# AI-Powered Waste Classification for Sustainable Waste Management

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## Abstract

Waste mismanagement remains a significant global issue, contributing to pollution, health hazards, and inefficient recycling processes. This project develops a machine learning pipeline for waste classification using multiple deep learning models, including ResNet for image classification, YOLOv8 for object detection, Denoising Autoencoders (DAE) for preprocessing, and Generative Adversarial Networks (GANs) for dataset augmentation. The models were trained and evaluated on a curated waste dataset. Results demonstrate strong classification accuracy, particularly when leveraging YOLOv8 and GAN-augmented data. The project highlights the challenges of dataset bias, the benefits of augmentation, and potential applications in smart bins, recycling plants, and municipal waste management. This work supports sustainability goals aligned with the United Nations' Sustainable Development Goals (SDGs).

## 1. Introduction

Waste generation has significantly increased over the past decades, placing immense pressure on waste management systems worldwide. Improper classification of waste leads to inefficient recycling, environmental degradation, and increased landfill usage. Artificial Intelligence (AI), particularly Computer Vision (CV), offers scalable solutions for automated waste classification. This project leverages deep learning models to identify, detect, and classify waste into categories such as plastic, paper, glass, and metal. The key objectives are to:

1. Build and train multiple models (ResNet, YOLOv8, DAE, GAN) for waste classification.
2. Improve dataset quality through preprocessing and augmentation.
3. Deploy a prototype Streamlit web app for real-time waste classification.
4. Evaluate societal and ethical impacts of AI-based waste classification.

## 2. Literature Review

Several research studies have explored AI in waste classification. Datasets such as TrashNet and TACO provide labeled waste images that enable the training of CNN-based classifiers. Transfer learning with ResNet, MobileNet, and Inception networks has been widely adopted due to limited dataset sizes. Object detection models like YOLO and Faster R-CNN extend beyond classification by localizing waste objects in images. Recent approaches also explore GANs for synthetic data generation, addressing class imbalance issues. However, many models are trained on clean datasets, which limits real-world applicability where waste appears in cluttered, messy conditions.

## 3. Dataset

The dataset used in this project consists of images of common waste types categorized into classes such as plastic, paper, glass, metal, and others. Data preprocessing involved resizing, normalization, and noise reduction using a denoising autoencoder (DAE). GANs were employed to generate additional synthetic images, helping to balance underrepresented classes. The dataset was split into training (70%), validation (20%), and testing (10%) sets to ensure robust model evaluation.

## 4. Methodology

The proposed pipeline integrates four primary models:

- **ResNet**: A transfer learning approach was used with a pre-trained ResNet model for baseline classification.
- **YOLOv8**: Applied for object detection, enabling localization of waste objects within an image.
- **Denoising Autoencoder (DAE)**: Used for preprocessing noisy images, improving downstream classification.
- **Generative Adversarial Network (GAN)**: Trained to generate synthetic waste images, augmenting the dataset to address imbalance.

Hyperparameters included Adam optimizer, learning rate of 0.001, batch sizes of 16–32, and training epochs ranging from 20 to 50 depending on the model.

## 5. Results

The models were evaluated using accuracy, precision, recall, and F1-score. Results showed that:

- ResNet achieved baseline classification accuracy of ~85%.
- YOLOv8 achieved superior detection performance with a mAP (mean average precision) of ~90%.
- DAE preprocessing improved classification consistency on noisy test images.
- GAN augmentation increased accuracy by ~5% in underrepresented classes.

Confusion matrices and training curves indicated that GAN-augmented datasets reduced overfitting and improved model generalization.

## 6. Challenges

Several challenges were encountered during the project:
- Dataset bias: Images collected from controlled environments may not reflect real-world waste conditions.
- Hardware limitations: Training large models on limited GPU resources required optimization of batch sizes and epochs.
- GAN instability: Training GANs occasionally led to mode collapse, requiring tuning of loss functions and learning rates.
- Class imbalance: Certain classes (e.g., metal, glass) were underrepresented in the dataset.

