needed
- A protocol or standard to build representative LCAs of plastics needs to be developed
- Incorporation of LCA research into on-going and relevant research
  - The prediction of service life of plastics with the consideration of additives
  - Standardization and the method of identifying additives used in plastics
- Develop reference LCIs for major plastic materials, additives, and prevailing processes to enable rapid and reliable LCA of plastics
- Develop a life-cycle screening tool focusing on plastics life-cycle

Contact Us

To begin a conversation about working together, [contact us by filling out the form on our website.]

You may also contact:

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Overview of terms

Terms	Description
Polymer	A large molecule composed of monomers typically connected by covalent bonds.
Plastic	A colloquial term for wide range of synthetic or semi-synthetic polymers.[1]
Bioplastic	While exact definitions vary, it generally refers to both biodegradable plastics and bio-based plastics.[19]
Compostable plastic	Plastic that is capable of biodegrading at elevated temperatures in soil under specified conditions and time scales, usually only encountered in an industrial composter (standards apply).
Degradable plastic	Plastic that is capable of a partial or complete breakdown as a result of e.g., UV radiation, oxygen attack, biological attack, which implies an alteration of the properties, such as discoloration, surface cracking, and fragmentation.[19]
Microplastic	The generic term for small pieces of plastic the longest dimension of which is under 5 mm.[20]
Bio-based plastic	A type of plastic derived from biomass such as organic waste material or crops grown specifically for the purpose, which may or may not be biodegradable.[19] It applies to both naturally occurring polymers and natural substances that have been polymerized into high molecular weight materials.
Biodegradable plastic	Plastic that is capable of biodegrading under biological process of organic matter, which is completely or partially converted to water, CO_2/methane, energy, and new biomass by microorganisms (bacteria and fungi).[19]
Fiber reinforced plastic	Composite material made of a resin matrix reinforced with fibers to enhance the mechanical properties [21]