

Article

Stakeholder Assessment on Closing Nutrient Cycles through Co-Recycling of Biodegradable Household Kitchen Waste and Black Water between Rural and Urban Areas in South India

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Abstract: Agricultural land degradation, urban migration, increasing food demand and waste, and inadequate sanitation systems all affect farmers, local society, and the environment in South India. Joint recycling of biodegradable secondary household resources to close nutrient cycles between urban and rural regions can address all these challenges and thus several SDGs at the same time. Efforts are being made to this end, but many attempts fail. The central research question is, therefore: how can co-recycling concepts be evaluated in this context? For this purpose, composting plants, biogas fermenters, and a high-tech concept to produce plant charcoal, design fertilizer, and biopolymers are considered. The aim of this study is to evaluate the recycling concepts from the stakeholders' perspective to avoid gaps between theory and practice. Six expert and one focus group interviews on two successful on-site case studies and 15 online expert interviews with thematic actors were qualitatively evaluated and presented in a social network analysis to identify preferences and indicators for the further evaluation of co-recycling concepts. The results show that the focus is on mature technologies such as compost and biogas. High-tech solutions are currently still in rudimentary demand but will play a more important role in the future. To evaluate such concepts, seven key indicators and their measured values were identified and clustered into the categories ecological, social, technical, economic, and connective. The results show that this methodology of close interaction with stakeholders and the evaluation of successful regional case studies minimize the gap between practice and theory, contribute to several goals of the SDGs, and thus enable such concepts to be implemented sustainably.

Keywords: India; circular economy; kitchen waste; black water; resource efficiency; sustainable development goals; natural fertilizer



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1. Introduction

1.1. Problem Status

India faces a number of challenges such as population growth, rapid urbanization, food security, water scarcity, environmental pollution, and climate change [1]. This is illustrated by the second largest population in the world, the generation of 62 million tons of municipal solid waste in urban areas in 2011, and the increase in population-based CO₂ emissions per capita from 0.98 in 2000 to 1.73 tons in 2014 [2,3]. In addition, factors such as rapid economic growth and a growing middle class influence production and consumption behavior, which has socio-economic and ecological effects [4]. These effects are also evident in waste management with regard to waste generation, collection, transport, treatment, and disposal [5].

Due to the large population, the high proportion of organic waste (defined as wet waste in India, which in this paper includes kitchen, green, and market waste) with 61% by weight in urban household waste and inadequate sanitary facilities, the biodegradable secondary household resources kitchen waste, green waste, and black water are considered to have great potential for agricultural use as natural fertilizer [6–8]. This is also an important point because the high energy requirements in the production of mineral fertilizers can cause the greatest environmental pollution in agriculture [9]. Furthermore, agriculture is the main source of livelihood in India as 70% of rural households largely depend on it, with 82% of farmers being smallholders [10]. Smallholder farmers must be guaranteed safe and affordable procurement of fertilizers [11]. The use of natural fertilizers, which can be produced from secondary household resources, can contribute to this and counteract long-term and widespread soils degradation by improving soil fertility [12].

The misconnection between rural and urban regions in terms of carbon and nutrient fluxes exacerbates all of these challenges, while the connection offers significant potential to address them [13].

1.2. Relevance

Alternative co-recycling systems (systems that consider different waste streams simultaneously) for black water and organic waste to those in developed cities that are resource-intensive and non-circular have the potential to reduce pollution and improve public health [14,15]. In addition, a regional circular economy can increase the resilience to environmental influences in communities [1]. This indicates a need for action worldwide, which is particularly advantageous in India when implementing new concepts by skipping traditional concepts.

The Indian government is taking steps to adapt the circular economy, for example through the Swachh Bharat Mission, in which stakeholders have shown that they can benefit from global best practices in public health, sanitation, energy, water and land conservation [1].

This underlines the fact that several Sustainable Development Goals (SDGs) can be addressed with appropriate circular economy concepts. Examples of the many possible contributions of circular concepts are SDG 7 “Affordable and Clean Energy” that can be obtained from secondary biological household resources and SDG 2 “Zero Hunger” in the context of sustainable agriculture [16,17].

1.3. Research Gap

Due to the increasing urgency of implementing circular concepts, the need for stakeholder perspectives and evaluated successful case studies is also increasing to ensure sustainable implementation using evaluation indicators. Since these perspectives are missing for South India and are important for the transferability and scaling of future concept implementation, these aspects are examined in more detail in this study.

1.4. Objectives

The aim of this study is to evaluate co-recycling concepts with biodegradable kitchen waste and black water from households for agricultural use and thus the closing of cycles between urban and rural regions in South India. We consider a high-tech concept (RUN—“Rural Urban Nutrient Partnership” [18]) with integrated vacuum toilets for the collection of black water for the joint recycling with separately collected kitchen waste to produce fertilizer (magnesium-ammonium phosphate), plant charcoal, and biopolymers (Figure 1) and compare this with the conventional technologies of anaerobic digestion and composting (Figure 2). To reach this goal, the following research questions are defined:

- Which is currently the most suitable co-recycling concept?
- What are currently the most suitable key indicators for the implementation of such concepts?
- How can these key indicators be assessed?