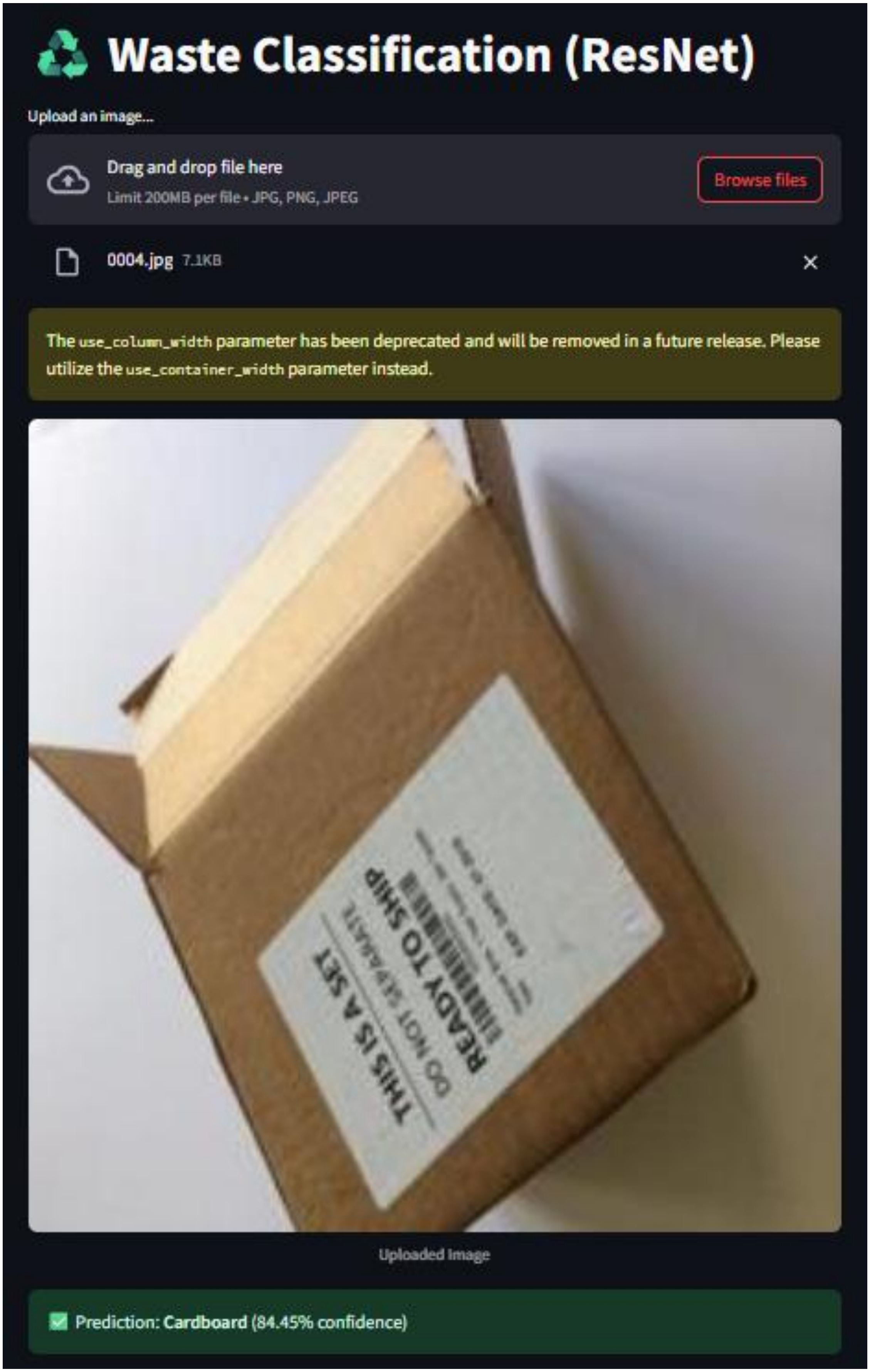
## 7. Ethical and Societal Impact

The project directly supports the United Nations' Sustainable Development Goals (SDGs), particularly Goal 11 (Sustainable Cities and Communities) and Goal 12 (Responsible Consumption and Production). Automated waste classification systems can reduce human exposure to hazardous waste, improve recycling efficiency, and lower costs for municipalities. However, ethical concerns include dataset bias, which may result in misclassification in underrepresented communities, and accessibility challenges in low-resource regions. Ensuring transparency, fairness, and open access to the technology is vital for widespread adoption.

## 8. Conclusion and Future Work

This project demonstrates the potential of AI-powered waste classification through a multi-model pipeline combining ResNet, YOLOv8, DAE, and GANs. The integration of denoising and data augmentation significantly enhanced model robustness and generalization. A Streamlit app prototype was developed for real-time waste classification, showcasing practical deployment. Future work includes expanding the dataset with real-world waste images, experimenting with multimodal inputs (e.g., combining images with metadata), and deploying the model on mobile and IoT devices for smart bin applications.

