Conductive Materials in Anaerobic Digestion: A Promising Strategy for Emerging Pollutant Removal

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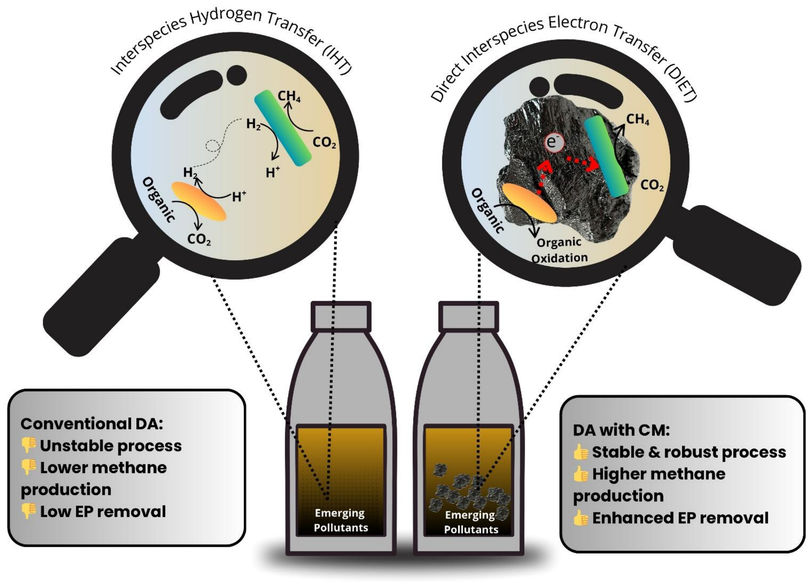
INTRODUCTION

The presence of emerging pollutants (EPs) challenges conventional wastewater treatment systems. Although anaerobic digestion (AD) enables energy recovery , its efficiency in removing recalcitrant compounds remains limited. Supplementation with conductive materials (CMs) serves as a targeted strategy to enhance microbial activity and accelerate pollutant degradation.