Figure 1. High-tech concept (1) of a rural urban nutrient partnership (RUN), as an example for short circular economy [18]. The image shows the closure between urban (right side) and rural areas (left side). The RUN plant produces fertilizer, plant charcoal, and biopolymers.

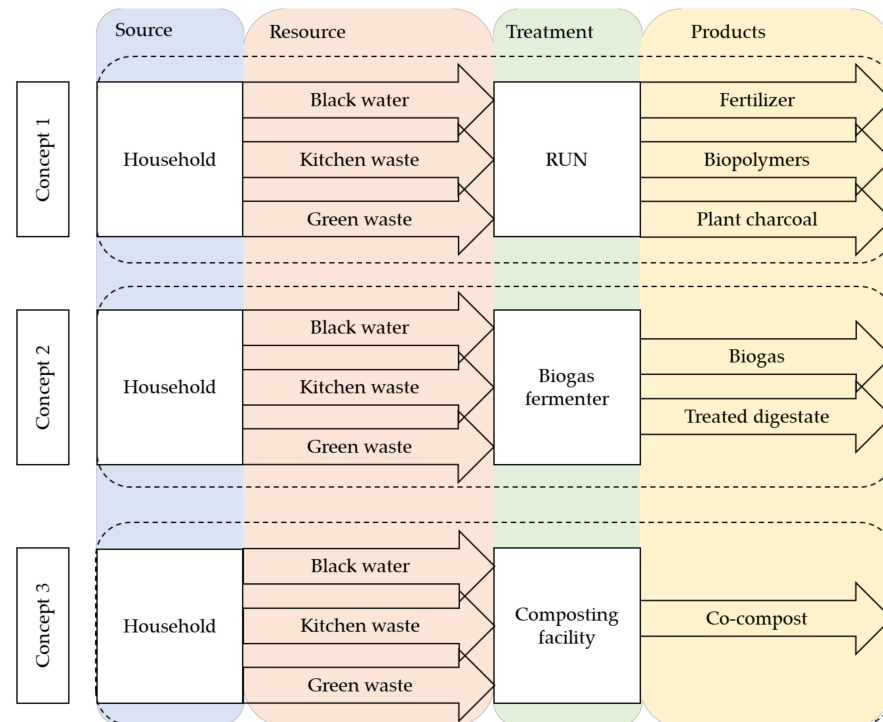


Figure 2. The three co-recycling concepts considered for the thematic online expert interviews. Comparing the high-tech RUN (rural urban nutrient partnership) concept with the widely used technologies biogas fermenter and compost facility.

The evaluation is based on case studies and stakeholder perspectives to avoid gaps between theory and practice, which is essential for the sustainable implementation of alternative concepts.

2. Materials and Methods

A multi-tool approach was used: a combination of digital thematic expert interviews, a social network analysis (phase 1), and an on-site evaluation of two case studies with further expert interviews and a focus group interview (phase 2). This was done in the sequence described in successive phases. Digital data collection took place from June to October 2021 and on-site data collection—from October to December 2021 in the peri-urban regions of Bangalore and Ooty in South India. Interviews lasted between 30 and 90 min.

2.1. Interviews with Thematic Stakeholders

In summary, it was asked how co-recycling with the use of urban and semi-urban household kitchen waste and black water for use in surrounding agriculture could be suitable for closing loops in South India. In this context, the focus was on practicability, implementation options, challenges, opportunities, suitability, experience, prerequisites, and framework conditions. These questions aimed to answer the research questions considering the RUN system, biogas digestion, and composting plants. The concepts were explained using a presentation and the RUN graphic (Figure 1).

The results were obtained by conducting semi-structured interviews with 15 thematic stakeholders involved in the circular economy in South India. The circular economy experts are active in organic waste and black water treatment and are local scientists, private investors and executive directors, managers and employees of non-governmental organizations, non-profit organizations, and corporations. In order to have a well-covered spectrum and excellent technical expertise, stakeholders were selected in equal parts who are either experts in biogas, compost, or plant charcoal and then the snowball principle was applied [19–21]. The interviews with additional stakeholders ended after the indicators, identified in the literature were discussed and no new indicators were added.

These interviews were conducted digitally face to face, recorded, and transcribed. The resulting data were qualitatively analyzed and coded, clustered and categorized according to the research questions, resulting in categories, key indicators, and evaluation criteria [19].

2.2. Social Network Analysis

The qualitative data from the interviews were used for a cognitive mapping method. This method was chosen due to a large amount of data and perceptions of different stakeholders and to authentically integrate the local knowledge. The method visualizes perceptions of social realities with networks of nodes and lines. This is based on a binary matrix that sets numbers for a relation (0) and no relation (1) and is visualized with software (as fc mapper: available at <http://www.fcappers.net/joomla/>, accessed on 10 January 2022). In this study, the correlations are not weighted as usual [21], in order to avoid bias [22]. Each asset is defined by its centrality, which is the sum of the ingoing and outgoing lines. It is assumed that the greater the centrality, the more important the indicator is for the implementation of a new alternative circular concept. The indicators from the social network analysis with high centrality were used as selection criteria for 7 key indicators, which were divided into 5 categories. These were identified for a successful implementation of a co-recycling concept of secondary household resources between urban and rural areas.

