REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1 (2024)
http://www.veterinaria.org
Accepted date: 12/06/2024, Revised date : 22/07/2024 , Published date : 15/09/2024

A Novel Approach To Comparative Analysis Of Carbon Emissions From Food Packaging Materials Using Multiple Lcia Methodologies

Sheshanth Pallakonda[1*], Dr. Hariharan[2]

[1*]Research Scholar, Department Of Mechanical Engineering Sunrise University, Alwar, sheshanthpallakonda94@gmail.com
[2]Professor, Department Of Mechanical Engineering Sunrise University, Alwar, vsh1968@gmail.com

Abstract:
In an era marked by heightened environmental consciousness, the sustainability of packaging materials is of paramount concern. This research delves into a comprehensive comparative analysis of carbon emissions stemming from four prominent packaging materials utilized in the food industry: steel, PET, glass fibre, and borosilicate. Employing a data-driven approach, emissions data for 1kg of each material was meticulously gathered using Sima Pro software. The study goes beyond conventional analysis by integrating three distinct Life Cycle Impact Assessment (LCIA) methodologies: CML, Recipe, and Environmental Footprint V3.1. This multifaceted methodology not only provides a nuanced understanding of carbon emissions but also offers a robust framework for comparison. Furthermore, the visualization of data was executed through custom Python code within the PyCharm IDE, ensuring accuracy and flexibility in graphical representation. By amalgamating diverse analytical techniques, this research contributes to a more comprehensive understanding of the environmental footprint of packaging materials, empowering stakeholders to make informed decisions towards sustainable practices in the food industry.

Keywords: Comparative analysis, Carbon emissions, Food packaging materials, LCIA methodologies, SimaPro, Steel, PET, Glass fiber, Borosilicate, Data-driven approach, Python code, PyCharm IDE, Sustainability, Environmental footprint.

Background of the study: Life cycle assessment (LCA) is a systematic approach used to evaluate the environmental effects of products or processes. It involves examining all the resources and waste generated at each stage of a product's life cycle, starting from the manufacture of raw materials and ending with its disposal. This methodology assesses the locations of the most significant effects and identifies areas where the most relevant enhancements can be implemented, while also recognising potential trade-offs [1-2].
It enables companies to explore areas in which they could enhance their performance. While there are LCA tools available for many sectors, there is currently no comprehensive LCA tool specifically designed to assess the environmental effects of different stages in the food supply chain or to facilitate the implementation of IoT technology for reducing food waste. This tool will be extremely beneficial considering the growing tendency in the food business to adopt new technologies. This research addresses the existing knowledge gap and adds to the existing body of literature [3-6].

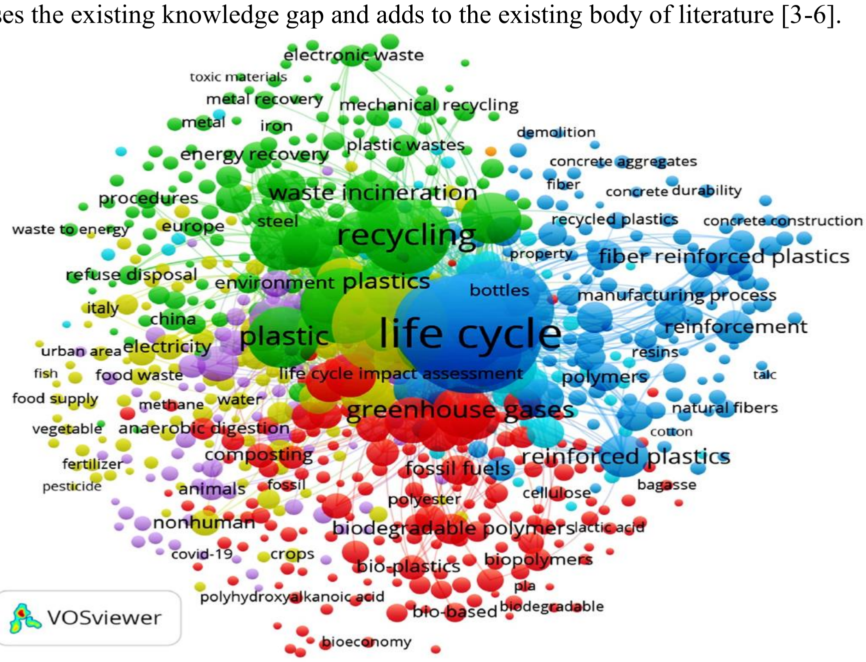

Fig 1. Keywords related to materials and life cycle evaluation organised in a network [3]

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Literature Review:
Recently, several computer tools have been created to evaluate the environmental effects of different products and organisations using a life cycle assessment (LCA) approach. Table 1 displays a selection of tools that have been suggested in the literature. This list does not aim to include every tool and methodology available, but rather to highlight some of the more notable ones that can be applied in real-world scenarios [1].

