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POLICY BRIEF: ENERGY RECOVERY FROM WASTE

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The recover of energy from waste can aid cities on their journey to net-zero emissions, helping tackle the dual challenges of climate change mitigation and the disposal of growing urban waste. Improved energy recovery across other domains can also help raise the overall efficiency of an energy system. However, such solutions must be implemented in a socially-responsible and environmentally-conscious manner for long-term sustainability. Cocody, Côte d'Ivoire, provides an example of successful community engagement in the management of waste.

INTRODUCTION

As urban areas grow, so does the amount of waste they produce, posing serious environmental, economic, and social challenges [1]. Cities are at the frontlines in tackling this challenge, while simultaneously contending with the threat posed by climate change. The two challenges are closely connected as poorly-managed waste not only affects local communities through local pollution and associated health risks, but also contributes to increased greenhouse gas (GHG) emissions, for example through methane released by landfills [2, 3]. Effective waste management strategies can help mitigate these impacts but more importantly, waste itself can become a resource.

Energy can be recovered from both 'waste' heat (from heat-generating processes) and from the transformation of physical waste. Both processes can help improve system efficiency and even avoid the use of fossil fuels while reducing the need for additional resource extraction. However, not all waste streams or waste-to-energy (WtE) processes are climate-neutral, requiring context-specific planning and careful implementation.

This policy brief will showcase a range of WtE solutions that are available to local and regional governments (LRGs) and compatible with their broader climate strategies. It will provide recommendations aimed at national and local stakeholders to help overcome implementation challenges. To ground these strategies in a practical context, the brief will feature a case study from Cocody, Côte d'Ivoire, that has integrated community involvement into its waste management strategy.

LOCAL GOVERNMENTS AND WASTE-TO-ENERGY SOLUTIONS

The role of local and regional governments is crucial in deploying WtE solutions as they typically oversee physical waste management in their territories, and may oversee other operations that allow for waste heat recovery (such as water treatment).

Not only can they influence operations through urban planning and waste collection and sorting, but they are a direct point of contact for their communities. They can directly liase with them, allowing for the tailoring of waste management solutions to their specific needs. They can also encourage better waste management practices (such as sorting or recycling) through public education campaigns and in partnership with civil society and private sector stakeholders [4]. LRGs are responsible for enforcing regulations related to waste disposal, and can even undertake larger infrastructure projects such as district energy networks.

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WHAT IS WASTE-TO-ENERGY?

Broadly, waste-to-energy is the use of waste to generate energy in the form of heat, fuels, or electricity [5]. This broad concept covers a number of different processes. While direct combustion allows for immediate energy generation, processes such as anaerobic digestion, pyrolysis, and gasification result in solid, liquid, and gaseous fuels of varying calorific values that can be used in industrial, household, or transport uses, or be further transformed or used to generate electricity or heat in power plants. Each process differs in terms of implementation costs and environmental and social impacts, and therefore must be carefully deployed according to the local context.

CLIMATE-COMPATIBLE WASTE-TO-ENERGY SOLUTIONS

Effective waste-to-energy projects require a blend of regulatory frameworks, community participation, viable technologies, and strong financial backing [6]. Waste-to-energy processes that are in alignment with climate goals typically involve biogenic i.e. organic feedstock. Other feedstocks, such as plastics, are derived from fossil fuels and so their use i.e. combustion only contributes to an increase in emissions. These inputs consume CO_2 as they grow and so when they are used to derive energy, there is ideally a net zero increase in atmospheric GHGs. Still, this is open to debate and highly context-specific depending on the type of feedstock, energy used in transport and processing, etc.

Ultimately, these produced fuels must be combusted to generate energy, releasing GHGs and other emissions into the atmosphere and surroundings, which must be sufficiently mitigated. In addition, while carbon capture technologies can be deployed in WtE plants, their use is not yet widespread. As WtE plants are often smaller than fossil fuel plants, such technologies cannot often achieve economies of scale, threatening the financial viability of already challenging projects [7][8].

However, in all cases, before WtE is adopted as a solution, it is crucial that the 'waste hierarchy' is respected to ensure long-term sustainability. Most WtE approaches can be seen as transitional technologies, rather than long-term solutions, due to the shift towards circular modes of production.

THE WASTE HIERARCHY

The waste hierarchy is meant to prioritize waste management processes, including conversion to energy, in a way that ensures sustainability. Waste must first be reduced in terms of its quantity and externalities. It must then be reused, if possible. If not, it can be further processed and materials recycled. Beyond this, other recovery means can be employed, including energy recovery. Finally, the waste must be disposed of. The need to respect this hierarchy can create further challenges for WtE projects as principles of circularity become more mainstream in an economy [9]..