2.3. Case Studies

Two successful case studies of co-composting plants in South India were evaluated by relevant actors including administrative directors and employees, plant managers, and workers. In this context, 6 expert interviews and 1 focus group (with the plant workers) discussion were conducted out on site. The interviews included questions about mass flows, framework conditions, and the identified key indicators and evaluation criteria. Stakeholders' statements on the key indicators were ranked on a scale from 1 to 4 (Table 1).

Table 1. Scale of evaluation criteria assigned according to stakeholders’ responses.

Scale	Value	Answers of Stakeholders
1	Insufficient	The criterion does not exist or is the reason for the failure of the concept.
2	Improvable	The criterion is seen as a major challenge and a change is necessary for a successful continuation of the concept.
3	Good	The criterion is satisfactorily met, but improvement is aimed.
4	Very good	The criterion is met and is not perceived as a challenge.

A composting plant is located in Devanahalli, in the peri-urban area of Bangalore in the state of Karnataka, which is operated by the municipality and receives technical support from the CDD Society [23]. The other two composting facilities (defined as a single case study) are located in Ketti and Athigaratty in the peri-urban areas of Udthagamandalam (Ooty) in Nilgiris in the state of Tamil Nadu and are managed by RDO Trust [24,25]. Both organizations are non-profit institutions.

The technical details (obtained from the interviews) about the process of producing the co-compost entails at first the manual separation of organic waste of possible contaminants. In addition to household kitchen waste, black water from households, public green waste and restaurant and market waste are used as resources. The black water first flows through several tanks. In Devanahalli these are closed for the additional production of biogas (which is currently not used) and in Nilgiris these tanks are open. Both have the concept of separating the solid from the liquid part by sedimentation. The solid part is dried under polycarbonate sheets between 20 and 25 days. Composting is done in layers with treated black water and organic waste in a weight ratio of 1 to 2 in Devanahalli and 1 to 4 in Nilgiris. It is composted for 42 days in Nilgiris, where it is turned once a week, and 60–75 days in Devanahalli, where it is turned every two weeks.

3. Results

The social network analysis shows indicators for and against the preferences for the co-recycling concepts compost, biogas, and the high-tech concept RUN. The results are visible in 5 main categories: “ecological”, “social”, “technical”, “economical”, and “connective” (Figure 3).

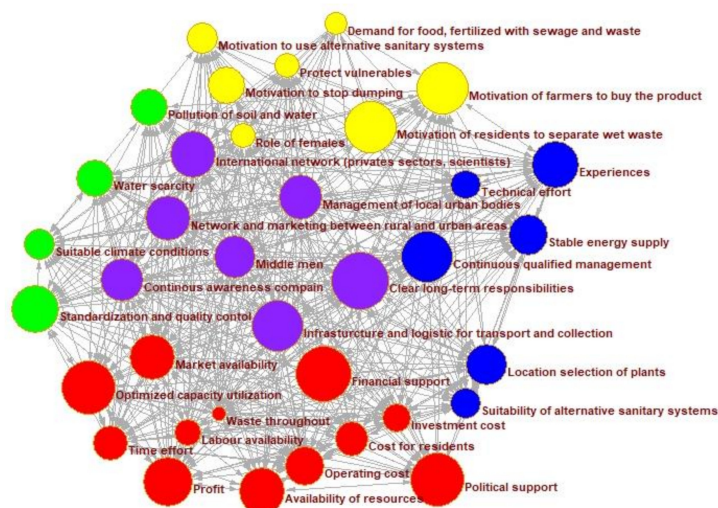


Figure 3. Social network analysis of indicators of co-recycling concepts between rural and urban areas from the view of thematic stakeholders. This is generated by using the cognitive mapping method (described in the material and method section). The indicators are represented by colored circles and the relation by lines. The larger the circle the higher its centrality and relevance for the concept. The color code is: green = ecological, yellow = social, blue = technical, red = economical, purple = connective.

The seven key indicators and their assessment criterion for the successful implementation of co-recycling concepts with secondary household resources were grouped into these five categories of social network analysis (Table 2).

Table 2. Key indicators from stakeholder perspectives and their evaluation options, clustered in categories. The key indicators were derived from the social network analysis and summarized.

Category	Key Indicator	Assessment Criterion
Ecological	Standardization and quality control	Measured values of the sales products and the wastewater after treatment in relation to limit values and definitions of specific measures if exceeded
Social	Motivation of residents to separate wet waste	Rate of segregation of wet (organic) waste
	Motivation of farmers to buy the product	Share of informed farmers and farmers who buy the product regularly
Technical	Continuous qualified management	Employee satisfaction and dealing with operating and management problems
Economical	Financial support	Assessment of the government support of the entire supply chain
	Optimized capacity utilization	Efficiency of capacity utilization
Connective	Logistics network and clear long-term responsibilities	Clear responsibilities at state, municipal and operational level, and the possibilities to resolve stagnations in the supply chain

The specific assessment based on the identified key indicators on the two case studies is shown graphically in the following figure (Figure 4).

