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SUSTAINABLE WASTE MANAGEMENT

Solid waste management of small island developing states—the case of the Seychelles: a systemic and collaborative study of Swiss and Seychellois students to support policy

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Abstract
Solid waste management (SWM) is a significant challenge for the Seychelles. Waste generation, fueled by economic development and tourism, increases steadily, while landfilling continues to be the main disposal path, thus exacerbating the island nation's specific weaknesses. Due to the small scale of the Seychelles economy, there is little capital available to stimulate innovations in SWM and generate the knowledge for setting priorities and guiding SWM action. Students from ETH Zurich and UniSey conducted a transdisciplinary case study (tdCS) to fill this knowledge gap and gain insights into the obstacles and opportunities related to sustainable SWM. The tdCS approach allowed students to gain comprehensive and in-depth knowledge about the SWM system required to set priorities for action and next steps. The government should streamline the different financial frameworks according to a clear principle (e.g., polluter pays principle). Specific biogenic waste streams represent a potential source of energy and fertilizers. Expanding the scope and densifying the network of collection points could help raise recycling rates of other waste fractions. Diverting biogenic waste and recycling more glass, metals, paper, and plastics would also significantly reduce landfilling rates. Regardless of future amounts of waste ending up on landfills, the latter must be reengineered before the surrounding environment suffers major adverse impacts. All these actions imply a government-driven approach which integrates the views of stakeholders and consumers alike.

Keywords Anaerobic digestion · Landfilling · Policy · Recycling · Seychelles · Small island developing state · Transdisciplinary case study · Waste management

Introduction

Background

The Seychelles is a small island developing state (SIDS) in the Indian Ocean heavily reliant on tourism and fisheries for its economy. The Seychelles faces unique economic and ecological challenges, characterized by particular vulnerability to climate change effects, land scarcity, and fluctuations in global markets. Sustainable development—at the intersection of economy, society, and ecology (Elkington 1994, 1998)—is therefore crucial to the Seychelles. Yet like other SIDSs, the Seychelles lack the human and financial resources to conduct the research necessary to understand wicked sustainability problems (Ackoff 1974; Lazarevic et al. 2012; Rittel and Webber 1973) and derive priorities for action. The usual way to cope with this resource scarcity is to rely on external technical consultants often funded by international organizations and institutions.

We present an alternative in the form of a collaborative students' project. If well prepared and coached, such projects—transdisciplinary case studies (tdCS)—can deliver broad and in-depth knowledge about a challenge in a relatively short time (Stauffacher et al. 2006). In 2016, a tdCS was organized jointly with the University of Seychelles (UniSey) and the Ministry of Environment, Energy, and Climate

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Change (MEEC) and conducted by students and faculty from ETH Zurich and UniSey. Solid waste management (SWM) was selected as topic of the tdCS due to its high ranking on MEEC's agenda. The main output of the tdCS is the report on SWM in the Seychelles (Lai et al. 2016). The present contribution presents the case study design, provides a synthesis of the results, and closes with the tdCS conclusions as well as the priorities and next steps as sketched by government representatives and tdCS coaches during a half-day workshop, which started with the presentation of the tdCS report.

Challenges of solid waste management in small island developing states and the Seychelles

SWM is a major issue affecting both developed and developing economies. One of the main SWM challenges is the increasing amount of waste generated annually (Wilson 2015). Economic growth, industrialization, population rise, and elevated standards of living are often correlated with increases in waste generation (Kothari et al. 2014). Besides waste generation, SIDSs have specific institutional, financial, technical, and educational SWM challenges, as summarized by Mohee et al. (2015). The review highlighted that SIDSs often struggle to produce clear policies and strategies to promote sustainable SWM, have little access to proper funding to set up the required SWM systems, lack the infrastructure to support SWM systems (e.g., paved roads and industrial land), and depend largely on foreign SWM know-how. All islands seem to face most of these challenges, regardless of their development stage or political status (Eckelman et al. 2014). A typical institutional challenge small island states or municipalities encounter is the difficulty in landfill planning and construction, as demonstrated by the existing body of literature on this topic (Chen et al. 2005; Kontos et al. 2003; Morrison and Munro 1999; Ramjeawon and Beerachee 2008). As for economies dependent on tourism, SWM is considered one of the most important environmental aspects in long-term development (Muñoz and Navia 2015). Manomaivibool (2015) found that tourists in a Thai tourism destination produced double the amount of waste compared to locals. On the island of Hawaii, Saito (2013) estimated that the tourism sector generated in 2010 10.7% of the island-wide waste. Arbulu et al. (2017) showed with an IPAT-based model that an increase of 1% on tourist arrivals growth rate in Mallorca would lead to an increase of 1.25% in municipal solid waste (MSW) generation. In short, SIDSs which mainly rely on tourism for economic growth face greater SWM challenges than other countries typically would.