According to the authors, polymers and fillers obtained from biological sources have the potential to replace components derived from oil. This would help reduce environmental damage by making plastic products biodegradable and decreasing the use of non-renewable resources [7]. However, before proceeding with attempts to replace oil-based polymers, it is crucial to determine the viability of socially acceptable biopolymer manufacturing, while also ensuring positive environmental and economic results.

This article presents a detailed framework that combines ex-ante Life Cycle Assessment with multi-attribute value theory and stochastic multi-acceptability analysis. The framework is used to evaluate new bio-based materials and consists of four consecutive processes [8]. In order to showcase its usefulness, the framework is utilised to evaluate small-scale starch films designed for food packaging. These films are compared to commercial polymers based on cost, environmental impact, and technical considerations. The evaluation is done from the viewpoints of three decision-makers who are involved in biopolymer and sustainability research [9-10].

The inclusion of functional fillers in goods made from PLA offers potential benefits in terms of cost reduction and improvement of characteristics. Nevertheless, current life cycle assessments of PLA containers primarily focus on the greenhouse gas emissions linked to PLA material exclusively, disregarding the environmental consequences of functional fillers and the subsequent transfer of environmental loads to other indicators [11-13]. According to another author, examining the expansion of production and different options for adding plasticizers shows the possibility of reducing environmental effects. However, these actions do not affect the order of preference for alternative solutions. The Stochastic Multi-Attribute Acceptability Analysis highlights the substantial impact of criterion weights on ranking results, whereas individual decision-makers tend to reach an agreement on the comparative evaluation [14-19]. Furthermore, materials undergo assessment for similar attributes through the application of material substitution factors. Starch films exhibit favourable outcomes, particularly in terms of rigidity, indicating the necessity for further investigation in demanding application domains.

In this study, authors [20-24] perform a comparative analysis of the environmental impacts of two food cold chain packaging systems. They use a method called life cycle assessment (LCA) to evaluate the cold food processes, water usage in glass and plastic bottles, materials used in manufacturing vacuum panels, carbon footprints in cigar production, and food packaging modules.

Author [24-28] recently The examined materials demonstrated favourable attributes in terms of acoustic and thermal insulation, fire resistance, and mechanical durability, making them appropriate for various applications in the building, packaging, and furniture sectors. An study of the life cycle conducted on a small-scale production model in Germany confirmed the advantages related to mitigating climate change and decreasing the need for fossil energy supplies.

Edible cups have surfaced as a potential solution to the global challenge of littering and plastic pollution caused by the waste of around 500 billion beverage cups each year. This research study investigates the environmental efficacy of edible cups in relation to commonly used cup materials such as paper, polylactic acid, polystyrene, polypropylene, and steel. The review intends to compare the environmental impact of several end-of-life treatment options for each type of cup, using life cycle assessment techniques and a littering indicator [29-30].

Literature Summary
The literature analysed in this review emphasises the increasing attention given to tackling environmental issues related to various characteristics of materials used in food packaging. Moreover, it is important to mention that certain studies have explored novel approaches, such as using Python-based graphical content, to improve the analytical capabilities and visual depiction of the research findings. This approach highlights the importance of using many disciplines to thoroughly evaluate and discuss the environmental effects of food packaging goods. This helps to make well-informed decisions that promote sustainability.

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Table 1. Various LCA techniques are accessible for evaluating the ecological consequences of diverse products [T1-T4]

Authors	System Boundary	LCI Database	Modelling Approach	Indicators	Analysis Tool
Hassan et al. [T1]	Gate-to-gate (excludes transportation and other life cycle stages)	Ecoinvent	ReCiPe and IPCC 2013	GW, DEQ, HH, RM	Excel
Hollberg et al. [T2]	Cradle-to-gate (from materials production to transportation)	Boverket	IPCC 2013	GW	Grasshopper 3D used as platform for the tool
Famigliett i et al. [T3]	Cradle-to-grave (from materials production to end-of-life stage)	-	EF 3.0	All categories of the EF method	Excel
Famigliett i et al. [T4]	Cradle-to-gate (from purchased feeds to dairy production)	Agribalyse, Ecoinvent , ELCD, USLCI, etc.	ILCD 2011 Midpoint +	All categories of the ILCD 2011 method	IT-tool

It was noted that the majority of the tools are based on the Excel software. The majority of them solely compute the global warming potential. The emphasis on this category is justified, as it is regarded as one of the most crucial indicators. Many plans and policies aimed at mitigating the impacts of climate change are built around it, as the objectives are stated in terms of decreasing carbon emissions. However, there are more signs that are important to consider. To address these indicators, researchers like Famiglietti et al. have developed tools, such as the ones provided in their studies [T3] and [T4]. Python can be utilised as a graphical user interface (GUI) to generate graphs that exhibit superior visualisation and more effective comparison in contrast to conventional Excel graphs.

Problem Statement: Although there is growing recognition of environmental concerns, the food industry still struggles with the task of choosing sustainable packaging materials. Although there are a variety of materials to choose from, accurately assessing their environmental impact is challenging because there is a lack of extensive comparison evaluations. Current research frequently neglects the ever-changing nature of carbon emissions and does not incorporate various Life Cycle Impact Assessment approaches, which restricts the level of comprehension. Moreover, the lack of intuitive tools for visualising and analysing data hinders stakeholders' capacity to make well-informed decisions. Hence, it is crucial to do research that fills these gaps by performing a comprehensive comparative analysis of carbon emissions from various packaging materials, utilising advanced Life Cycle Impact Assessment (LCIA) methodologies and new visualisation tools.