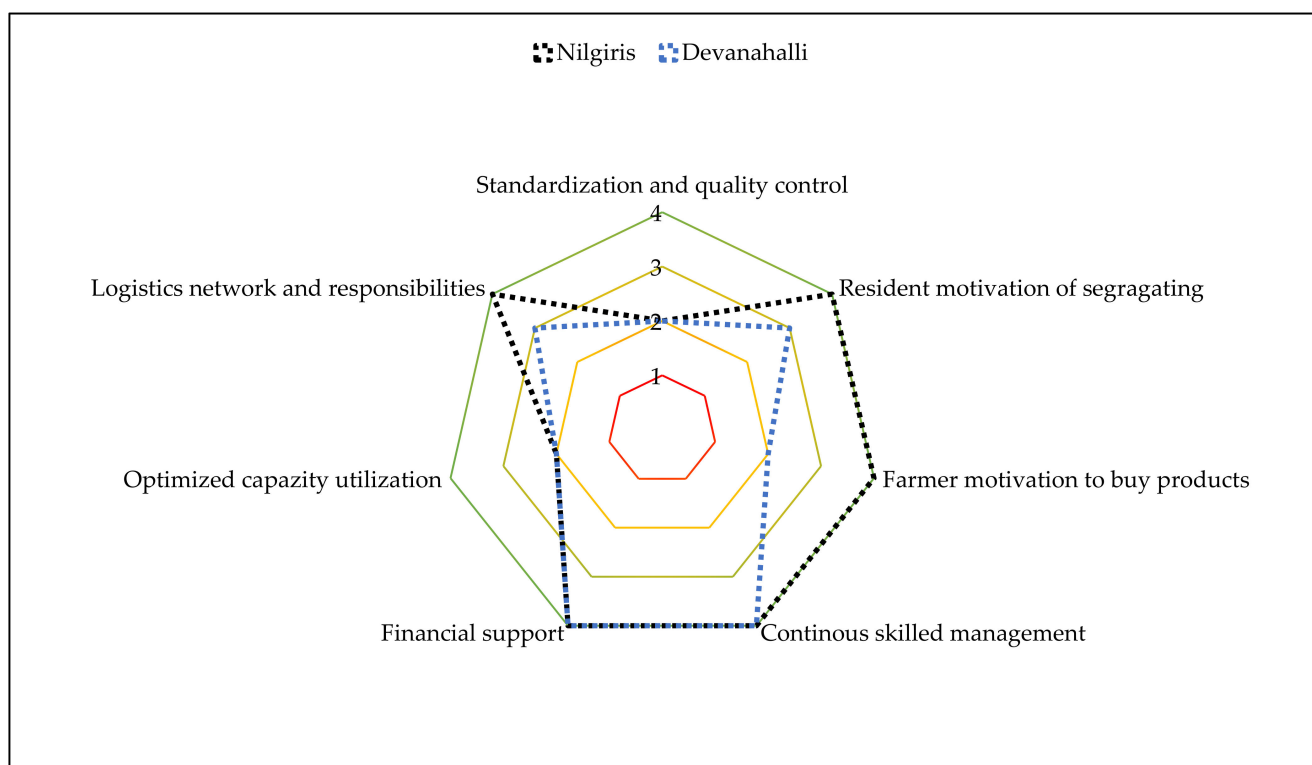


Figure 4. Evaluation of two case studies, based on the identified criteria and the assessment of the stakeholders (1 = insufficient; 2 = satisfactory; 3 = good; 4 = very good).

The preferences of the respective categories from the perspective of the thematic stakeholders are presented in detail below. The key indicators are explained in more detail based on the case studies and the opinion of the experts on site.

3.1. Ecological

Mixing black water with wet waste for recycling is critical from an ecological point of view since many different chemicals are used in the cleaning of sanitary facilities and it is not known whether these can be found in recycled products. On the other hand, the nutritional value that could be brought into local agriculture through co-recycling is viewed positively.

All co-recycling concepts can reduce the impact on the environment. On the one hand, it can be reduced through use because, for example, long transport routes and the production of fertilizers could be saved. On the other hand, it can be reduced by avoiding waste dumping. Improper disposal of black water and wet waste has significant negative impacts on the environment such as soil and water pollution and creates additional problems during the dry season. Water scarcity during periods of drought and degradation of agricultural soils are widespread in southern India. Here the necessity of using natural compost (compost from waste streams) is pointed out to improve water retention capacity and soil fertility in the long term. As the environmental impact is acute, it has often been stressed that quick and effective solutions should be implemented to improve the situation.

A fertilizer with a low probability of contamination in combination with the use of plant charcoal, as provided for the RUN system, was rated positively. Nevertheless, the prevailing opinion is that co-compost offers a solution to a large number of current problems in South India. Co-fermentation was particularly advocated for very densely populated urban areas where there is less space for co-compost. It has been argued that in this way dumping and negative environmental impacts on regions near cities can be avoided.

Key Indicator: Standardization and Quality Control

Regular checks and tests are required to avoid the contamination of the soil and water. In both case studies (which are described in the materials and methods section), regular checks of compost and treated wastewater for micropollutants and pathogens as well as temporary checks for raw input (black water and organic waste), heavy metals, and nutrients are carried out at university laboratories. If the specified limit values were exceeded, action plans were defined and implemented.