Waste-to-energy technologies

Below are some examples of WtE processes that can allow for energy recovery from different kinds of waste while limiting their climate change impacts:

- **Landfill gas recovery:** This allows for the capture and utilization of 'landfill gas'—primarily made up of methane—which is released as organic matter decomposes in landfills. Like other gaseous fuels, it can be used in heat or electricity generation. Its primary purpose as a climate change mitigation tool is that it helps avoid the continued generation of methane in landfills, which is a potent GHG [10]. If this gas is upgraded into biomethane, it can be used to directly substitute natural gas with a lower carbon footprint.

- **Anaerobic digestion:** Organic matter is transformed into biogas and other solid and liquid byproducts in the absence of oxygen. This typically takes place in biodigesters, which can be deployed at various scales (such as for households as well as large agricultural operations). The byproducts can be used as fertilizers, while biogas can be used to generate heat or electricity, or directly in biogas stoves for households or communities.

- **Transesterification:** Food oils and fats can be transformed through chemical processes into liquid biofuels such as biodiesel and other byproducts. Biodiesel can be used as a fuel in transport.

- **Pyrolysis:** This involves using high heat to break down organic matter, in the absence of oxygen, to produce solid (biochar), liquid (bio-oils), and gaseous products which can be combusted to produce heat and/or electricity.

- **Gasification:** With high heat and limited oxygen levels, complex or mixed feedstock can be turned into combustible gas along with solid and liquid byproducts.

- **Waste heat recovery:** While this is not a conversion process as such, it can still be used to great effect to improve overall energy system efficiency. For example, in power plants that use biomass, waste heat released during electricity generation can be harnessed in combined heat and power (CHP) plants to power district energy systems or industrial processes that require heat or cooling. Lower-temperature heat released by hot water passing through wastewater systems can also be used for similar district heating/ cooling purposes.

CHALLENGES IN WASTE-TO-ENERGY PROJECTS

Waste-to-energy projects can face a complex array of challenges during implementation that must be overcome. These vary according to the size and scope of the project, but there are some common features.

- **Ensuring adequate and appropriate feedstock:** This must be done to ensure that there is sufficient input to render WtE projects viable, both in terms of volume as well as composition. Investment in soft and hard infrastructure is essential to support waste collection and sorting. The feedstock must be segregated either at the source or during processing to ensure the highest energy yields in the fuel that is produced.

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Without such measures, there is a risk of inefficiencies leading to increased environmental pollution, lower yields and therefore lower financial returns.

- **Environmental risks:** While energy recovery from waste can be a viable solution, it must be carefully deployed within the context of an LRG's broader waste management strategy as well as its climate and energy goals. Feedstock management for biogenic waste, if improperly implemented, can result in methane emissions. Similarly, the lifecycle emissions of biogenic waste and their overall impact can be challenging to identify, and detailed studies are needed. Storage and handling of such waste also creates the risk of water contamination and odors, pests, etc. which can affect public health and also create community resistance to such projects.

- **Financial viability:** Waste-to-energy projects, especially larger facilities, can be costly and complex undertakings. However, given the critical role of LRGs in waste management, they can make good partners in configurations such as public-private partnerships (PPPs) [11]. However, in other cases, barriers such as high tipping fees i.e. the fee levied by the facility to cover the cost of handling and processing the waste, can affect their attractiveness as a waste-management option for LRGs.

Moreover, advanced waste management technologies, such as automated sorting, transformation technologies, and digital monitoring tools are often inaccessible due to high costs and technical expertise requirements [12]. The lack of data on waste generation and composition can also make it difficult to plan and implement effective waste management strategies.

- **Lack of community awareness and potential resistance:** In many regions, public participation in waste management is limited due to a low awareness of the environmental impacts of improper waste disposal as well as cultural attitudes. Households often lack knowledge about proper waste segregation, recycling, and composting practices [13]. Cultural factors can also affect the willingness of communities to engage in sustainable waste management practices [14].

Moreover, communities can resist WtE projects near them, especially when dealing with physical waste, due to the odors, pests, and perception of cleanliness. In many developing cities, informal waste pickers play a significant role in waste collection and recycling. However, this sector often operates outside the formal waste management system, lacking access to proper training, protective equipment, and legal protection. The health impacts to the workers themselves can be severe due to being in proximity with waste, hazardous material, pests, etc. [13] Such informal systems, if not engaged with properly, can also make it difficult to ensure adequate feedstock supply.

MAIN INSIGHTS AND RECOMMENDATIONS

Addressing the challenges related to WtE projects requires a multi-dimensional approach that incorporates technical, economic, social, and regulatory strategies. This section offers some recommendations for different stakeholders.

For local and regional governments

- Encourage community participation. Studies have shown that awareness campaigns, educational programs, and incentives play a crucial role in changing public attitudes towards waste, significantly improving recycling rates as well as sorting [15, 16, 2]. Events such as neighborhood clean-ups and workshops also foster a sense of community ownership and accountability. Using local languages, engaging community leaders, and tailoring campaigns to cultural contexts can significantly enhance public participation. Partnering with schools, youth groups, and community-based organizations can also broaden outreach and support sustainable behaviors.