Methodology:
The primary objective of this research is to conduct a comprehensive comparative analysis of carbon emissions associated with four prominent packaging materials used in the food industry, namely steel, PET, glass fibre, and borosilicate. The study aims to utilize three distinct Life Cycle Impact Assessment (LCIA) methodologies: CML, Recipe, and Environmental Footprint V3.1, to provide a nuanced understanding of the environmental footprint of these materials. The emissions data for 1kg of each packaging material was meticulously gathered using Sima Pro software. Sima Pro is a widely used tool for life cycle assessment (LCA) and LCIA. The data collected from the Sima Pro Software which is displayed in the analytical results section. Also, a python code was written in pycharm to obtain a graph which were displayed in the results section for the 3 methodologies with four different materials.

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Life Cycle Impact Assessment (LCIA) Methodologies:
CML: This approach evaluates the potential ecological consequences of various materials over their whole lifespan, considering numerous impact categories such as global warming potential (carbon emissions), acidification, eutrophication, and so on.
Recipe: This LCIA methodology assesses the environmental effects by taking into account a comprehensive inventory of resources, emissions, and other inputs associated with the entire life cycle of materials.
Environmental Footprint V3.1: This methodology offers a uniform method to evaluate and compare the environmental impact of products or processes, with a specific emphasis on carbon emissions and other pertinent indicators.
Analytical Identification: In this study, 4 different materials with 3 different methods were analysed for the output characteristics such as carbon foot print and its sub components which is displayed using the software known as Sima Pro. Each method is performed on these 4 materials and the output responses recorded were shown in the below tables each and describe their performance in details and its significance.

Table 1. CML Method Values for Steel, PET, Glass Fibre and Boroscate

Attribute	Steel	PET	Glass Fiber	Boroscate
CML2001-Aug. 2016, Abiotic Depletion (ADP elements) [kg Sb eq]	3.11E-07	3.62E-07	9.06E-05	0.000317
CML2001-Aug-2016, Abiotic Depletion (ADP fossi) [MJ]	24.6	65.2	21.5	27.9
CML2001-Aug. 2016, Acidification Potential (AP)[kg S02 eq.]	0.00427	0.00287	0.0113	0.00705
CML2001-Aug. 2016, Eutrophication Potential (EP)[kg Phosphate eq.]	0.000381	0.000403	0.000603	0.00167
CML2001-Aug. 2016, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) kg DCB eq.]	0.00369	0.0157	0.00203	0.00368
CML2001-Aug. 2016, Global Warming Potential (GWP 100 years) [kg CO2 eq.]	2.16	2.25	1.52	1.86
CML2001-Aug. 2016, Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO2 eq.]	2.16	2.25	1.52	1.85
CML2001-Aug-2016, Human Toxicity Potential (HTP inf.) [kg DCB eq.]	0.154	0.0898	0.042	0.48
CML2001-Aug. 2016, Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	65.4	97.1	75.7	213
CML2001-Aug. 2016, Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	-5.52E-14	6.36E-12	1.84E-11	5.54E-13
CML2001-Aug. 2016, Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	0.00097	0.000496	0.000584	0.000442
CML2001-Aug. 2016, Terrestric Ecotoxicity Potential (TETP inf.)[kg DCB eq.]	0.0012	0.00443	0.00345	0.00571

Table 2. Recipe Method Values for Steel, PET, Glass Fibre and Boroscate

Attribute	Steel	PET	Glass Fibre	Boroscate
Recipe 2016 v1.1 Midpoint (E)-Climate change, default, excl biogenic carbon [kg CO2 eq.]	2.05	2.09	1.47	1.77
Recipe 2016 v1.1 Midpoint (E)- Climate change, incl biogenic carbon [kg CO2 eq.]	2.05	2.09	1.47	1.77
Recipe 2016 v1.1 Midpoint (E)-Fine Particulate Matter Formation [kg PM2.5 eq.]	0.00172	0.000679	0.00269	0.00173
Recipe 2016 v1.1 Midpoint (E)-Fossil depletion [kg oil eq.]	0.57	1.61	0.566	0.676
Recipe 2016 v1.1 Midpoint (E)-Freshwater Consumption [m3]	-0.000124	0.0219	0.00597	0.00288
Recipe 2016 v1.1 Midpoint (E)-Freshwater ecotoxicity [kg 1,4 DB eq.]	0.000235	0.0006	9.81E-05	0.000161
Recipe 2016 v1.1 Midpoint (E)-Freshwater Eutrophication [kg P eq.]	8.67E-07	3.28E-06	4.62E-06	1.78E-06