The lack of sufficient basic data for the characterization of wet waste, black water, compost, and wastewater, as well as uniformly structured standards in a guide, which is necessary for the upscaling and transfer of concepts to other regions, is problematic. Furthermore, clearer time rules for measuring and testing could be improved. Both case studies showed a large discrepancy in the answers between the respondents.

3.2. Social

Much attention was paid to the social aspects. The management of black water and wet waste is essential for health reasons, for people, animals, and the environment, but also to support the local population.

It has often been emphasized that the smallholders who make up most Indian farmers need more support, which also serves to ensure food security. Farmers should have affordable, safe, and natural fertilizers such as co-compost available.

In addition, sanitation is needed for all, with a special emphasis on the urgency for women. A high-tech vacuum toilet will only be available to a minority in certain regions. No problem is seen with the motivation to use such a toilet if a toilet has already been used. Therefore, the focus is currently on the nationwide expansion of the sanitary facilities. With technologies that have been known and tested for many years, it is possible to reach many regions and people.

For people to be able to buy food that has been fertilized with organic waste and black water, there needs to be awareness and a market for all co-recycling concepts. Residents are expected to be less reluctant to design fertilizers (such as magnesium-ammonium phosphate), although this aspect is not considered significant.

From the stakeholders' point of view, the main thing is not to create any disadvantages and to enable as many actors as possible (including the socially disadvantaged) to add regional value, which is why they are more committed to tried-and-tested technologies such as biogas fermenters and compost facilities.

3.2.1. Key Indicator: Motivation of Residents to Separate Wet Waste

In both case studies, a lot has been and will be invested in ongoing awareness raising. Measures include street motivation via microphones, information brochures, and garbage cans that are freely available to households. To improve segregation, waste in Devanahalli will be segregated manually when collected on the means of transport.

Part of this motivation is also an acceptance of the technology, where the not-in-my-backyard syndrome occurs. In Devanahalli and Nilgiris, the co-composting facility was built on a former dumping place, which initially met with resistance from residents in Devanahalli. Positive experiences, absence of odor, and visual preferences promoted acceptance.

Even if these aspects are considered, continuous campaigns have to be brought even more into focus.

3.2.2. Key Indicator: Motivation of Farmers to Buy the Product

This indicator is strongly influenced by external circumstances. Cost and accessibility of co-compost and alternative products (with greater competition in Nilgiris), as well as water scarcity and soil fertility, play a role here as long-term factors. The prerequisite is that the farmers are informed, advised, and supported in the conversion from conventional fertilizer to natural fertilizer and the practical implementation. Both case studies show that most farmers trust local organizations and are willing to try new opportunities after the benefits become apparent. Free samples, participation in information and awareness-raising events, and positive personal or shared experiences provide additional encouragement. Then the willingness to invest a little more at the beginning increases to benefit in the long term if the additional investment is within the scope of the possibilities. The cost of 5 to 7 rupees (~0.06–0.08 €) per kilogram of co-compost is lower than that of chemical fertilizers in both case studies. In Devanahalli, conventional fertilizer costs about four times more per kilogram (using ammonia-based chemical fertilizer No. 5 as an example) and in Nilgiris (using muriate of potash MoP as an example)—about three times more. Fertilizer No. 5 has a nutrient content of 6:12:6% NPK, which is much higher compared to the co-compost in Nilgiris (0.9:0.5:0.5% NPK) and Devanahalli (0.7:0.2:1% NPK). The advantages of co-compost, such as the high content of organic carbon and the improvement of soil properties, mean that the recommended quantities for co-compost are equal to or at most double those for mineral fertilizers, which is why combinations are usually applied—with positive results. Therefore, chemical fertilizer is only substituted to a certain extent. For comparison: farmyard manure costs about 3 to 5 rupees/kg (~0.04–0.06 €) in Nilgiris and is thus closer to the cheaper price range than co-compost.

Points that could be improved: more focus on advertising would be crucial in Devanahalli, as well as more pick-up stations (within a radius of 20 km). Both case studies could offer farmers more transport support and information dissemination on the availability of co-compost.

3.3. Technical

From a technical point of view, co-composting was particularly emphasized as it has proven itself in practice over the long term. These are mainly small and decentralized systems in which technical challenges can be solved independently, without downtime or external maintenance. Given the recent pandemic, it has been suggested that independence is a major issue.

Experience has shown that this concept works more long-term and more sustainably in South India than biogas plants and high-tech concepts such as waste incineration plants.

Most stakeholders clearly preferred compost instead of biogas to high-tech solutions, while hardly anyone saw much potential in high-tech solutions, also because of the more complex structures in responsibility and supply chains. Problems with technical knowledge or knowledge transfer are not seen.

Another point that reinforces this assessment is the unstable energy supply in large parts of southern India, which would be a basic requirement for a high-tech concept like RUN. Such a system is also hard to imagine in rural regions, which is why the choice of location is crucial and severely restricted.