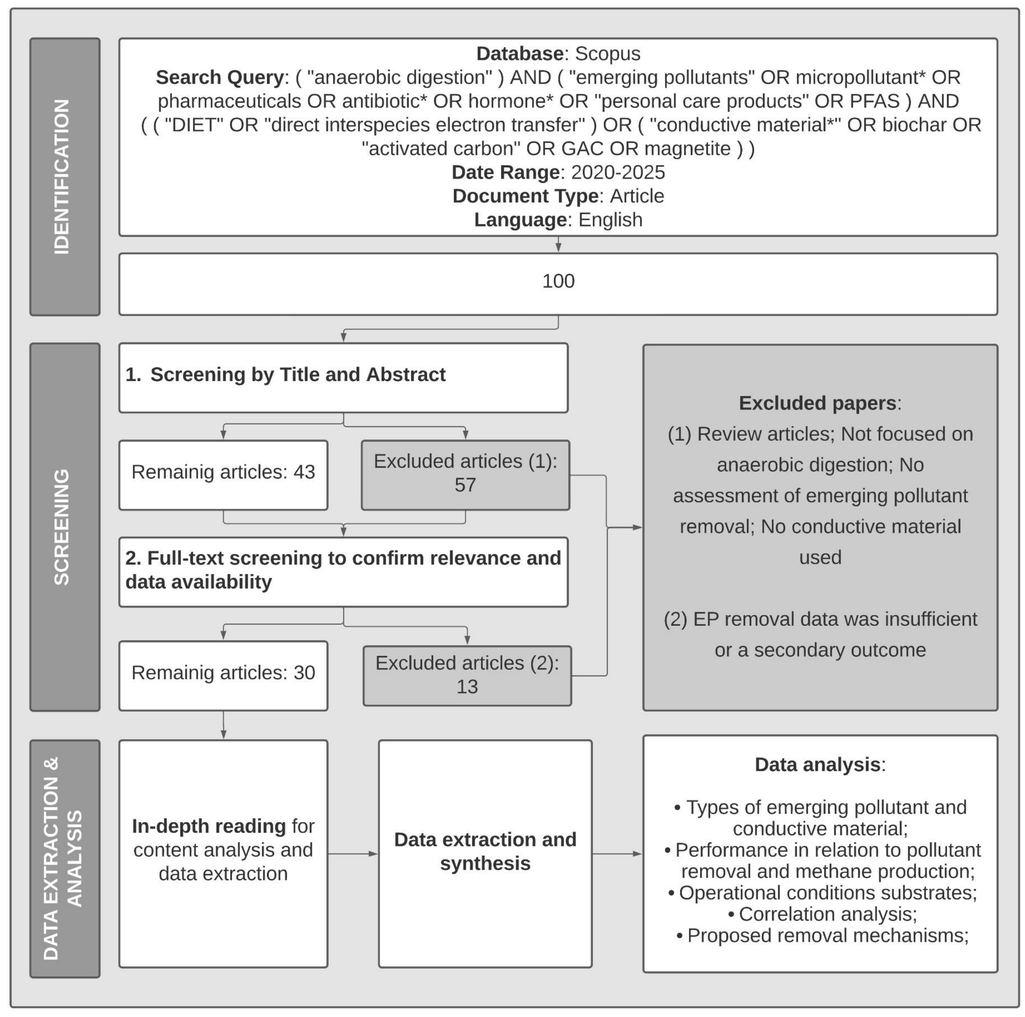


OBJECTIVE

This study aims to systematically review the literature on the removal of Emerging Pollutants in Anaerobic Digestion enhanced by conductive materials, in order to identify key mechanisms, performance, knowledge gaps, and future research directions.

METHODOLOGY

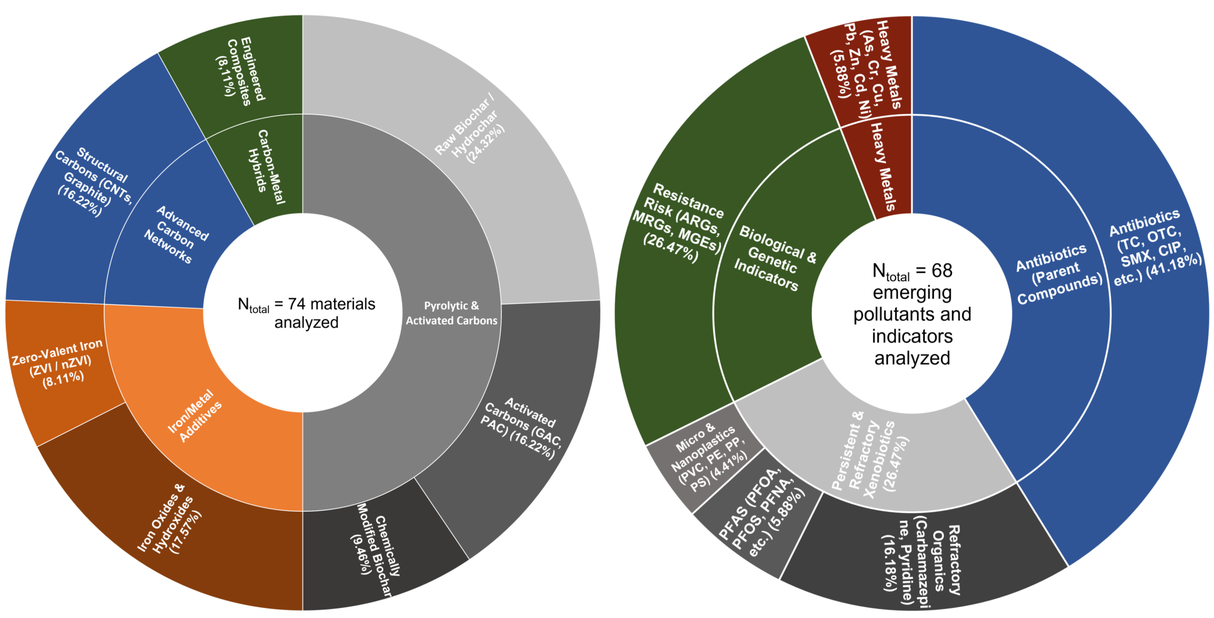
The systematic literature review was conducted following the PRISMA guidelines:



RESULTS AND DISCUSSION

Bibliometric Trends

- Carbonaceous media (Biochar/AC) dominate (50.00%); iron additives comprise 25.68%.
- Antibiotics are the main focus (41.18%); ARGs/MGEs represent 26.47%.

