Implementation of a medium chain fatty acid extraction biotechnology in the Global South: A case study of Morocco

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Abstract

The implementation of technologies in the context of waste management can be a good opportunity to improve waste management systems (WMSs) in the Global South. Experiences in the past show that the implementation of technical measures always needs a comprehensive analysis of the actual waste management system (van de Klundert, Anschütz, 2001). Moreover, to ensure a successful implementation not only physical components as existing infrastructures should be investigated (Wilson, Cowing, 2013), but also soft components as Governance, institutional capacities (Independent Evaluation Group, 2017), social (Ma, Hipel, 2016), financial aspects and market conditions, which can be good drivers as well as inhibitors of development (Godfrey et al., 2019, Wilson, 2007). The scope of this paper is to analyze if the existing circumstances in Marrakech (Morocco) are given to implement a specific biotechnology. The biotechnology under study is an approach to extract medium chain fatty acids (MCFAs) out of leachate. These MCFAs can be refined into high-quality biobased products as lubricants, solvents, biofuels (Kannengiesser et al., 2018, Saadoun et al., 2021) or biopolyester. Technical and non-technical implementation criteria are identified and analyzed in cooperation with relevant stakeholders. As result the implementation potential for the biotechnology under study is described as well as recommendations for action are derived to increase the chances for a successful implementation.

Keywords

biotechnology, waste management systems, assessment, Global South, bioeconomy, medium chain fatty acids

1. Introduction

The world is facing a lot of different environmental challenges as for example the climate crisis or the over exploitation of natural resources. (IPCC, 2018) These global challenges affect all countries in our world, but its consequences and the way they are dealt with can vary significantly from country to country. Waste management can play a very important role in combating these challenges. A well-functioning waste management system (WMS) that focuses an orderly waste disposal can contribute to the reduction of greenhouse gases and other emissions into the soil and groundwater. (Kaza et al., 2018) By implementing a circular economy that focuses on recirculating waste and resources back into the economic cycle, the depletion of natural resources (especially fossil resources) can be reduced further.

Circular bioeconomy, which is a part of the circular economy, wants a transformation towards a low-emission society and economy that primarily focuses on the increased (re)use of biobased materials. (Stegmann et al., 2020) A legitimate critique of this concept is that the increased demand for biobased products may compete with food production. Due to this, the use of e.g. organic waste or leachate is a good alternative for the production of biobased products, as they are not a competitive factor to food security. That is why waste biorefineries are also seen as a possible solution to realize a sustainable circular bioeconomy with a big potential to overcome the global issues concerning climate and resource depletion. (Leong et al., 2021) One biotechnology that can precisely contribute to this is a technology to extract medium chain fatty acids (MCFA) out of waste leachate or other carbon loaded waste liquids (e.g. leachate from waste collection trucks, percolates from organic waste treatment, etc.). (Saadoun et al., 2021) The use of leachates from waste as feedstock to produce high value biobased products for industry and to allow a recirculation of carbons in the economic value chain

through upcycling is a solution that is still being researched (Kannengiesser et al., 2018), but may be implemented on a larger scale in the near future (Reddy et al., 2020).

In a research project called "Trans4Biotec: Know-how transfer in waste management for developing new biotechnology applications in developing countries", which is sponsored by the German Federal Ministry of Education and Research (BMBF) in cooperation with the German Academic Exchange Service (DAAD), the Technical University of Darmstadt, in cooperation with business partners (Jager Biotech and EAD) and three African universities from Morocco (University Cady Ayyad – Marrakech and University Abdelmalek Essadi – Tétouan) and the Ivory Coast (University Nangui Abrogoua - Abidjan), is elaborating concepts to implement such a biotechnology in the participating countries.

Studies and experiences show that the transfer of technologies especially concerning waste management from the Global North to the Global South often were not successful (Filho et al., 2016), due to various reasons as technological constraints, lack of qualified personnel or technical infrastructure, a missing legal basis or political will (Pfaff-Simoneit, 2012, van de Klundert, Anschütz, 2001, Wilson, 2007).