The potential for biogas plants was seen in densely populated areas due to the lack of space, the direct use of energy, and the closed construction. However, if fermentation residues from biogas plants are not processed and marketed, disposal can be difficult because the liquid part could get into the wastewater.

Key Indicator: Continuous Qualified Management

Detailed instruction, regular training, and clear responsibilities are the key words for continuous and qualified maintenance of a system. Both case studies show a high functionality of this area due to adequate local management support. Management in combination with highly motivated employees make after-sales services unnecessary, as problems or stagnations can be effectively resolved. The high level of motivation is generated and maintained through better salaries and more structured working hours compared to the previous activities of employees. Higher job security also plays a role here, due to the continuous need for compost and waste and black water disposal. This sense of security has been reinforced by the recent impact of the pandemic.

In Devanahalli, unused biogas escapes into the atmosphere because biogas is produced but is no longer used after the demolition of the plant house where it was directly used. In Nilgiris, the compost heaps give off unusually strong odors, which could indicate that these can be improved with building material.

All this underlines the importance of a functioning and good management system.

3.4. Economical

The investment costs are lower for composting plants than for biogas digesters, which in turn are lower than for high-tech plants (like RUN). Experience has shown that investment-intensive concepts are often not profitable, and examples where it works are easy-to-use, low-cost technologies that make products locally marketable at low prices.

The competition for biogas is difficult because liquid gas (LPG) is subsidized, and the state relies on other renewable energies such as sun and wind. It is clearly perceived that the decision about a concept depends heavily on the orientation of the government level. Political support is an important indicator for this sector.

The government support chemical fertilizers in South India. The design fertilizer would therefore fit in well with the already established structures. Conventional fertilizers are very popular and in high demand, with natural fertilizers increasingly coming into focus again. Compost is marketable, but still needs financial support and nationwide offers for broader use.

For residents, the overall schemes should also entail costs to support the waste and black water management, which is partly the case.

High-tech concepts harbor many uncertainties and biogas is not the focus of energy in South India. This shows that co-compost is the most popular option here too.

3.4.1. Key Indicator: Financial Support

In Nilgiris, 20% of production costs can be covered by the sale of compost, while in Devanahalli it is 21% (both values refer to the year 2020). These values show the high dependency on financial support. Without government support, it is very difficult to make such a concept profitable if the framework conditions are not adapted. These adjustments would have to be decided at the government level, such as reduced subsidies for chemical

fertilizers and greater support for the entire production chain of natural and local fertilizers. In addition, strict rules and controls, while preventing corruption, ensure that improperly disposed waste and black water are avoided. This supports planning, capacity optimization and reduces the impact on the environment and climate. The costs for residents should also be adjusted via waste fees to promote such systems. All these points can help reduce or even eliminate the need for direct financial support.

3.4.2. Key Indicator: Optimized Capacity Utilization

Optimum utilization of the system capacities is necessary to increase profitability, which is already possible in the planning phase with suitable scaling. The insufficient database for the available resources turned out to be problematic in both case studies (also due to changes in the data basis in long-lasting planning phases), which is why the utilization shows potential for improvement. Therefore, despite correct theoretical calculations, there were deviations from reality in practice. The achieved capacity, measured on black water, is 38% in Devanahalli and 22% in Nilgiris, while the plant capacity is 6 m³/day in Devanahalli and 6.7 m³/day in Nilgiris. Table 3 shows the mass flows achieved for both case studies.

Table 3. Mass balances from the two case studies in Devanahalli and Nilgiris in 2020.

Category	Unit	Devanahalli	Nilgiris
Kitchen waste	t·a ⁻¹	540	2120
Green waste	t·a ⁻¹	108	-
Black water	m ³ ·a ⁻¹	840	534
Compost	t·a ⁻¹	33	522

The scaling is improved with each plant, as in Nilgiris, where the subsequent plant can be better assessed based on previous experience in the region.

There are also natural resource fluctuations that occur due to certain situations such as the Corona Pandemic or market conditions (in Devanahalli). This problem requires plans to deal with the fluctuations in the raw material. In Devanahalli there is often a surplus of wet waste that is composted separately in a designated place. In Nilgiris, tea residues are used in other compost compositions to compensate for the lack of wet waste. This problem exists in Nilgiris in contrast to Devanahalli as the population density is lower and more farmers are recycling wet waste themselves, suggesting the need to identify unused resources. Capacity utilization could improve due to increased focus on restaurant and market waste and improved management of kitchen waste from households.

Another aspect is the additional utilization of dry waste streams, such as plastic. In Devanahalli, a local distribution center increases total return, while in Nilgiris, dry waste is transported to Coimbatore, shifting the value.

Optimum plant utilization is an important point among all concepts considered to increase local added value and use local resources optimally, instead of long transports with negative effects on the climate and independence. Small and decentralized systems in semi-urban and semi-rural areas are often preferred in South India, as in the case of the two case studies.

3.5. *Connective*

The connecting aspect has often been highlighted by stakeholders as an important sustainability factor for the circular economy.

