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COMPARATIVE ANALYSIS OF IMAGE-BASED AI TOOLS FOR DETECTING RECYCLING MATERIAL AND CO_2 ESTIMATIONS

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ABSTRACT
Waste management and recycling represent an essential concept in sustainable urban development. This field benefits from community participation, as collective action plays a crucial role in enhancing recycling activities. With artificial intelligence emerging as a transformative technology, new possibilities have emerged for raising awareness about recycling practices, thereby helping people make better decisions regarding their purchasing choices and recycling behaviors. AI tools such as ChatGPT, Google Gemini, and similar platforms have become popular resources that people incorporate into their daily lives to gather information, generate ideas, and even seek advice. These AI platforms are easily accessible and can be used for free, making them attractive and widely used by individuals. However, understanding the degree to which these AI tools are reliable and comprehending how they actually respond to users remains critically fundamental. This study investigates how various AI platforms analyze images of waste materials to identify their type and estimate the corresponding CO_2 emissions saved through proper recycling or disposal. The study compares how image recognition models and LLMs provide information about recycling. The aim is to support the development of policies that help raise awareness about environmental issues and encourage citizens to engage in environmentally responsible behavior. The study also compares the results provided by different AI tools and assesses their credibility to check how reliably they inform users about recycling practices.

Keywords: Waste management, Artificial Intelligence, Environmental awareness

1. INTRODUCTION
Global challenges, climate change, limited resources, and pollution continue to compromise the environment. Thus, it is more urgent than ever to raise awareness about environmental sustainability. Behavioral change is required on both the individual and community levels. The starting point is the individual awareness about how personal habits impact the environment. Individual behavior influences and motivates the wider community to adopt eco-friendly practices that protect the environment.
In recent years, governments, policy makers, and researchers have devoted considerable attention to artificial intelligence (AI) solutions and innovative tools. In this technological revolution, artificial intelligence (AI) tools have offered innovative new ways to solve persistent urban and environmental problems. Among these tools, AI-powered platforms such as ChatGPT, Google Gemini, and innovative waste systems are all being integrated into daily life in various ways, from education to productivity. From an urban perspective, AI has been used to predict waste generation, manage sorting processes, and even use smart recycling bins to detect fill levels and reduce CO_2 emissions. Furthermore, image recognition allows the identification and classification of items in photographs. This technology helps citizens to engage in the recycling process and sustainability in several ways. People can learn about the products they are using, their materials, and whether they are recyclable or not. It is also possible to understand how their choices impact the environment. This personalized feedback can catalyze change by encouraging people to purchase more sustainable items and align their choices with urban sustainability goals.

This can open the door for municipalities and policymakers to design effective recycling strategies, increase individual participation in circular economy initiatives, such as identifying recyclable materials, estimating their CO_2 emissions, and helping people assess and determine the products they use. Researchers have studied smart recycling bins equipped with AI and image recognition. It showed that these smart bins can provide real-time feedback, prompting users to adopt more effective recycling habits [1], [2], [3]. Furthermore, AI is also utilized in tracking carbon emissions. Smart applications help users estimate CO_2 emissions by analyzing their waste and offering feedback on their recycling habits, offering a personalized alternative to traditional carbon footprint calculators. AI tools and image-based calculators can help turn images into insights and raise awareness about environmental impact [4], [5], [6]. By enhancing recycling efficiency and visibility, this encourages public participation by making recycling easier and more transparent [3], [7]
Despite these promising technologies, there is still a limitation in understanding the accuracy of these AI tools, specifically when it comes to identifying materials and estimating environmental impact. Thus, even though they are widely accessible and easy to use, the question of reliability in the context of ecological awareness still requires assessment. To address this gap, this study aims to investigate how different AI applications and platforms, specifically those utilizing image recognition, handle images of recyclable items and their associated CO_2

emissions, examining how popular tools like ChatGPT and Gemini evaluate recyclable items and CO_2 savings. Comparing these results across platforms, the study sheds light on the credibility and reliability of AI-generated responses in encouraging people to become environmentally responsible and raise awareness.

2. EVALUATING AI TOOLS FOR WASTE IMAGE RECOGNITION AND CO_2 ESTIMATION

This study focuses on understanding how different AI platforms analyze images of waste and provide feedback to understand better the reliability and potential of AI platforms in promoting environmental awareness. The aim is to evaluate how these platforms, specifically ChatGPT and Gemini, are able to identify material and estimate CO_2 emissions. This section focuses on the methodology employed and the study's results.

Typically, calculating CO_2 emissions is done using CO_2 calculators, spreadsheet tools, or reference tables. These tools have their standard factors they take into consideration to predict the carbon footprint of recyclable items. Considering the life cycle assessment (LCA) models, such as WARM (Waste Reduction Model), which is based on the U.S. Environmental Protection Agency's or the European Union's CO_2 waste factor databases. In short, these models work by estimating CO_2 emissions based on values related to material types, production processes, and other life cycle assessments. Despite being based on scientific grounds and commonly used in both planning and policy, these tools require users to input data manually, which makes them more challenging for individuals to use and commit to.