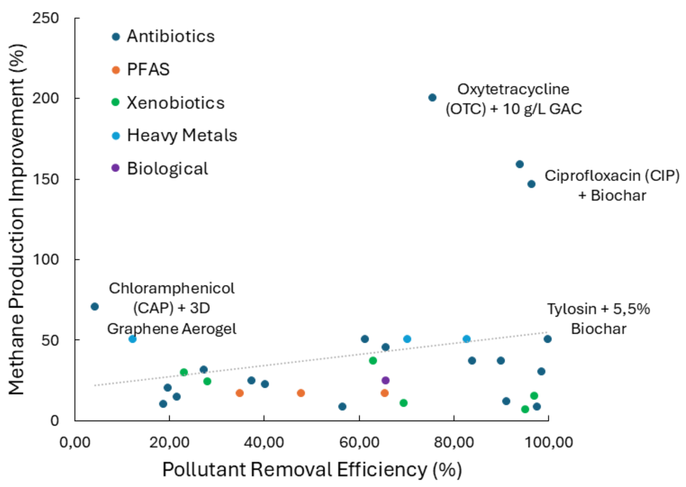


Efficiency & Methane production

Antibiotics/Xenobiotics reach ~100% removal. PFAS show a tight, sorption-governed range (35%–79%).

CMs decouple toxicity from kinetics via two phases:

- *Phase 1* (0–3 d): Adsorptive shielding protects biomass from acute shock.
- *Phase 2* (Long-term): DIET catalysis accelerates VFA conversion to CH_4.



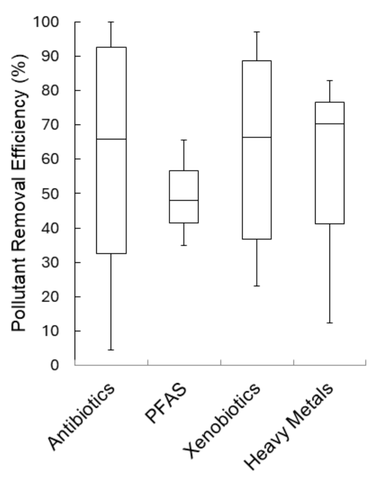


Table 1. Performance Highlights

Target Pollutant	Conductive Material	Removal (%)	Methane Gain	Ref
Cefazolin	15 g/L Bamboo Biochar	**~100%**	Offset -28% inhibition	You et al., 2025
Oxytetracycline	10 g/L Graphite Felt	**98.6%**	+30.0% (1.3-fold)	Burboa-Charis; Alvarez, 2020
	10 g/L GAC	**75.7%**	+200.0% (3.0-fold)	
Paracetamol	Pomegranate Biochar	**96.0%**	225.5 mL/gCOD	Alhajeri; Tawfik, 2024
Pyridine	15 g/L GAC	**97.0%**	+15.4%	Yang et al., 2024
Arsenic	Paper Mill Biochar	**82.8%**	+50.0% (1.5-fold)	Jiang et al., 2022

Biochemical Pathways

•**Antibiotics (CIP, TC, CAP):** Ring cleavage & nitro-reduction. CMs accelerate toxic intermediate biotransformation into CO_2 and CH_4.

•**Analgesics (Paracetamol, Salicylate):** Multi-ring enzymatic opening. Fast breakdown into acetate and simple metabolites.

•**Persistent Compounds (PFAS, Acrylamide):** Amidase-catalyzed ammonification (acrylamide) and CM-facilitated reductive defluorination (C-F cleavage for PFAS).

CONCLUSIONS & FUTURE PERSPECTIVES

Successfully decouples toxic inhibition from kinetics, achieving up to 100% pollutant removal and +200% CH_4 yield.

Combined protection via initial adsorptive shielding and long-term DIET catalysis.

Unlike fragile antibiotics, highly persistent PFAS are bounded by sorption constraints (35%–79%), requiring specialized engineered matrices.

Research must shift from synthetic batch assays to continuous-flow configurations treating real wastewater.

ACKNOWLEDGMENTS

The authors thank Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001 (PDSE Fellowship 88881.218646/2025-01) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) (Process 311403/2022-0) for their support.

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