Waste generation in the Seychelles has increased recently due to market liberalization and economic development fueled particularly by tourism, which resulted in a dramatic increase of net imports of consumer goods and durables. From 2000 to 2016, net imports of goods increased by 450% (United Nations Statistics Division 2016). One can easily imagine the additional waste quantities coupled with such an increase. Waste amounts are likely to soar with per capita gross domestic product and population rising steadily in the last decades (IMF 2016; UN DESA 2015), in addition to the strong reliance on tourism as a key economic sector. Such a trend is unlikely to be reversible unless a radical change in consumption modes and tourism practices takes place. SWM in the Seychelles has been handled by STAR, a government-contracted company, since 1997. Presently, STAR landfills all major fractions of waste, with the exception of polyethylene terephthalate (PET), aluminum cans, and large scrap metal (Fig. 1). Landfilling is known to pose environmental concerns including leaching of pollutants (Kjeldsen et al. 2002), methane emissions (Adhikari et al. 2006; Nolasco et al. 2008), and resource depletion (Laurent et al. 2014a). Additionally, because land is scarce and expensive in the Seychelles, landfilling will incur significant costs to the government in the future, all the more so if remediation for purposes related to environmental protection, land reclamation, and/or public health must take place (Panagos et al. 2013). Landfill construction has so far not kept up with waste generation: unit 1

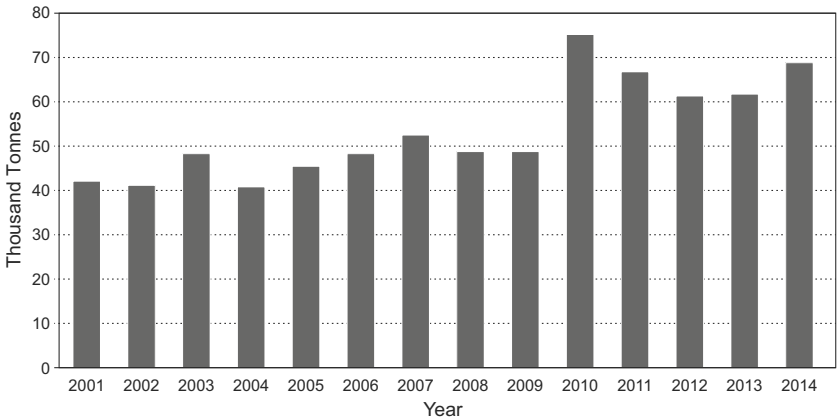

Fig. 1 Annual tonnage of waste delivered to the Providence landfills from 2001 to 2014 (Source: Landscape and Waste Management Agency, LWMA, adapted from Lai et al. 2016)

of the Providence II Landfill on Mahé, the largest island in the archipelago, is expected to reach full capacity much faster than the planned 10 years. Despite the future costs, the government has not yet implemented its targets for waste management or reduction (Lai et al. 2016; Talma and Martin 2013).

A particular challenge for SWM development in the Seychelles is scale. There is little financial and human capital available to support SWM projects, particularly to stimulate recycling initiatives or advanced waste treatment like incineration (Ramjeawon and Beerachee 2008). Additionally, the volume of total waste generated provides insufficient quantities to have economically viable treatment systems. The small economies of scale prevent waste businesses from generating revenues to overcome operation and investment costs. Consequently, and because costs of remediation are externalized to future generations, landfilling of all sorts of unsorted waste, including hazardous waste, without gas capture, is the cheapest option for waste treatment in the short-medium term. The Providence II landfill is one of three sanitary landfills in the Seychelles equipped with a composite plastic material to prevent leaching; yet, the leachate treatment facility was at the time of the study out of service.