Furthermore, a benchmark value is needed to evaluate the credibility of CO_2 estimations by AI platforms' results. For this purpose, the value of the reuse and recycling emissions of a 500 mL PET bottle, which are 33.1 g and 11.7 g CO_2, respectively, was used as the primary reference points. These values were extracted from an LCA model using the CES EduPack model [8].The CES EduPack model references major international databases and offers reliable environmental data sources for the carbon footprint. This will help the research assess if the AI-generated data falls close to the benchmark result or not.

Thus, the selected images will represent a 500 mL PET bottle to compare against the benchmark values. The images criteria included realism; the images were selected to mimic what a user might typically upload. The bottle image will be uploaded in two conditions: one with the whole bottle, and the second, a crumpled one, to see how the AI reacts in both scenarios. This is also to determine if some platforms are more effective only under ideal conditions. The used image will be clear, not blurry or dark.

The comparison metrics taken into consideration were related to the information necessary for recycling estimation. The metrics include the following points added in the table:

Table 1. Comparison criteria

Metric	Description
Material identification	Does the AI recognize the item in the image?
CO_2 Estimation	Does the AI give a CO_2 value within the correct range 33.1 g for PET reuse?
Citation and Reference Data	Does it explain how the calculation was made? Did the response mention data sources?
Raising awareness	Does the AI response go beyond simply answering the question and contribute to educating or motivating the user?

Furthermore, to ensure the comparability of all AI tools, prompts were structured to be consistent across all platforms. Each AI model was asked using clear, neutral words. Each AI was also given the exact image of the plastic bottle and was asked clear questions. The following prompts were given:

What material is this item made of? What is its size, and how much CO_2 can be saved by recycling it properly? If possible, include a source or explain how you calculated the CO_2 value. Please keep your explanation simple for general understanding.

Each of the questions above was added to represent a specific comparison criterion. The following table connects the metrics with the prompt question

Table 2. Comparison criteria

Metric	Description
Material identification	What material is this item made of
CO_2 Estimation	How much CO_2 can be saved by recycling it properly?
Citation and Reference Data	If possible, include a source and explain how you calculated the CO_2 value
Clarity for Non-Experts	Please keep your explanation simple for general understanding.

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The selected AI platforms were ChatGPT 4o, Gemini 2.5 Flash, Llama 4 Maverick, Perplexity Pro Search, and Claude Sonnet 4. These platforms are widely used, easily accessible, and well-known to general users. They are either available for free or at a low cost, making them practical for everyday use. They also represent language models from various major companies, including OpenAI, Google, and Meta, showcasing different AI training methods.

The following images represent the test items: a 500 mL PET bottle. In one state, the bottle is in its original form—tall and empty. In the second image, the bottle is crumpled and deformed to see how the AI tools would respond to both the original and crumpled conditions of the 500 mL PET bottle.

Figure 1. The image used for AI tools

The analysis of the above image on AI platforms reveals that AI tools possess strong capabilities in image analysis. Starting with ChatGPT 4o, it showed a clear and detailed response. It was able to identify the material and the size correctly; however, it gave a higher CO_2 value compared to the benchmark. But it did note that the value might vary depending on several factors. It provided references with a mathematical equation that explained how the number was calculated. The answer was clear and direct.

Gemini 2.5 Flash was able to identify the material successfully and gave a CO_2 estimate that was close to the benchmark. It provided detailed references and informed the user that reusing the bottle is better than recycling.
Llama 4 Maverick was also able to determine the material and size correctly. It referred to a standard reference, used an equation for the calculation, and gave a number that was closer to the benchmark.
Perplexity Pro Search correctly identified the material and size. It gave a CO_2 value that was slightly lower than the benchmark. Although it cited a reference, it was only a website link. However, the explanation it provided was simple and straightforward.
Claude Sonnet 4 correctly identified the material and size and gave a CO_2 estimate that was close to the benchmark. Furthermore, it explained the different ways to handle the bottle and provided a key takeaway for the user.

Table 3. 500 ml water bottle AI tools analysis result.

Metric	ChatGPT 4o	Gemini 2.5 Flash	Llama 4 Maverick	Perplexity Pro Search	Claude Sonnet 4
Material Identification	PET, 500ml	PET, 500–1000ml (estimated)	PET, 500ml	PET, 500ml	PET, 500ml
CO_2 Estimation	120g	15g	42.57g	15g	25–65g
Citation and Reference Data	EPA WARM, CES EduPack	ALPLA, denkstatt, POLYPVC, Swedish Deposit System	EPA	TimeForChange.org, 1.5kg/kg PET	ALPLA, Sciencing, Stanford, ACS, Packaging Europe
Clarity for Non-Experts	Clear and simple	Clear with real-world examples	Math-based, clear	Very simple	Clear with analogies
Raising Awareness	No reuse mention	Explains reuse vs. recycle	No awareness scenario	No awareness context	Explains the cumulative impact

Figure 2. The crumpled bottle image used for AI tools

The second image was the same plastic bottle, crumpled. The result further confirms that AI platforms have strong recognition capabilities in material identification.