- Integrating informal workers and systems into the can increase recycling rates, ensure feedstock supply, and lead to overall welfare improvements for workers. Some cities have successfully formalized waste pickers' roles by providing them with official recognition and training [13, 2].

- Investing in adaptable waste collection systems is crucial to develop the WtE value chain. Basic yet efficient technologies, such as pedal-powered carts or modified tricycles, have proven effective in navigating narrow streets and densely populated areas [17]. These low-cost solutions are particularly valuable in informal settlements, where conventional waste collection trucks cannot operate effectively. Affordable and context-specific smart waste management technologies, such as GPS tracking for collection routes and IoT sensors for monitoring waste bins, can also help [23].

- Implementing pilot projects allows cities to refine these technologies and integrate them gradually without overwhelming existing systems.

- Collaborations with community-based organizations (CBOs) have proven successful in expanding waste collection coverage in areas underserved by traditional municipal services. These partnerships can lead to increased waste collection and sorting rates, improved environmental awareness, and enhanced community engagement [18, 19, 20]. In some cases, such collaborations have even contributed to poverty reduction by creating employment opportunities within the waste management sector [21].

- There should be adequate investment in monitoring and verification of WtE plants, including the storage of waste, emissions controls, etc.

- Regional cooperation between cities might also allow for the sharing of resources, knowledge, and best practices. This can lead to the development of joint waste management strategies that capitalize on economies of scale and reduce operational costs, particularly for larger projects [22].

For national governments and agencies

- National governments should create clear frameworks that set standards for waste management and classification, emissions, and specify targets for landfill diversion, etc., creating incentives for final disposal

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technologies. These regulations need to be supported by effective enforcement mechanisms to ensure compliance and accountability at the local level.

- Facilitate training programs for local government officials and waste management professionals to build technical abd financial expertise and improve service delivery related to WtE projects.

- Facilitate partnerships between public authorities and private enterprises to boost investment in waste management and WtE projects. This includes developing favorable policies for private sector involvement across the value chain, as well as framework contracts and guidelines for public sector participation in the same.

- Financial support can be provided to de-risk investments, or guarantee returns through feed-in-tariffs and other similar mechanisms.

For the private sector and financial institutions

- Consider entering into PPPs with LRGs to increase project viability, particularly feedstock supply, and adopt context-appropriate technologies.

- Explore diverse revenue streams, including tipping fees, returns from energy sales, and sales of byproducts such as ash.

- Engage with communities early to reduce backlash, particularly those whose livelihoods or welfare is impacted by WtE plants.

GET TO KNOW: COCODY, COTE D'IVOIRE

The coastal commune of Cocody, in Abidjan, Ivory Coast, has undergone rapid urbanization. Its coastal villages, traditionally known for their production of Attiéké (a local cassava-based food), have had to coexist with an increasingly urban landscape.

The transformation of cassava into Attiéké, a cornerstone of the local economy, has also been a source of environmental degradation. Traditional production methods relied heavily on firewood, contributing to deforestation, air pollution, and carbon dioxide emissions. Additionally, waste products from cassava processing were often discarded improperly, polluting nearby lagoons. Sanitation issues, air pollution, and bad odours were common concerns raised by local residents.

To address these issues, the local government, in partnership with village leaders and other stakeholders sought to modernizing this production process. Key components included the construction of a new production facility equipped with machinery manufactured in Ivory Coast. These machines replaced manual tasks by utilizing biogas produced from cassava peels and waste effluents through biodigesters, reducing the reliance on firewood.

The new production unit not only improved environmental outcomes but also fostered economic empowerment. Women and young girls, who traditionally did most of the labour, were provided with legal recognition and access to financial resources. These groups received training in the use of new ecological equipment, increasing

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their technical skills and enabling them to produce Attiéké more efficiently. Biodigesters allowed the waste to be transformed into biogas, which could be used for cooking, significantly reducing dependence on butane and firewood.

The project has resulted in a healthier living environment, with reduced indoor air pollution and cleaner public spaces. The modernized process has increased the profitability of Attiéké production, transforming it into a viable livelihood. The project also demonstrated the potential for replication, with plans to scale up to other villages in Cocody and even nationally.

Despite the project's successes, challenges remain. Administrative delays, particularly in securing funding from the town hall, have posed obstacles. Additionally, there is ongoing uncertainty about whether the biodigesters will maintain sufficient efficiency to consistently meet cooking needs. These challenges highlight the importance of continuous technical support, flexible scheduling for community engagement, and the need for robust monitoring of new technologies. Still, Cocody's example underscores the importance of local leadership and community engagement in co-creating sustainable solutions.

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