Knowledge gap

Despite the pressing challenges in SWM, the current policymakers in the Seychelles lack a broad and up-to-date understanding of current solid SWM practices and potentials beyond what is known from individual consulting studies. Because these studies are highly specific to a certain topic, policymakers are forced to connect the dots between different economic sectors, various stakeholders, and seemingly unrelated waste streams (Morrison and Munro 1999). Only with such a big picture or systems analysis (Eckelman et al. 2014) can meaningful priorities be defined in order to avoid problem shifting (Laurent et al. 2012) so that next steps can be taken in an efficient way in the difficult context of SWM in small island states and municipalities. Material flow analysis (Brunner and Rechberger 2004; Eckelman and Chertow 2009) is just one among several systems analysis tools that allow generating a big picture of SWM. A broad understanding does not mean researchers should be superficial in their scope. On the contrary, in-depth enquiries should be possible to fill knowledge gaps and address specific, yet pressing issues.

The situation in the Seychelles is an example of a combination of serious challenges and lack of investment to generate the knowledge required to guide action. Therefore, new ways to fill the knowledge gaps are sorely needed. We propose a students' project as promising solution. In light of the Seychelles' SWM challenges, an interdisciplinary approach is required to yield the broad understanding described above. Last but not least, the approach should also be transdisciplinary in order to increase the chances of uptake of findings by stakeholders (Joos et al. 1999; Krütli et al. 2010): involving stakeholders in defining problems and formulating strategies for action and integrating stakeholder and expert knowledge into research itself.

Study goal and guiding questions

The goals of this case study were to understand contemporary SWM in the Seychelles and to gain insights into the obstacles and opportunities for sustainable SWM. The goal was broken down into three guiding questions:

1. What are institutional and financial challenges of SWM in the Seychelles? What is the fate of waste streams? How do consumers perceive the institutional and financial frameworks as well as the fate of waste streams? What are environmental risks posed by landfills?
2. What strategies do stakeholders such as the government, consumers, and waste managers propose in order to meet SWM challenges? What are obstacles preventing their implementation?
3. How could the future of waste management look like with an implementation of these strategies?

Answering these guiding questions lays the foundation for defining priorities and sketching next steps towards sustainable SWM in the Seychelles. With the case study, we also aim to demonstrate the feasibility of inter- and transdisciplinary research on SWM in small island states and municipalities and thus its potential contribution to solving waste issues in such specific contexts.

Methods

Description of the transdisciplinary case study

The tdCS team conducted the case study in two phases. During the semester from February through June 2016, ETH students engaged in literature review, background research, research plan development, and field phase preparation. About halfway through this period, the students engaged in a two-day workshop involving stakeholders from Sustainability for Seychelles (S4S) and the Landscape and Waste Management Agency (LWMA). This preparatory phase was followed by three weeks of intensive field research in the Seychelles in June–July 2016, a collaborative effort by both UniSey and ETH students.

One key output of the preparatory phase was the faceting of the case into seven subprojects to answer the guiding questions provided in section "Study goal and guiding questions". Indeed, to achieve a balance between a comprehensive,

systemic overview and in-depth work, the case study was split into smaller groups as depicted in Fig. 2. The key features used in this system picture were determined through a literature study of waste systems in SIDSs as well as respective key documents of the Seychelles. Integrated waste management can be separated into influencing factors—legal institutions, the economy, and societal behavior—and the phases of the waste cycle: waste production, waste collection, and waste disposal/recycling. Accordingly, the case study was split into seven groups of 18 ETH Zurich master's students with diverse disciplinary backgrounds and 18 bachelor's students at UniSey. The research questions developed and methods employed by each group are described in section "Research questions and methods".

Researchers and teachers from ETH Zurich and UniSey guided students throughout the case study. An advisory board bringing together the MEECC and administration, business, and civil society provided additional support. Students intensively engaged with a variety of stakeholders from government, administration, business, NGOs, and civil society. More information on the didactics related to student coaching and transdisciplinary tools to develop the system picture and research design can be found in Krütli et al. (2018).