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Recipe 2016 v1.1 Midpoint (E)-Human toxicity, cancer [kg 1,4-DB eq.]	0.00416	0.0717	0.00978	0.0235
Recipe 2016 v1.1 Midpoint (E)-Human toxicity, non-cancer [kg 1,4-DB eq.]	3.86	17.7	1.29	6.79
Recipe 2016 v1.1 Midpoint (E)-Ionizing Radiation [kBq Co-60 eq. to air]	0.0168	0.202	0.108	0.0104
Recipe 2016 v1.1 Midpoint (E)-Land use [Annual crop eq.y]	0.0374	0.0248	0.0671	0.00628
Recipe 2016 v1.1 Midpoint (E)-Marine ecotoxicity [kg 1,4-DB eq.]	4.13	3.71	0.985	3.39
Recipe 2016 v1.1 Midpoint (E)-Marine Eutrophication [kg N eq.]	1.37E-05	1.82E-05	2.78E-05	4.30E-05
Recipe 2016 v1.1 Midpoint (E)-Metal depletion [kg Cu eq.]	0.0632	0.00253	0.103	0.192
Recipe 2016 v1.1 Midpoint (E)-Photochemical Ozone Formation, Ecosystems [kg NOx eq.]	0.00277	0.00273	0.00406	0.0113
Recipe 2016 v1.1 Midpoint (E)- Photochemical Ozone Formation, Human Health [kg NOx eq.]	0.00276	0.00262	0.00402	0.0113
RECIPE 2016 v1.1 Midpoint (E)-Stratospheric Ozone Depletion [kg CFC-11 eq.]	1.32E-07	7.02E-07	5.61E-07	4.85E-07
Recipe 2016 v1.1 Midpoint (E)-Terrestrial Acidification [kg SO2 eq.]	0.00334	0.00216	0.00906	0.00542
Recipe 2016 v1.1 Midpoint (E)-Terrestrial ecotoxicity [kg 1,4-DB eq.]	0.423	0.467	0.329	1.12

Table 3. Environmental Footprint Method Values for Steel, PET, Glass Fibre and Boroscate

Attribute	**Steel**	**PET**	**Glass Fibre**	**Boroscate**
EF 3.1 Acidification [Mole of H+ eq.]	0.00512	0.0035	0.0129	0.0103
EF 3.1 Climate Change-total [kg CO2 eq.]	2.17	2.27	1.52	1.86
EF 3.1 Climate Change, biogenic [kg CO2 eq.]	0.000524	0.00705	0.00971	0.00232
EF 3.1 Climate Change, fossil[kg CO2 eq.]	2.17	2.26	1.51	1.86
EF 3.1 Climate Change, land use and land use change[kg CO2 eq.]	0.000339	0.000146	0.00017	0.000194
EF 3.1 Ecotoxicity, freshwater-total [CTUe]	3.32	30.6	3.69	40.4
EF 3.1 Ecotoxicity, freshwater inorganics [CTUe]	3.16	30.3	3.66	40.4
EF 3.1 Ecotoxicity, freshwater organics [CTUe]	0.158	0.281	0.026	0.0752
EF 3.1 Eutrophication, freshwater [kg P eq.]	8.70E-07	3.31E-06	4.63E-06	1.79E-06
EF 3.1 Eutrophication, marine [kg N eq.]	0.00109	0.000985	0.00159	0.00457
EF 3.1 Eutrophication, terrestrial [Mole of N eq.]	0.0118	0.0107	0.0172	0.0525
EF 3.1 Human toxicity, cancer-total [CTUh]	1.3E-09	7.92E-10	2.92E-10	2.74E-10
EF 3.1 Human toxicity, cancer inorganics [CTUh]	6.83E-11	5.90E-10	1.49E-10	2.48E-10
EF 3.1 Human toxicity, cancer organics [CTUh]	1.23E-09	2.02E-10	1.43E-10	2.61E-11
EF 3.1 Human toxicity, non-cancer-total [CTUh]	5.47E-09	2.54E-08	1.72E-08	2.35E-08
EF 3.1 Human toxicity, non-cancer inorganics [CTUh]	5.24E-09	2.50E-08	1.71E-08	2.33E-08
EF 3.1 Human toxicity, non-cancer organics [CTUh]	2.32E-10	3.97E-10	1.23E-10	1.72E-10
EF 3.1 lonising radiation, human health [kBq U235 eq.]	0.0131	0.156	0.0838	0.00809
EF 3.1 Land Use [Pt]	0.922	2.44	5.66	0.419
EF 3.1 Ozone depletion[kg CFC-11 eq.]	-4.69E-14	5.40E-12	1.56E-11	4.70E-13
EF 3.1 Particulate matter [Disease incidences]	2.20E-07	2.50E-08	7.98E-08	7.35E-08
EF 3.1 Photochemical ozone formation, human health [kg NMVOC eq.]	0.00431	0.00367	0.00501	0.0116
EF 3.1 Resource use, fossils [MJ]	24.8	67.8	23.7	28
EF 3.1 Resource use, mineral and metals [kg Sb eq.]	5.51E-07	8.67E-08	3.25E-07	3.72E-08