In order to increase the successful implementation of waste technologies and in this case a biotechnology in countries of the Global South, the needed preconditions of the biotechnology will be identified. In a first analysis of Campitelli et al. (2018) the legal basis, the waste management focusing on waste collection, waste composition as well as waste and leachate treatment in Marrakech and Abidjan has been analyzed. These results show that according to the waste management system it is generally possible to implement the biotechnology in these cities. But the authors also stated that further analyzes need to be done. (Campitelli et al., 2018)

For this study required technical and non-technical implementation criteria for the biotechnology are analyzed for possible implementation at the landfill of the city of Marrakech. So, the scope of this study is to analyze the existing circumstances, describe the implementation potential for the biotechnology and recommendations for action to promote a successful implementation.

2. Materials and Methods

In this chapter a more detailed description of the biotechnology for MCFA extraction is presented as well as the approach to examine the implementation potential.

2.1 Biotechnology of MCFA extraction

MCFA are an essential feedstock to produce biobased products such as lubricants and biofuels, which traditionally are deriving on petroleum (Reddy et al., 2020). Kannengiesser et al. (2018) developed an innovative biotechnology to produce MCFAs as renewable feedstock out of residual waste and especially organic waste. This biotechnology produces MCFAs through the treatment of liquid wastes (leachate) coming from landfills or also liquids out of waste collection trucks (see Figure 1).

The biotechnology can be subdivided into three fundamental steps (see Figure 1) 1) substrate generation or acquisition, 2) enrichment process and 3) refining stage. During the 2nd step the liquids are first digested and the contained organic matter is thereby reduced into short and medium chain carboxylic acids through a process named chain elongation. This latter starts by adjusting the pH between the range of 5.5 and 6.5 for the microorganism to produce the MCFAs (Agler et al., 2012). The chain elongation process itself starts by adding an electron donor such as ethanol or methanol (Saadoun et al., 2021). The duration of the first maturation lasts for around a week. The duration of the maturation can vary depending on the starting conditions of the leachate e.g. digestions stage and supplement contents for microorganism growth. Later a non-polar extraction solvent such as biodiesel is added simultaneously to separate the MCFAs from the liquid phase during the production, which hinders the saturation of the process (Kannengiesser et al., 2016). The extracted MCFA are then recovered by a liquid refining process in a refining unit and converted by transesterification e.g. with ethanol into biobased products. The liquid phase, after the extraction of MCFAs, can be used as a fertilizer in agriculture after a necessary post treatment.

By treating the leachate with the extractive fermentation and by extracting the MCFA, the organic load in the leachate can be valorized to create products of higher value and reduce the remaining organic load. Nevertheless, the extraction technology must be combined with a subsequent wastewater treatment plant (WWTP).

The enrichment and the refining process can be performed centrally, i.e. together in one plant, or decentralized, whereby the two processes take place in different plants or at different locations. For example, the enrichment process can take place directly in one or more landfills to enrich the leachate. The different MCFA-enriched leachates can then be transported to a refining plant. Such a decentralized concept can be a good solution to process substrates from different suppliers, which also means that the refining plant can be designed for a higher throughput.

The possible throughput of the extraction technology (small scale) currently lies at 30 – 50 m³ leachate per year. The modular design of the extraction plant components enables a subsequent expansion of the plant to increase the throughput.