From the point of view of network management, which includes the connection of logistical aspects and clear responsibilities in all areas, high-tech concepts such as RUN are viewed particularly critically. Since such concepts are very complex, it is primarily about the central control of all areas, the connection of the different stakeholders, and a responsible umbrella unit of different levels. This applies to all co-recycling concepts in

the exchange between rural and urban areas but becomes more difficult as the concept becomes more complex.

Experience has shown that other high-tech projects have had problems with unclear responsibilities in production and along the supply chain. Problems that arose here remained partially unsolved.

Future potential for high-tech concepts such as RUN is seen in urban and semi-urban regions for newly emerging, prosperous, and established settlements of a minority. However, many boundary conditions must be covered for this, with well-functioning infrastructure, clear responsibilities, and the network to all parties involved being important aspects.

Key Indicator: Logistics Network with Clear and Long-Term Responsibilities

Co-recycling concepts are complex and involve many actors, which poses challenges for network management.

For clear responsibilities, an umbrella organization at the government level, but also central and long-term responsibilities at the regional, local, and operational levels are necessary. As in the case studies, the actors must be motivated to pursue common goals. As a result, fluctuations, or other challenges in the supply chain between the collection, transport, and distribution can be better managed.

Site planning is another important aspect here to meet the needs of farmers, residents, and infrastructure, which is why the case study selection fell on semi-urban and semi-rural regions. Needs are, for example, the availability of resources, products, and markets as well as the elimination of middleman problems. In addition, it is the task of the central levels to look at the socially disadvantaged, such as waste pickers and smallholders so that they are not neglected in these concepts. In Nilgiris, women from socially disadvantaged backgrounds were offered a secure and better-paid job (compared to previous jobs) as a part of a self-help group in the co-composting facility.

For further training and promotion of the overall concept, exchange in an international network that integrates various thematic actors such as business and research is desirable. Both case studies are in international exchange with non-governmental organizations, universities, and civil society organizations.

A challenge in both case studies was that black water was occasionally discharged into the environment to save fuel for transport to the co-composting facility, which was addressed with strict controls and awareness programs. Honey suckers are often privately owned, while waste disposal is contracted by the municipality and has fewer problems in this regard. Safe and good working conditions are further aspects that help to reduce and stop dumping.

4. Discussion

4.1. Potential of Alternative Circular Co-Recycling Concepts

Looking at the different SDGs that can be directly addressed through the implementation of suitable cycle concepts [4,7,12] the potentials for compost, biogas, and the RUN concept differ within the considered framework. In India, due to the cost-benefit ratio, the greatest potential is seen in small and decentralized compost technologies [1,12,26]. Additionally, India has struggled with waste-to-energy methods such as incineration and pyrolysis, and mature technologies such as biogas fermenters and compost facilities are showing better success [26]. Large-scale biogas plants with subsequent composting were also seen as problematic [27]. Nevertheless, there is also a need for large cities to integrate incinerators with optimal separation for success [27], showing differences in approaches between urban and rural regions. Moreover, in the broader emerging market context, it is proposed to focus biodegradable waste on mature technologies (like biogas and compost) rather than expensive high-tech solutions (like RUN) [26,28,29].

Farmers who use co-recycling products to manage their land sustainably can also benefit, although there is no standard solution and the technology should be adapted to the circumstances [28]. Using black water after appropriate treatment improves sustainable

agricultural soils while providing a wastewater disposal solution [29]. Smallholders are sometimes exposed to a high price dependence of chemical fertilizers, which is why composted digestate and compost can be the best alternatives for them [11]. This shows that the best options to implement SDG 2, which relates to food security and sustainable agriculture, are mainly seen in the context of co-compost or vermicomposting [7,11]. In urban areas, in-vessel composting is a good solution to quickly produce hygienic and high-quality compost [30], again pointing to the need to differentiate between urban and rural areas.

Co-fermentation can improve biogas yield through synergy effects, which can contribute to SDG 7 in terms of affordable and clean energy [31–33]. A high-quality fertilizer is added to the energetic advantages [34]. Heavy metals can be within tolerable heavy metal limits here while composting and drying can completely remove pathogens [11]. Even if anthropogenic trace substances, such as harmful medicines, can be inactivated [15], more attention must be paid to this area for more clarity [14]. Decentralized installed biogas fermenters can create additional livelihoods in India and have a positive effect on health and the environment [35]. Biogas digesters are established and are therefore seen as an accessible and possible solution to energy, waste, and greenhouse gas problems, while being able to handle varying waste streams and can have modern emission control measures and high efficiency [36]. In both the Indian and global context, there is a dependency on political decisions as to which renewable energy sources are favored [37]. Biogas technologies are therefore in competition with other renewable energy technologies such as solar and wind in India [38].

Plant charcoal has the potential to reduce climate-relevant emissions, sustain soil health and enhance crop yields, especially in tropical soils [39]. There is also a big potential for recycling phosphorus, especially when using struvite fertilizer (which is also produced in the RUN concept) as it is considered a safe fertilizer [40]. Although high-tech solutions are promoted in India, they are problematic because the informal recycling sector is often not involved and these concepts frequently fail because they are not adapted to the waste composition [41]. The informal sector is an important part of waste management, so participation is necessary, also to improve working conditions and promote integration [27,38]. There already are successful integration approaches [42,43]. In addition, it has also been shown that transport and containers are more important for successful implementation than high investments [27].