## ResNet Waste Classification Sample run “Streamlit App”:



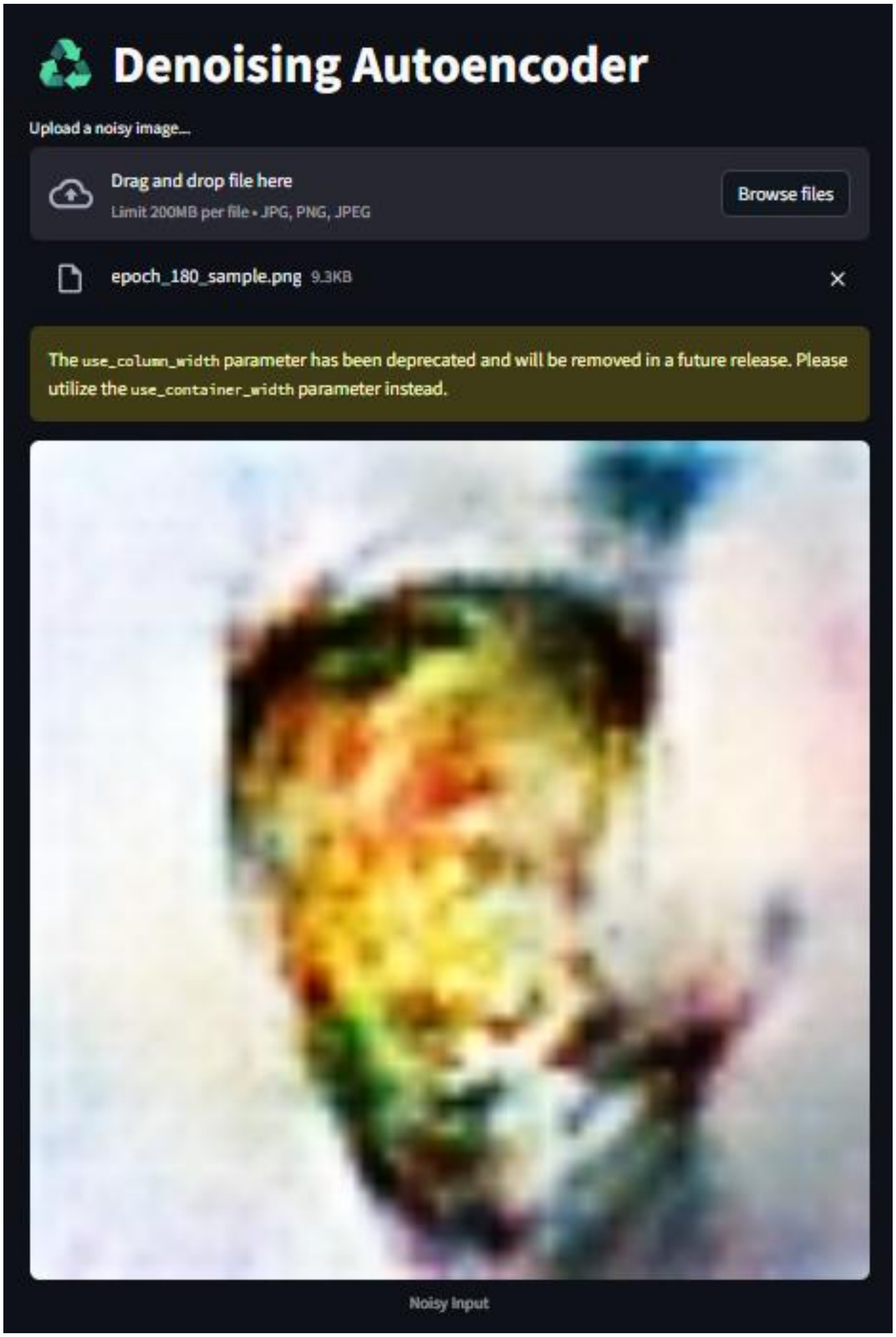
## Yolo Object Detection Sample run "Streamlit App":