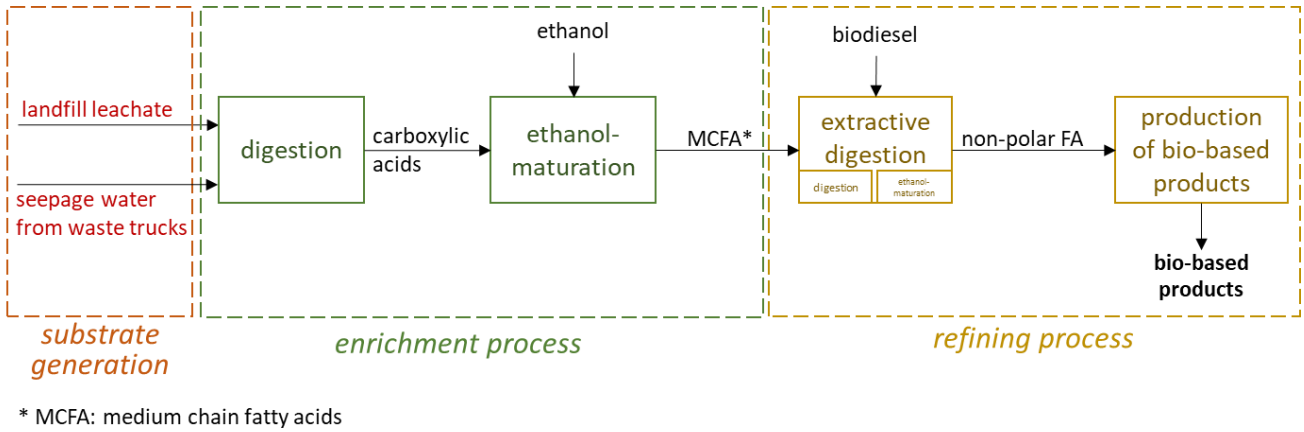

Figure 1: Schematic illustration of the biotechnology process chain for different substrates

2.2 Approach to examine the implementation potential

In order to identify, if this biotechnology can be implemented in Marrakech 15 implementation criteria (technical and organizational criteria) has been identified in a first place. These criteria have been elaborated in a workshop with the technology developers. The assessed criteria mainly describe the preconditions that have to be in place in Marrakech and in the specific landfill in order to realize a successful implementation of the biotechnology. In addition to own researches also interviews with relevant stakeholders have been conducted in 2019 to find out whether the required preconditions are in place. The interview partners were responsible persons from:

- the Direction of Water and Sanitation (Moroccan Ministry of Interior),
- the Municipality of the City of Marrakech, which is responsible for the waste management in Marrakech,
- the company ECOMED, which is responsible for the waste disposal in Marrakech as well as
- the company Pizzorno, which is in responsible for the collection in Marrakech.

Based on own researches and the interview-results an implementation potential has been examined, which shall promote a successful implementation of the biotechnology in the city of Marrakech.

3. Results and Discussion

In this chapter the relevant criteria for the implementation of the biotechnology are presented in 3.1. Following in 3.2 these criteria are verified for the case of Marrakech to determine the implementation potential. Based on these results required implementation measures are derived.

3.1 Relevant implementation criteria

To guarantee a successful implementation and a smooth operation of the biotechnology a total of 15 criteria have been identified by the workshop participants. The identified criteria can be subdivided into technical and non-technical criteria (see Table 1). Technical criteria include, for example, all the material resources and infrastructural requirements necessary for the construction and operation of the biotechnology. Non-technical criteria, in contrast, refer to personnel requirements and necessary concepts, as well as financial and social criteria.

Table 1: Implementation criteria for the MCFA extraction technology divided into technical and non-technical criteria

Technical criteria	Non-technical criteria
1. Existence of leachate basins (minimum: controlled landfill)	11. Starting funding/investments to build and operate the biotechnology
2. Minimum leachate generation per year at site: 30 m³	12. Local available qualified staff during construction and operation phase
3. Available area to build an enclosed plant (30 to 40 m² for small scale)	13. Provision of a protection concept against heat/cold and fire
4. Access to electricity	14. Existing demand for biobased MCFA
5. Access to good transport connection and road infrastructure	15. Acceptance work / awareness campaigns for biobased products
6. Connection to a WWTP	
7. Local availability of materials for construction of the biotechnology	
8. Local availability of auxiliary and operating materials (e.g. extraction oils)	
9. Regular monitoring / analysis of process parameters	
10. Presence of local refining facilities	

As described in 2.1 the extraction process can be directly placed on landfills, if leachate supply is guaranteed for example by existing leachate containments and the leachate quality is sufficient (Saadoun et al., 2021). So, the landfill must have as minimum the status of an engineered/controlled landfill (World Bank, 2012), for which possible access to the generated leachate is guaranteed. The minimum leachate generation on site shall be 30 m³ per year to feed the small scale pilot plant. It is also important to know, if hazardous wastes are disposed on the landfill, because this could have negative impacts on the process, the product quality as well as the safety of the employees. Fundamental for the construction and further for the operation of the biotechnology for example on a landfill, is an area of 30 to 40 m² (small scale) for the construction of the enclosed plant for the extraction process. The enclosing is a safety measure for the process to protect it against theft.