4.2. Importance of the Methodology

Due to the high complexity and breadth of stakeholders, cooperation and interaction are considered important in this context in order to follow consistent paths in research and new implementation in practice [12]. The integration of different views and advice underlines the importance of the unifying aspect [12,35]. This is important to understand the interplay between the circular economy and the local context of the local and thematic experts and stakeholders [1,44]. Threats and opportunities are made visible by stakeholders, which is necessary for sustainable concept implementation [37]. These can be used to support specific calls for political support [37].

4.3. Potential of the Indicators

The categories technology, economy, ecology, social affairs and politics are mainly used for the circular economy [28,39,40,45,46]. It is assumed that political, economic, and legal aspects are the key indicators, and that ecological and social aspects are derived from them [37]. The inclusion of the stakeholder perspective shows a stronger focus on social aspects [47]. Here, our own categories and indicators as defined in the results section can be embedded.

In our study, great importance is attached to the category “connective” in the context of the circular economy. International cooperation is one of the main drivers for the optimization of circular economy concepts [36]. It benefits both Indian industry and communities in

the transfer of technologies that have proven beneficial in the promotion of health, energy, water and land conservation, and cost savings [1]. For the implementation, the leadership and commitment of top management coupled with clear and strong responsibility are the most important factors in the circular economy [45]. Added to this are the long-term and clear responsibilities of the municipalities in waste management [5,26,48].

A successful circular economy depends above all on the political will to create the necessary framework conditions, which underlines the role of the state. [1,38,39,48,49]. Otherwise, the hurdles are high and in many cases not profitable [46]. The high financial dependency in emerging countries is also due to the high investment costs, which makes clear the need for successful business principles [12,50]. The lack of a suitable market and good marketing of recycled products is also noted [50]. The potential of composting plants can be economical for several Asian countries if the framework conditions are right and, for example, good quality is guaranteed and the market value is given [49]. In this study, financial support is considered essential, since the framework conditions are currently designed in such a way that profitable implementation is not yet possible.

Similar economic and logistical factors can also be found in the context of the industrialized countries [37]. The fact that availability and logistics management is an essential factors in optimizing capacity utilization is consequently a global factor [35]. The database on the amount and composition of waste streams in India is often insufficient, which is necessary for optimally adapted technologies and scaling, which is why it is considered necessary to implement pilot plants first [27].

Technical aspects are contradictory. On the one hand, the lack of qualified specialists is seen as a key barrier [5], on the other hand, technical aspects for implementing a concept are seen as unproblematic [37]. The latter is confirmed in this study, based on the two case studies and the thematic expert interviews.

A key factor in social issues is the separation rate [27]. Communication innovation, consumer behavior, acceptance, and continuous awareness campaigns play an important role here [1,40,49]. Both in India and worldwide there is a need for improvement in civil society awareness of waste management and separate disposal [48].

Another persistent problem is the illegal dumping of waste and black water into the environment to save on fuel costs [47]. This study shows that awareness programs and rigorous reviews can reduce this.

If the composting facility is operated improperly, there is a risk of pathogens in the compost as well as nitrogen and carbon, which can escape into the environment as gases that are harmful to the climate [7,15]. Samples show that Indian and international standards for heavy metal levels in major Indian cities are not always undercut [8]. To counteract this, tests are carried out regularly.

4.4. Data Quality and Limitations

By integrating different stakeholders with different backgrounds, the results could be influenced by how familiar the interviewees are with each circular economy technology [37]. There are limitations due to the number of actors and case studies as well as the regional perspective.

4.5. Further Research

The transferability of these indicators to other regions in India as well as to other countries could be further explored as overlaps have been identified. Additional case studies should be included to support the findings. Additionally, this study shows that alternative solutions for miscalled facilities and better planning tools are needed to appropriately scale new facilities, which also points to improved and adapted management systems and network management. To ensure sustainability, broader interest groups should also be considered and involved.

5. Conclusions

Overall, biogas received partial support from stakeholders' perspectives, with co-composting of black water and wet waste being the most popular, underlined by numerous positive arguments packaged as indicators. The current situation in South India shows a focus on these mature technologies and the majority sees great potential in co-compost in particular. The most difficult perceived scenario in comparison was that of RUN's high-tech solution, with co-recycling generally raising more concerns than mono-recycling. Nevertheless, combinations with alternative and even more environmentally friendly concepts are seen, especially for the future once the pressing problems have been solved. Thus, RUN can be a good, decentralized option for prosperous new developments if the focus is on high compatible sustainability and recycling rates of valuable materials, closed loops, and reduced wastewater. It is agreed that there is no ultimate technology or concept. The choice depends on the circumstances and location but currently shows a clear preference as described.

This study also shows that the inclusion of the stakeholder's perspective and the focus on successful case studies lead to a realistic picture of the current situation and can contribute to the sustainable implementation of new circular economy concepts. This could be transformable not only for southern India but also for emerging countries, as there are global overlaps, as the discussion shows.

In conclusion, co-composting to close urban-rural cycles can address several SDGs and pressing issues in India, underscoring the urgent need to focus on implementation.

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