ChatGPT 4o was able to recognize the material as PET and estimated the CO_2 of the crumpled image better than the first image. It included the mathematical steps and reference behind the estimation and explained the importance of recycling plastic bottles to raise awareness.
Gemini 2.5 Flash, even though it was able to recognize the material, was a bit hesitant about its size, estimating between 500 and 1000 ml. It gave a higher estimation than the benchmark. The answer included some real-world examples about how recycling reduces energy consumption. It kept the awareness message strong and engaging.
Llama 4 Maverick was also able to identify the bottle's material and size. It offered a close, calculated CO_2 saving. The result was mathematical, precise, and referenced. However, it lacked any awareness message.
Perplexity Pro Search provided a brief and accurate breakdown. The estimation was less than the benchmark regarding the CO_2 savings. But it was able to identify the material and the size. The references were added, though again they were limited. The result was direct and straightforward, but it did not give any awareness of the environment.

Claude Sonnet 4 gave a comprehensive response. It was able to identify the material, estimate the CO_2 saving, and gave a very close number to the benchmark. Additionally, it provided resources and references, and offered a real-world example to raise awareness.

Table 4. Crumpled 500 ml water bottle AI tools analysis result.

Metric	ChatGPT 4o	Gemini 2.5 Flash	Llama 4 Maverick	Perplexity Pro Search	Claude Sonnet 4
Material Identification	PET, 500ml	PET, 500–1000ml (estimated)	PET, 500ml–1L	PET, 500ml	PET, 500ml
CO_2 Estimation	33.1g	150g	47.5g	15g	25–65g
Citation and Reference Data	EPA WARM, EU database, CES EduPack	LCA statistics from recycling organizations like the EPA	EPA	TimeForChange.org	ALPLA Group, Stanford, TappWater, ACS, NIH, Packaging Europe
Clarity for Non-Experts	Clear with strong analogy	Simple but vague	Clear, technical	Brief and easy	Clear, with analogies
Raising Awareness	Yes, included examples	Yes, added real-world explanation	No awareness message	No awareness included	Yes, plant & scale comparison

In short, both the crumpled and clean images were correctly identified by all AI platforms in terms of materials and estimated size. The AI tools did not differentiate the number between recycle and reuse, however some platforms did state that reuse is better than recycling. And their results differed in terms of CO_2 emissions estimates, references used, and potential for raising awareness.

Claude Sonnet 4 offered the most balanced result. It was on point and delivered realistic CO_2 emissions, cited the resources, and translated the data into insight, making it suitable for public education.
Llama 4 Maverick also gave a close performance with accurate values and reliable resources. However, it was more direct and had no interaction in terms of awareness or giving any education back to the user.
Gemini 2.5 Flash and ChatGPT 4o, on the other hand, yielded different results in terms of CO_2 estimation, despite correctly identifying the material and size in both the crumpled and normal bottle images. However, this could be according to the made calculations as well, and the used waste factor databases.
Perplexity Pro Search did very well in terms of analyzing the images; however, in terms of resources, it just focused on web-based references.

3. CONCLUSION

According to the study comparing the AI tools and models, the following results can be observed:

- Claude Sonnet 4 had the most inclusive response: source-rich, awareness-driven, and accurate.
- Llama 4 Maverick excelled in calculation accuracy but did not give any awareness or user interaction.
- ChatGPT 4o and Gemini 2.5 Flash did well in terms of structure, well-referenced analysis on the crumpled image, and awareness.
- Perplexity Pro Search was based on a website search without proper sourcing.

Beyond the tools and looking at the theoretical observations, the following points can be derived as the primary key points:

-This analysis highlights that current AI platforms are more helpful in raising initial awareness than for providing entirely accurate or reliable environmental metrics.

-It is clear that even if the AI were able to recognize the material and size, it does not necessarily mean it will give an accurate result.

-Citing the resources does not mean that the AI ensures the credibility of the answer.

-In terms of CO_2 estimation AI tools do not depend on any region specific recycling systems.

The above findings demonstrate that AI tools show strong capabilities in material identification, consistently accurately recognizing PET plastic. Moreover, AI tools were able to estimate the size and identify the bottle in both normal and crumbled states. This highlights the potential of AI tools, particularly in sustainability education and policy. The outputs can support policymakers, researchers, and educators in raising awareness and promoting community behavior change. However, while their accessibility makes them valuable for informal learning, their environmental claims must be presented with more precise explanations and confidence levels to avoid misleading users. To achieve better results, it would be beneficial if some of these tools invested in creating AI versions that base their results on recycling activities, thereby avoiding the risk of misinformation and utilizing AI capabilities for sustainability. Future research could focus on developing AI models linked to resources and may also explore localized waste management systems, if they exist. It could also explore how AI can be combined with people researchers, curriculum, or mobile tracking apps to engage people in understanding their individual and collective environmental impact.

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