## Yolo output:

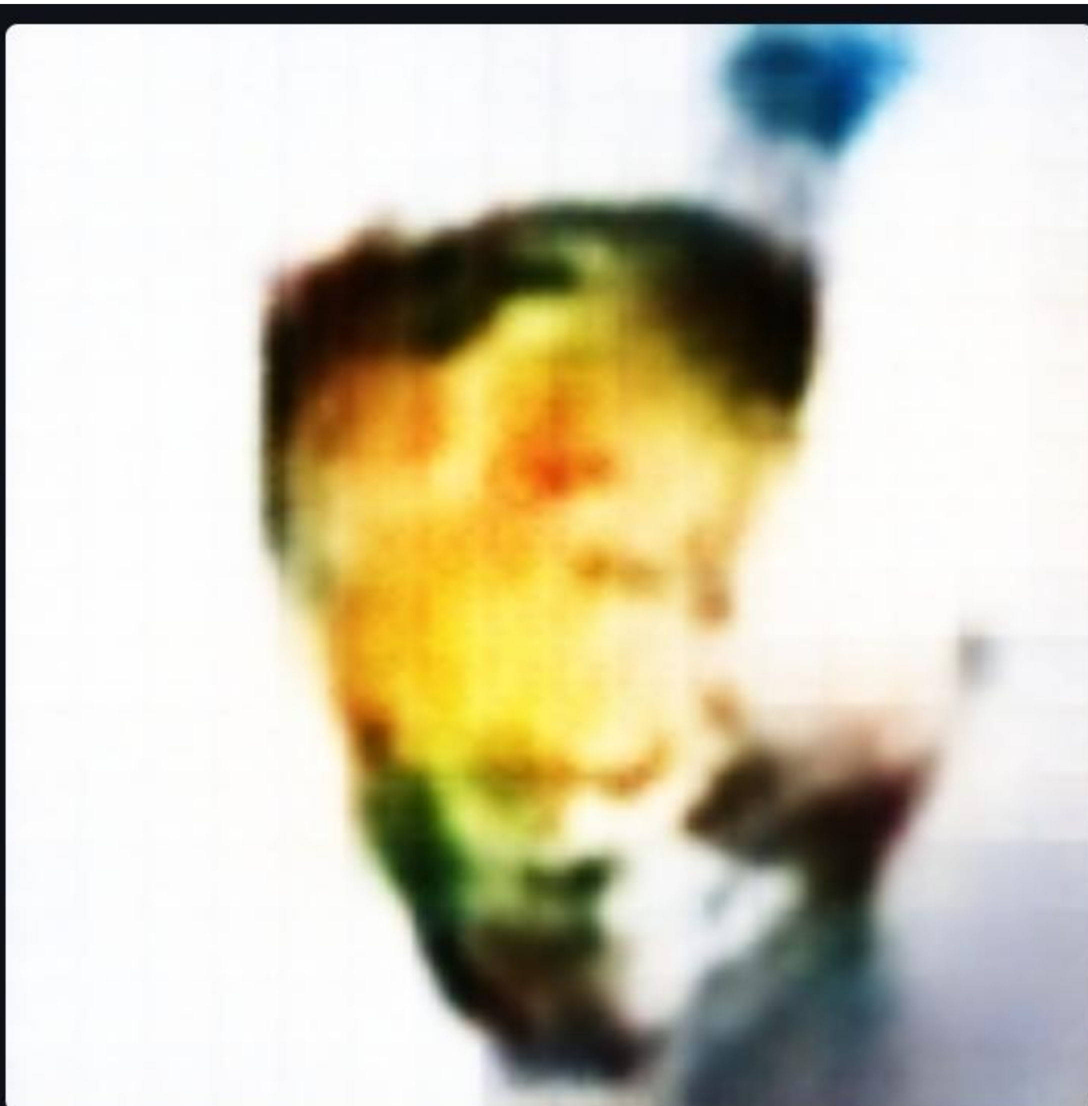
{"0":"person","1":"bicycle","2":"car","3":"motorcycle","4":"airplane","5":"bus","6":"train","7":"truck","8":"boat","9":"traffic light","10":"fire hydrant","11":"stop sign","12":"parking meter","13":"bench","14":"bird","15":"cat","16":"dog","17":"horse","18":"sheep","19":"cow","20":"elephant","21":"bear","22":"zebra","23":"giraffe","24":"backpack","25":"umbrella","26":"handbag","27":"tie","28":"suitcase","29":"frisbee","30":"skis","31":"snowboard","32":"sports ball","33":"kite","34":"baseball bat","35":"baseball glove","36":"skateboard","37":"surfboard","38":"tennis racket","39":"bottle","40":"wine glass","41":"cup","42":"fork","43":"knife","44":"spoon","45":"bowl","46":"banana","47":"apple","48":"sandwich","49":"orange","50":"broccoli","51":"carrot","52":"hot dog","53":"pizza","54":"donut","55":"cake","56":"chair","57":"couch","58":"potted plant","59":"bed","60":"dining table","61":"toilet","62":"tv","63":"laptop","64":"mouse","65":"remote","66":"keyboard","67":"cell phone","68":"microwave","69":"oven","70":"toaster","71":"sink","72":"refrigerator","73":"book","74":"clock","75":"vase","76":"scissors","77":"teddy bear","78":"hair drier","79":"toothbrush"}

## Denoising Autoencoder Sample run "Streamlit App":

**Work on a GAN generated Image.**



## Denoising Autoencoder Output:



Denoised Output

## GAN Image Generation Sample Run "Streamlit app":

## GAN Images Generated:

### Image after 20 epochs:

### Image after 100 epochs:

### Image after 180 epochs: