

## **Integrating Social Value into Circular Waste-to-Energy Strategies for Humanitarian Settings: A Life Cycle Sustainability Approach**

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Humanitarian operations often face critical constraints in infrastructure, technical capacity, and resource availability, which results in unmanaged waste streams and poses risks to both the environment and local communities. In such contexts, waste management decisions have strong social implications, influencing community health, safety, livelihood opportunities, and levels of participation in crisis response. Within the Bio4HUMAN project, an integrated framework is applied to assess circular waste-to-energy strategies capable of delivering environmental benefits alongside socio-economic value in two humanitarian settings: South Sudan and the Democratic Republic of the Congo. In this study, a combined environmental and social Life Cycle Assessment (LCA–SLCA) is used to compare the environmental and socio-economic benefits in the two sites, evaluating environmental improvements as well as employment generation, community empowerment, and enhancements in social well-being.

Anaerobic digestion (AD) represents a robust solution for organic waste valorisation, producing locally available energy while supporting safer and cleaner living conditions [1, 2]. Four AD configurations were examined: (i) a modular micro-AD unit designed for lignocellulosic residues; (ii) a single-stage thermophilic digester suitable for mixed biowastes; (iii) a mesophilic micro-biogas system for varied organic fractions; and (iv) a domestic digester for food or animal waste operating under mesophilic or thermophilic conditions.

Findings indicate that domestic-scale digesters offer the most practical and socially beneficial option for decentralised humanitarian contexts, beyond achieving notable environmental improvements up to 90% reduction in key impact categories. The technology requires minimal technical training, enabling rapid adoption by local users. The system also supports the production of a digestate that can enhance soil fertility, contributing to food security initiatives. Socially, domestic AD fosters local capacity building, reduces exposure to open dumping and burning, and creates opportunities for

income generation by energy production and digestate utilisation. These aspects are particularly relevant in humanitarian scenarios, where strengthening agency, dignity, and community cohesion is as critical as reducing environmental burdens.

Overall, the study underscores the need to integrate social dimensions into sustainability assessments of waste management solutions. The proposed combined LCA-LCC-social approach provides a holistic perspective that supports the selection of circular Waste-to-Energy options enhancing social resilience and contribute to more equitable humanitarian interventions.

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### **References**

- [1] Mengistu M. G., Simane B., Eshete G., Workneh T. S., (2016). "The environmental benefits of domestic biogas technology in rural Ethiopia ". *Biomass and Energy*, 90, 131-138. Dio: 10.1016/j.biombioe.2016.04.002
- [2] Nzila C., Dewulf J., Spanjers H., Tuigong D., Kiriamiti H., Langenhove H. V. (2012). "Multi criteria sustainability assessment of biogas production in Kenya ". *Applied Energy*, 93, 496-506. doi: 10.1016/j.apenergy.2011.12.020