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EF 3.1 Water use [m^3 world equiv.]	-0.0657	0.877	0.212	0.105

Results and Discussions: The emissions data collected for each material were analysed using Sima Pro software and the LCIA methodology outlined above. Each methodology was utilised to analyse the emissions data of steel, PET, glass fibre, and borosilicate in order to ascertain their individual carbon footprints and other pertinent environmental implications. Subsequently, the findings were gathered and juxtaposed to yield insights into the comparative sustainability of the packaging materials. Additionally, a Python method was developed to provide graphical representations.
Data visualisation was performed using customised Python code in the PyCharm Integrated Development Environment (IDE). The comparative analysis results were accurately and flexibly shown using Python's tools, including Matplotlib and Seaborn. Bar charts are used to visually display the carbon emissions and other environmental implications of different packaging materials under various LCIA approaches.

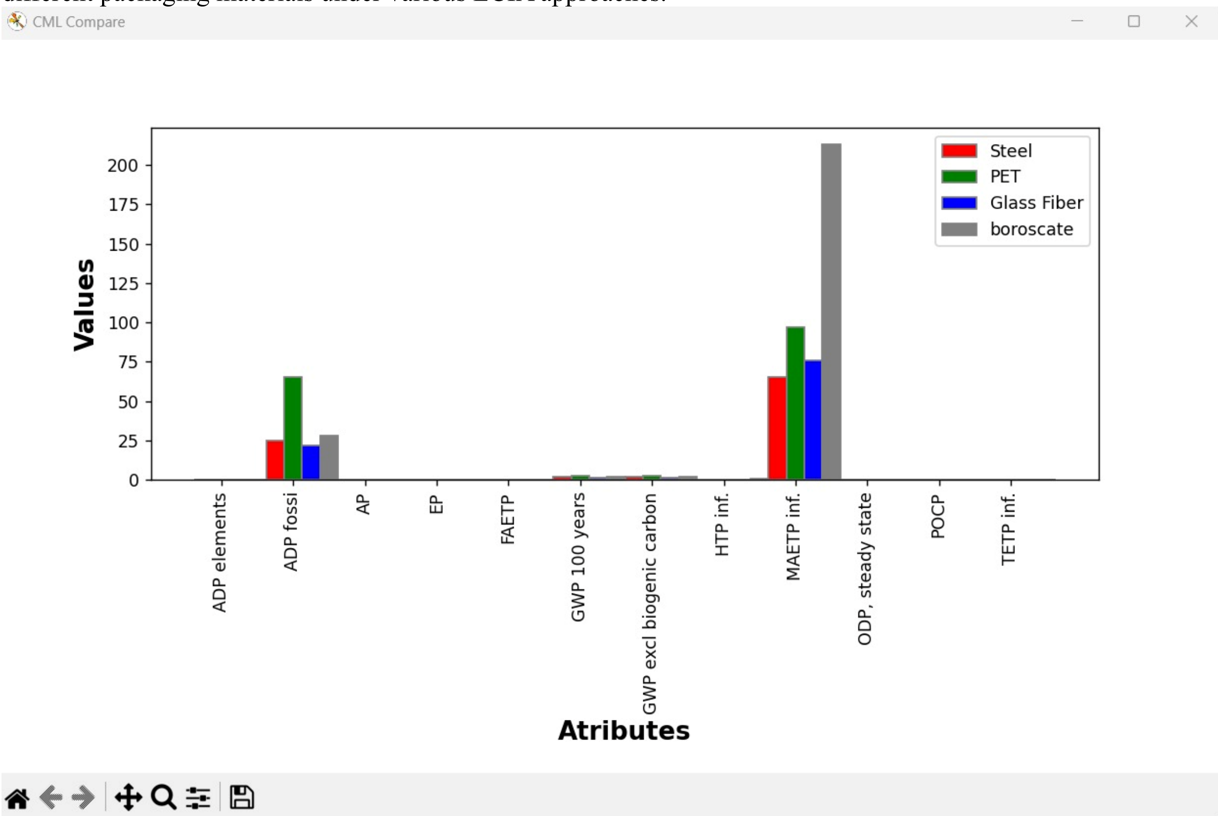

Fig 2. Result for CML

The CML technique allows for a comparative examination of carbon emissions from food packaging materials, highlighting the specific environmental implications associated with different parameters. Abiotic Depletion (ADP) refers to the substantial reduction of non-living resources linked to glass fibre and borosilicate materials, which raises questions about their long-term sustainability. The Acidification Potential (AP) and Eutrophication Potential (EP) highlight the moderate environmental impact of glass fibre and borosilicate, specifically in terms of their role in the creation of acid rain and the enrichment of nutrients in water bodies. The Freshwater Aquatic Ecotoxicity Potential (FAETP) suggests that PET and borosilicate materials have moderate to high levels of toxicity, which could pose a threat to freshwater environments. The Global Warming Potential (GWP) demonstrates moderate effects on all materials, highlighting the necessity of implementing mitigation techniques to tackle climate change concerns.
The Human Toxicity Potential (HTP) highlights the elevated dangers that borosilicate material presents to human health in comparison to other materials. The Marine Aquatic Ecotoxicity Potential (MAETP) assessment indicates significant environmental hazards linked to all components, with borosilicate in particular posing a notable risk to marine ecosystems. Ozone Layer Depletion Potential (ODP) and Photochemistry. The Ozone Creation Potential (POCP) suggests minimal effects on the environment for most materials, with the exception of PET, which has a small impact on the depletion of the ozone layer. The Terrestrial Ecotoxicity Potential (TETP) indicates that PET and glass fibre materials pose moderate threats to terrestrial life. These findings offer important insights into the environmental impact of food packaging materials, helping stakeholders make more sustainable choices and adopt better practices.

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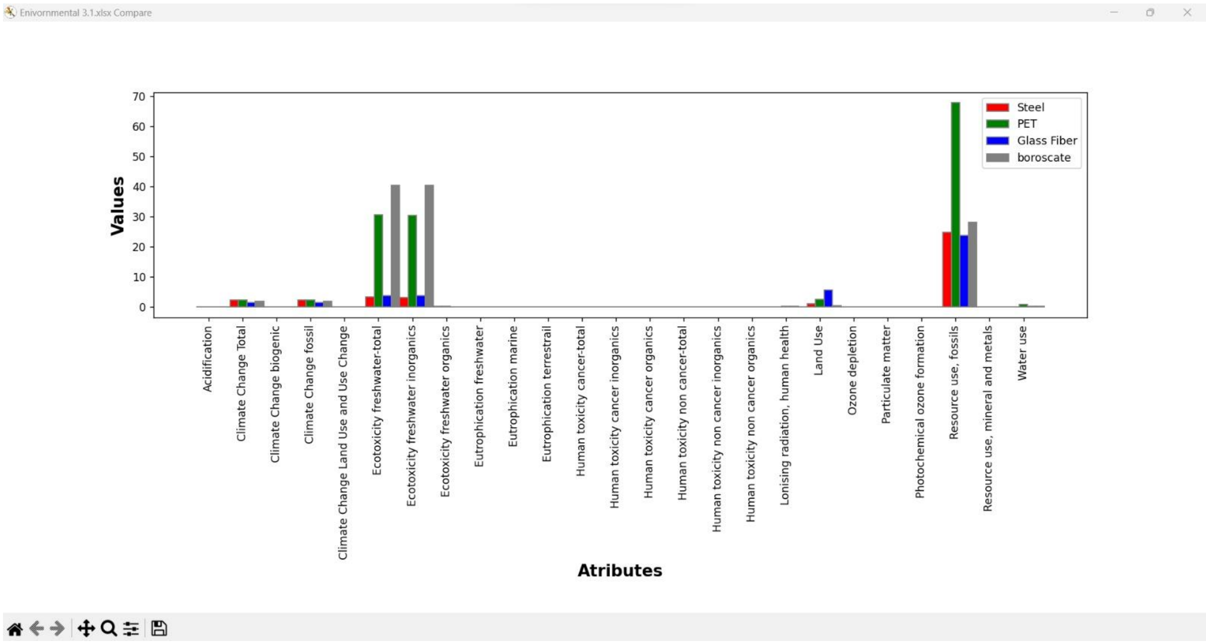

Fig 3. Result for Recipe

The analysis comparing food packaging materials using the Recipe 2016 v1.1 Midpoint (E) LCIA approach demonstrates a wide range of environmental impacts across different criteria. Climate change, including both biogenic carbon and non-biogenic carbon, underscores the significant impact of PET and Borosilicate materials, emphasising their role in intensifying global warming. The creation of fine particulate matter highlights issues about air quality, with PET and Borosilicate demonstrating greater impacts compared to Steel and Glass Fibre. The depletion of fossil fuels highlights the considerable dependence of PET on finite resources, which presents obstacles to achieving long-term sustainability. PET's significant contribution to the depletion of freshwater resources and the toxicity of aquatic environments is shown by its high levels of freshwater consumption and ecotoxicity.

Human toxicity evaluations indicate that PET and Borosilicate have greater effects on both cancer and non-cancer toxicity when compared to Steel and Glass Fibre. Ionising radiation and the reduction of metal content emphasise the environmental impacts of PET and Borosilicate, indicating potential hazards to human health and the availability of resources. area use assessments identify Glass Fibre as the material that requires the greatest area, while marine ecotoxicity and eutrophication highlight the negative effects of PET and Borosilicate on marine ecosystems. Borosilicate's substantial environmental impact is seen in various areas, including stratospheric ozone depletion, terrestrial acidification, and ecotoxicity. These findings offer important insights into the environmental consequences of food packaging materials, helping stakeholders make more sustainable choices and adopt better practices.