Despite of the implementation of a decentralized or central biotechnology concept (see 2.1), access to electricity to run the process is necessary. However, power black outs would not disrupt the process massively, only stop the process; for example, the used mechanical stirrers would stop to stir. A possible, but not preferable solution could be the use of diesel-generators on site to overcome possible power failures. To increase the sustainability of the process also the use of existent biogas from the landfill, which could be converted into electrical energy, or the use of solar energy can be alternative solutions, if they are available on site. A good road infrastructure and traffic connection is relevant to ensure the transportation of the input (leachates, extraction oils, etc.) or the output (e.g. extracted MCFAs, or wastewater), if no other direct connections (e.g. leachate supply, sewerage system) are available. If a decentralized concept shall be implemented the refining process, should be outsorced. Consequently, it is essential that possible refining facilities are existent to enable the refining of fatty acids into biobased products.

The structure of the plant is designed to ensure the local availability of construction materials, other auxiliary and operating materials. A concrete dependence on materials from abroad should be avoided whenever possible to support

the local markets and to enable future maintenance without costly imports. For the operation of the biotechnology auxiliary and operating materials such as chemicals and extraction oils shall be provided. Regular monitoring and analysis of the process parameters (total organic acids, pH, chemical oxygen demand – COD, etc.) must be performed to avoid oversaturation of the products in the leachate that cause inhibition of the process, also loss of organic load into competing processes like methane productions. As mentioned above the pH shall be in a range between 5.5 and 6.5, the available organic acids load between 40 to 60 g/l substrate and COD must be higher than 10g O_2 per liter of substrate.

Besides non-technical criteria as the starting funding and investments are needed for the plant construction and also for its operation. If national funds are missing, there is a possibility of cooperation with foreign investors and international organizations (e.g. Worldbank), which support such projects in the context of development cooperation. The biotechnology requires various job profiles for example technicians (e.g. wheel loader or trained waste collector), chemical laboratory assistants as well as environmental or mechanical engineers. Concepts to protect the biotechnology against excessive heat or cold as well as fire/explosion are necessary. The temperature range in the enclosed plant should be between min. 30°C and max. 60°C. Due to the high use of solvents and the possible proximity to landfills, there is a fundamental risk of fire and explosion, which has to be reduced by suitable prevention concepts. Moreover, the market demand for biobased MCFA should exist so that a potential sale of the products is ensured. However, it may be necessary to conduct acceptance work, especially for companies; in order to reduce possible prejudices regarding biobased products out of waste material and to prove that, despite the use of inhomogeneous feedstock (leachates, waste), the quality of the final product (MCFA) is comparable to homogeneous feedstock.

3.2 Evaluation of the implementation criteria and derivation of measures for the case of Marrakech

Marrakech is the fourth largest city in Morocco. Marrakech generates between 850 to 900 tons of municipal solid wastes daily (Ouchen, 2018). The city council of Marrakech delegated the waste collection and disposal to private operators. (Ouchen, 2018, State Secretary of the Ministry of Energy, Mines and Environment, GIZ, 2019) They have three companies in charge for waste collection and one responsible operator for the waste disposal (Ouchen, 2018). According to Hafidi (2015), the municipal solid waste of Marrakech has a high amount of organic waste (around 70%) and a high moisture rate, which as a result produces an huge amount of leachate (Hafidi, 2015). In Marrakech, there are two landfills: Al Azzouzia and El Mnabha. Al Azzouzia is an uncontrolled landfill located 15 km from Marrakech and closed since 2014. El Mnabha is located 42 km from Marrakech and has the status of a controlled landfill. In a study of Saadoun et al. (2021) three different possible liquid substrates from Marrakech: I) leachate from Al Azzouzia landfill, II) leachate from El Mnabha and III) liquids from waste collection trucks has been analyzed regarding their MCFA production potential. The most promising substrate is the one from the active landfill El Mnabha. Here, the largest amounts of carboxylic acids have been detected at the beginning, with approx. 25,000 mg/l and also after addition of the extraction solvents, the highest concentration of MCFA (C6 to C8) produced at approximately 5,000 to 7,000 mg/l has been identified. (Saadoun et al., 2021)

Based on the results of Saadoun et al. (2021) the active landfill in El Mnabha in Marrakech is a potential site to implement the decentralized extraction technology. The potential for the implementation of a small scale pilot plant (annual 30 to 50 m³ throughput) is analyzed below by verifying the implementation criteria (see Table 1). The results of the implementation analysis are presented in Table 2.