Research questions and methods

In Table 1, we provide an overview of methods used in the seven topics, including research questions. Each research question contributes to at least one of the three guiding questions presented in section "Study goal and guiding questions". The reader is referred to the tdCS report (Lai et al. 2016) for more information on methods and materials as well as on the students involved in each subproject.

Results and discussion

In this section and following the sequence of the tdCS guiding questions, we present and discuss the most important and striking results. We first address the contemporary state of SWM in terms of the institutional and financial frameworks and strategies suggested by stakeholders for improvement. We proceed in the same way with respect to the fate of waste streams. We then report on and discuss consumer awareness with respect to frameworks and waste streams. We close the section by reporting on feasibility spaces of future SWM in the Seychelles. Detailed results can be found in the tdCS report (Lai et al. 2016).

Institutional and financial frameworks

The government outlined goals in its policies and plans to take on waste management, but many have not been realized. The students' analysis of the legal framework found that governmental organizations face three significant obstacles preventing their implementation: unclear allocation of responsibilities, lack of financial flexibility, and unspecific policy. In particular, the analysis revealed that there is a strong emphasis on goals, targets, priorities, strategies, etc., while there is little practical documentation on how to implement these goals, e.g., guidelines for setting up collection points or collecting waste-related data. Guidance on waste management operations is of critical importance for ensuring smooth functioning of organizations handling waste. Malta, an island state of the EU, provides guidance documents and reporting templates for producers of different types of waste: packaging waste, waste electrical and electronic equipment

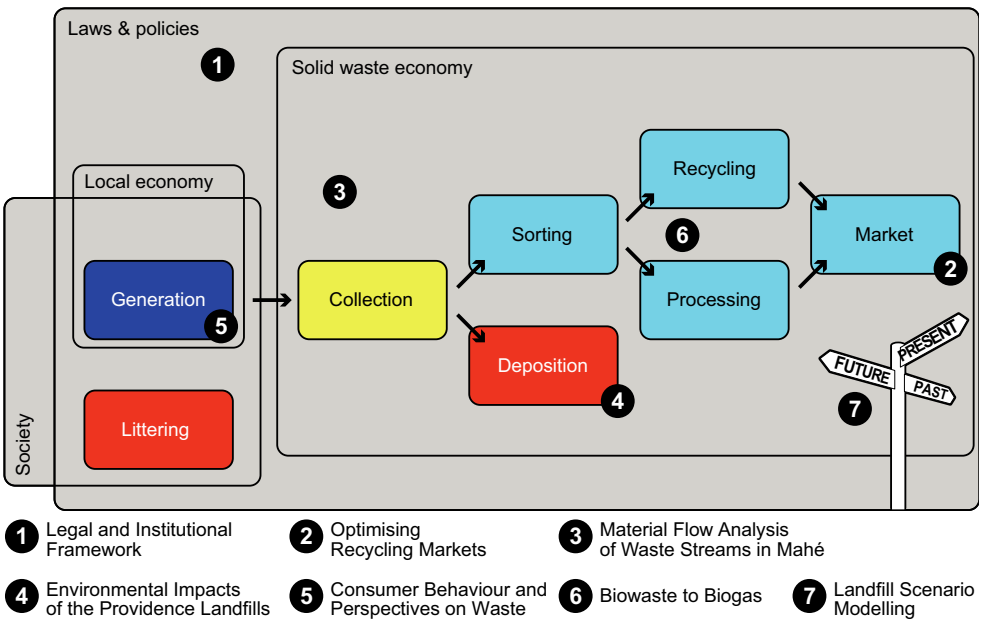

Fig. 2 Case study system picture and group breakdown (adapted from Lai et al. 2016)

Table 1 Description of subprojects with respect to research questions and associated methods; numbers next to the research questions refer to the three main tdCS guiding questions