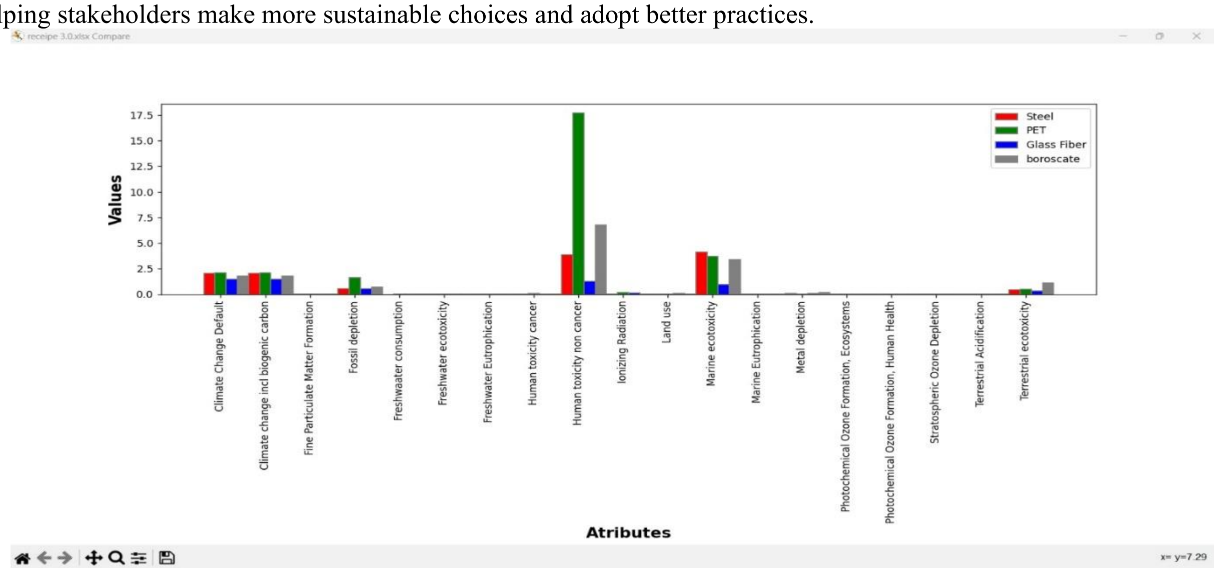

Fig 4. Result for Environmental Footprint

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The Environmental Footprint (EF) 3.1 technique is utilised to evaluate the influence of several elements on the environmental performance of food packaging materials in numerous categories. Polyethylene terephthalate (PET) exhibits a lesser acidification potential when compared to Borosilicate, Steel, and Glass Fibre. This suggests that PET has a reduced impact on the development of acid rain. When it comes to climate change, Steel and Borosilicate have slightly lesser impacts compared to PET and Glass Fibre. This indicates potential benefits in reducing greenhouse gas emissions. PET and Glass Fibre exhibit significantly greater impacts on freshwater ecotoxicity, underscoring the potential hazards they provide to freshwater environments in comparison to Steel and Borosilicate. Steel exhibits the lowest eutrophication potential in different ecosystems, suggesting that it has the capacity to cause the least amount of nutrient enrichment.
The substances PET and Borosilicate have a greater impact on human toxicity, affecting both cancer and non-cancer health concerns, which suggests a potential danger to human well-being. PET exhibits the most significant influence on ionising radiation, indicating possible hazards to health. Glass Fibre has the greatest influence on land use, whereas PET has the largest water usage, which raises issues about the efficient use of resources. These findings offer important insights into the environmental impact of food packaging materials, helping stakeholders make more sustainable choices and adopt better practices.

Python code developed for this research

```
"""Importing Libraries"""
import numpy as np
import matplotlib.pyplot as plt
import xl_data_etrc as xl_dt
data = xl_dt.get_data()  # Getting from the excel sheet
for x in data:
    # set width of bar
    barWidth = 0.25
    # Setting up the graph properties
    fig = plt.subplots(figsize=(10, 8), num=f"{x} Compare")
    plt.subplots_adjust(bottom=0.5)
    #   Getting Keys from the dictionary
    keys = list(data[x].keys())
    # Storing data into specific local variables
    steel = data[x][keys[0]]
    pet = data[x][keys[1]]
    glass_fibre = data[x][keys[2]]
    boroscate = data[x][keys[3]]
    #   Setting up the labels for the excel data
    label = {
        'CML.xlsx': ['ADP elements', 'ADP fossi', 'AP', 'EP', 'FAETP', 'GWP 100 years', 'GWP excl biogenic carbon',
  'HTP inf.',
'MAETP inf.', 'ODP, steady state', 'POCP', 'TETP inf.'],
'Enivornmental 3.1.xlsx': ['Acidification', 'Climate Change Total', 'Climate Change biogenic',
'Climate Change fossil',
'Climate Change Land Use and Use Change', 'Ecotoxicity freshwater-total',
'Ecotoxicity freshwater inorganics',
 'Ecotoxicity freshwater organics', 'Eutrophication freshwater',
'Eutrophication marine', 'Eutrophication terrestrail', 'Human toxicity cancer-total',
'Human toxicity cancer inorganics',
'Human toxicity cancer organics', 'Human toxicity non cancer-total',
'Human toxicity non cancer inorganics',
'Ozone depletion', 'Particulate matter',
'Photochemical ozone formation', 'Resource use, fossils',
 'Resource use, mineral and metals', 'Water use'],
'receipe 3.0.xlsx': ['Climate Change Default', 'Climate change incl biogenic carbon',
'Fine Particulate Matter Formation', 'Fossil depletion',
'Freshwaater consumption', 'Freshwater ecotoxicity', 'Freshwater Eutrophication',
'Human toxicity cancer', 'Human toxicity non cancer',
'Ionizing Radiation', 'Land use', 'Marine ecotoxicity', 'Marine Eutrophication',
'Metal depletion', 'Photochemical Ozone Formation, Ecosystems',
'Photochemical Ozone Formation, Human Health', 'Stratospheric Ozone Depletion',
'Terrestrial Acidification', 'Terrestrial ecotoxicity']
```