The landfill El Mnabha is a controlled landfill. The generated leachate is collected in a basin and evaporated up to know. A potential access to this leachate as feedstock for the extraction technology is possible. Based on average numbers of the Direction of Sanitation of Morocco 205 m³ of leachate are produced daily, which fulfills the minimum leachate generation criteria. The available area, access to electricity as well as a good transport connection and road infrastructure are available. A WWTP is located approximately 13 km from the landfill. The administration building at the entrance of the landfill is connected to the sewerage system. Currently, the leachate is not directed to the WWTP, but the extraction technology could potentially be connected to the WWTP to ensure that the outgoing liquids from the extraction process can be treated further. However, it is necessary to verify if the extraction process is a sufficient pretreatment step to direct the extraction effluents to the WWTP for further treatment.

The required materials for the plant construction are locally available in Morocco. However, the chemical products needed during the extraction process are partly available in Morocco. Chemicals and monitoring materials as for example quick-tests for the analysis of the organic acids content and COD as well as the extraction solvent ethanol and chemicals for

conducting the pH analysis has to be imported. Generally, the monitoring of the process parameters is possible, because the required staff for doing such analysis is available in Marrakech. But due to the dependence of the needed chemicals for the analysis this criterion is also partially met. Nevertheless, this criterion cannot be influenced directly. Generally, Marrakech has refining facilities, which could be potential customers of the biobased MCFAs. A next step is to determine whether these refining plants have a real interest in using these MCFAs for further use.

Regarding the funding and investments on national and international level specific funding programs exist, which promote the implementation and operation of innovative biotechnologies in Morocco. As part of the above-mentioned Trans4Biotec project, the existing research and teaching cooperation with Cady Ayyad University has ensured that qualified personnel will be available to operate such a facility in the future. A concept to protect the technology against heat/cold and fire is actually available. Important to mention is to ensure a stable temperature (approx. 35°C) for the extraction process as a consequence the extraction technology should be isolated. However, the concept still needs to be adapted so that this technology can be operated at a landfill site. Due to the possible emissions from either the landfill or the technology, the risk assessment regarding fire and explosion has to be re-evaluated. Generally, a market for bio-based products is existing in Morocco. Therefore, the extracted MCFA can be used to generate biobased products. As known from the global north, the waste-based image of the products could be a problem, even if the quality of these products is similar to fossil-based products. So, awareness campaigns and acceptance work has to be performed in future to address possible fears and prejudices and to overcome them.

Table 2: Verification of the technical and non-technical implementation criteria for the case Marrakech

Technical criteria	**met**	**partly met**	**not met**
1. Existence of leachate basins (minimum: controlled landfill)	x		
2. Min. leachate generation: 30 m³/a	x		
3. Area to build an enclosed plant (30 to 40 m²)	x		
4. Access to electricity	x		
5. Access to good transport and road infrastructure	x		
6. Connection to a WWTP		x	
7. Local availability of construction materials	x		
8. Local availability of auxiliary and operating materials		x	
9. Regular monitoring / analysis of process parameters		x	
10. Presence of local refining facilities	x		
Non-technical criteria	**met**	**partly met**	**not met**
11. Funding/investments to build and operate the technology	x		
12. Local available qualified staff	x		
13. Provision of a protection concept against heat/cold and fire		x	
14. Existing demand for biobased MCFA	x		
15. Acceptance work / awareness campaigns			x

Conclusion

The implementation of a facility to extract MCFAs from local leachates in Marrakech is generally feasible, but certain verifications still need to take place to make the implementation successful and long-term. Recommendations for action in order to proceed are the verification if the remaining liquids from the extraction process are sufficient for a direct discharge to the WWTP or if additional treatment steps need to be inserted. Along with this, a possible connection of the extraction technology to the WWTP for the discharge and further treatment of the residual liquids has to be examined. Moreover, the explosion and fire protection concepts has to be adapted to conditions of the landfill site, to guarantee maximum protection. The potential collaborations with local refining facilities for further processing of MCFAs as well as with potential customers has to be examined. In this context it can be of great importance to develop a concept for customer conviction to overcome existing prejudices of biobased products.

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