Subprojects	Research questions	Method(s)
1. Legal and institutional framework	What are the legal and institutional frameworks of SWM and how do they function? (**1**) How does collaboration between SWM actors take place, as well as internally within these institutions themselves? (**1**) What financial mechanisms currently exist/are available and how can they be applied to SWM? (**1**)	Document analysis Semi-structured interviews with 17 stakeholders from consultancy, government, industry (STAR), and NGOs
2. Recycling markets	What is the current state of the recycling systems in terms of the relevant stakeholders and recycling initiatives, past and present? (**1**) What options for waste separation and collection exist and how can they be improved? (**1**, **2**) What are perspectives on recycling and recycled products at the household level? (**1**, **2**)	Document analysis Semi-structured interviews with 13 stakeholders from government, industry (recycling and waste management companies), and NGOs Household surveys (23 consumers)
3. Material flow analysis of waste streams in Mahé	What types of products (classified by material) enter the Seychelles and in what quantities? (**1**) How do materials in each stream exit the Mahé system and in what quantities? (**1**) How are the materials used in terms of their flows between stakeholders? (**1**)	Material flow analysis/accounting (MFA, Brunner and Rechberger 2004) of PET bottles, cans (steel and aluminum), glass, scrap metal, and paper and cardboard in Mahé
4. Environmental impacts of landfills	Can substances in waters surrounding the Providence landfills be identified and measured to serve as evidence of landfill leaching? (**1**) Do certain stakeholders observe changes in the environmental conditions of the vicinity of the Providence landfills and to what extent do they connect this to possible leachate from the landfills? (**1**) How do governmental and non-governmental stakeholders perceive the state of the landfills? (**1**, **2**)	Inductively coupled plasma optical emission spectrometry (ICP-OES) of inorganic compound parameters of water samples at 10 different sites surrounding the landfills Providence I and II on Mahé (outlets from the leachate pre-treatment plant (LPTP) of Providence II, coastal waters, ponds, and groundwater). Among the 10 sites, one is a reference site (R-0407-1), located on the east coast of Mahé, south of the landfill where there are fewer industries nearby. Semi-structured interviews with 15 representatives of associations (Seychelles Fishing and Boat Owners Association), government, industry, and scientific research
5. Consumer's perspective	How do consumers perceive waste management in the Seychelles? (**1**, **2**) What are decisive purchase criteria from the perspectives of consumers and retailers? (**1**, **2**)	Semi-structured interviews with 40 consumers and 15 retailers
6. Potential for biogas production	Which suppliers offer high potential feedstock for an anaerobic digester yielding biogas and organic fertilizers? (**3**) What is the demand for the end products? (**3**)	Potential biogenic waste suppliers ranked with multi-criteria analysis (MCA, Dodgson et al. 2009) with following criteria: - Biogas yield - Complexity of pre-treatment - Seasonality - Amount currently going to landfill - Value of feedstock - Organic dry matter (volatile solids, VS) - Distance to supplier For each supplier, the ranks were averaged to a single score. Semi structured interviews with 31 feedstock suppliers and customer stakeholders
7. Landfill scenario modeling	What could the total amount of waste landfilled over the next 25 years be under a "business as usual" (BAU) scenario? (**3**) What events, policies, and other developments affect landfilling rates? (**3**)	Storyline-and-Simulation (SAS) approach (Alcamo 2001, 2008) - Time horizon: 2040 (as in Seychelles Strategic Plan: Sustainability Appraisal Report (UPC 2015)) - Identification of impact factors of waste landfilling rates based on literature - Construction of a model of waste landfilling rates in the Seychelles as a function of impact factors (here population and economic growth) and landfilling tonnages in 2015 - Storyline development based on literature, expert knowledge, and other information - Implementation of storylines in waste landfilling rate model The impact of different storylines, e.g., a development with respect to treatment of biogenic waste, on the amount of waste landfilled in the future was quantified with the waste landfilling rate model.

(WEEE), old batteries and accumulators, as well as end-of-life vehicles (ELVs).[1] Moreover, financial mechanisms are incoherent: a levy on cans and PET bottles financing their collection feeds into a waste management fund, while a household monthly tariff supporting collection and landfilling of mixed waste flows directly into the state budget instead. Such observations could help refine the institutional and financial challenges SIDSs face in SWM as identified by Mohee et al. (2015). Lohri et al. (2014) suggest a more sustainable financing scheme of SWM than fixed tariffs, a scheme allocating costs to affluent waste producers and to the state that should recover such costs directly through property and income taxes. Such a scheme could complement the polluter pays principle (Abu Qdais 2007) and has the advantage of making available resources to safeguard public goods (e.g., prevent pollution from landfills).