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```
}
#   Setting up the bar graph properties
br1 = np.arange(len(steel))
br2 = [x + barWidth for x in br1]
br3 = [x + barWidth for x in br2]
br4 = [x + barWidth for x in br3]
# Make the plot
plt.bar(br1, steel, color='r', width=barWidth, edgecolor='grey', label='Steel')
plt.bar(br2, pet, color='g', width=barWidth, edgecolor='grey', label='PET')
plt.bar(br3, glass_fibre, color='b', width=barWidth, edgecolor='grey', label='Glass Fiber')
plt.bar(br4, boroscate, color='grey', width=barWidth, edgecolor='grey', label='boroscate')
# Adding Xticks
plt.xlabel('Atributes', fontweight='bold', fontsize=15)
plt.ylabel('Values', fontweight='bold', fontsize=15)
plt.xticks([r + barWidth for r in range(len(steel))], label[x], rotation=90)
plt.legend()
plt.show()
```

Python Code used to generate Graphs - Xl_data_etrc.py File
This file is used to extract data from the excel workbook.

```
import openpyxl as xl
def get_data():
    '''
      This function is used to get the from the excel workbook
    return:
    It will return a dictionary consist of every data from the excel workbook
    '''
    file_nm = ['CML.xlsx', 'Enivornmental 3.1.xlsx', 'receipe 3.0.xlsx']
    wr_dt = {}
    for x in file_nm:
        wb = xl.load_workbook(x)
        sh_dt = {}
        for name in wb.sheetnames:
            sh = wb[name]
            sh_lst = []
            for row in range(1, sh.max_row + 1):
                val = sh.cell(row=row, column=2).value
                if val is not None and type(val) != str:
                    sh_lst.append(val)
            sh_dt[name] = sh_lst
        wr_dt[x] = sh_dt
        wb.close()
    return wr_dt
```

Conclusions: In conclusion, the Environmental Footprint (EF) 3.1 methodology offers a comprehensive assessment of the environmental impacts associated with food packaging materials across various categories. PET and Glass Fiber often exhibit higher impacts on factors such as freshwater ecotoxicity, human toxicity, and water use, indicating potential environmental risks compared to Steel and Borosilicate. However, Steel and Borosilicate demonstrate advantages in areas such as acidification potential, climate change impact, and eutrophication potential, suggesting their potential for lower environmental impact in certain categories. Considering these findings, the choice of the "best" method depends on the specific priorities and objectives of the study. While the EF 3.1 methodology provides a holistic perspective by covering a wide range of impact categories, the selection of the most suitable method should align with the key environmental concerns and priorities of stakeholders. Therefore, a comprehensive evaluation of multiple LCIA methodologies, including EF 3.1, Recipe, and CML, allows for a more robust comparative analysis, enabling stakeholders to make informed decisions towards sustainable food packaging practices.

Future Scope: The future potential of this research includes numerous attractive opportunities for additional investigation and improvement. Firstly, there is the possibility of expanding the impact categories beyond those that were examined in the current study, such as climate change, ecotoxicity, and human toxicity. By considering variables such as biodiversity loss, water shortage, and resource depletion, a more full comprehension of the environmental impact of food packaging materials can be achieved.

Furthermore, future studies could integrate developing Life Cycle Impact Assessment (LCIA) approaches in order to improve the precision and significance of environmental impact evaluations. This could entail incorporating more recent iterations of established procedures or investigating wholly innovative approaches that encompass a wider spectrum of environmental effects.

Furthermore, there is a chance to carry out more thorough life cycle assessments of substitute packaging materials, taking into account their complete life cycle from the extraction of raw materials to their disposal or recycling at the end of their useful life. This comprehensive method would offer significant insights into the environmental consequences of various packaging alternatives. In addition, future research might explore the environmental consequences of novel packaging solutions, such as bio-based materials and smart packaging systems, in light of continuous progress in materials science and packaging technology.

Incorporating both social and economic considerations, such as consumer preferences and regulatory frameworks, is essential for creating sustainable packaging solutions that are in line with societal demands and aspirations. Utilising the results of comparative Life Cycle Impact Assessment (LCIA) studies in practical situations within the food industry and policy-making organisations provides chances for involving stakeholders, advocating for policies, and creating practical guidelines to encourage the use of more sustainable packaging practices.

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