The analysis revealed two concrete issues hindering sustainable SWM in the Seychelles. In the contract between the competent waste management authority, LWMA, and STAR, LWMA is required to pay STAR per ton of waste tipped at the landfill. In practice though, STAR is paid a flat fee of 6 million SCR (ca. 360,000 EUR or 450,000 USD) per month. In either cases, STAR has no incentive to divert waste from the landfill, although STAR intended 20 years ago, when the contract was made, to handle different waste streams with the aim of diverting recyclables from the landfill. This has for unknown reasons not been implemented. Another issue affecting institutions is the lack of appropriate reporting. Law mandates the competent waste management authority, the LWMA, to monitor contracted waste collection and provide statistical data on waste generated, processed, and disposed. Yet, stakeholder interviews hinted at the lack of systematic data collection and reporting, which is known to be crucial for planning (Wilson 2015).

In interviews, stakeholders suggested ways of overcoming the institutional and financial challenges of SWM in the Seychelles. STAR, the company currently responsible for waste management, could be paid according to tonnage of waste diverted from landfills, instead of receiving a flat fee per month. In other words, the waste management company would be paid according to performance indicators (Bartone et al. 1991). Performance indicators can be linked to environmental impacts (Meylan et al. 2013), so that the company is incentivized to set up collection schemes. However, such a change would require a new contract between the Seychelles government and the waste management company. The opportunity for such a change presented itself at the end of 2016, as STAR's contract expired then. The government implemented a two-year interim solution in order to find a new contractor. In addition, the government is considering reducing the contract duration of 20 years in order to stimulate competition. Typically, such contracts last 4 to 8 years in other countries, enough for private companies to recover investments in fleets and equipment (Bartone et al. 1991). Finally, stakeholders suggested introducing a bed fee for tourists, which would contribute to shifting the financial burden of SWM to the most affluent waste producers (Lohri et al. 2014) and making available resources to safeguard public goods.

[1] http://era.org.mt/en/Pages/Producer-Responsibility.aspx

Fate of waste streams

Biogenic waste is one of the main components of total waste going to landfills (approx. 50% of collected waste, Wilson 2004). The current management scheme of PET bottles, cans, paper, and glass is displayed in Fig. 3a). Nearly all material streams enter the Seychelles as imports because local production is on a small scale, if existent, and is therefore negligible. The main waste management facilities in the Seychelles include redeem centers, landfills, and privately owned facilities processing separately collected waste into new products or preprocessing it for export. Figure 4 provides a map of the main SWM infrastructure on the main island Mahé. Consumers can bring back PET bottles and metal cans to redeem centers and in exchange redeem monetary deposits. There are four redeem centers on Mahé and one each on Praslin and La Digue, two smaller islands. There are five landfills, three on Mahé and one each on Praslin and La Digue. On Mahé, the Providence I and II landfills receive any kind of waste, while the Anse Royale landfill accepts only inert waste. As of 2016, Providence I had virtually reached its capacity, and Providence II (unit 1) was expected to have enough capacity to be in operation for 9 years. The government-contracted company STAR conveys municipal and commercial waste to landfills. As for privately owned facilities processing waste into new products, the SeyBrew beer brewer reuses glass bottles from consumers, Rogan downcycles glass to construction material, and Navin upcycles waste paper to egg trays, take-away boxes, and other products. PET bottles and metal cans are preprocessed (e.g., PET pressed into bales) prior to export by Harini and DE-Recycling, respectively.

The MFAs showed that paper and glass fractions mostly go to landfills, except for small fractions which are diverted and recovered by individual recycling companies, i.e., Navin and Rogan. The informal sector collects large proportions of cans and PET bottles from public bins, litter, and the landfill itself. The informal collectors are financially compensated through the levy system when they bring these items to the redeem centers. Applying MFA to the four waste streams not only revealed the amounts landfilled each year compared to recycling, but also the need for better, more reliable data. The latter are crucial to ensure sound planning with respect to infrastructure and financing (Arena and Di Gregorio 2014;

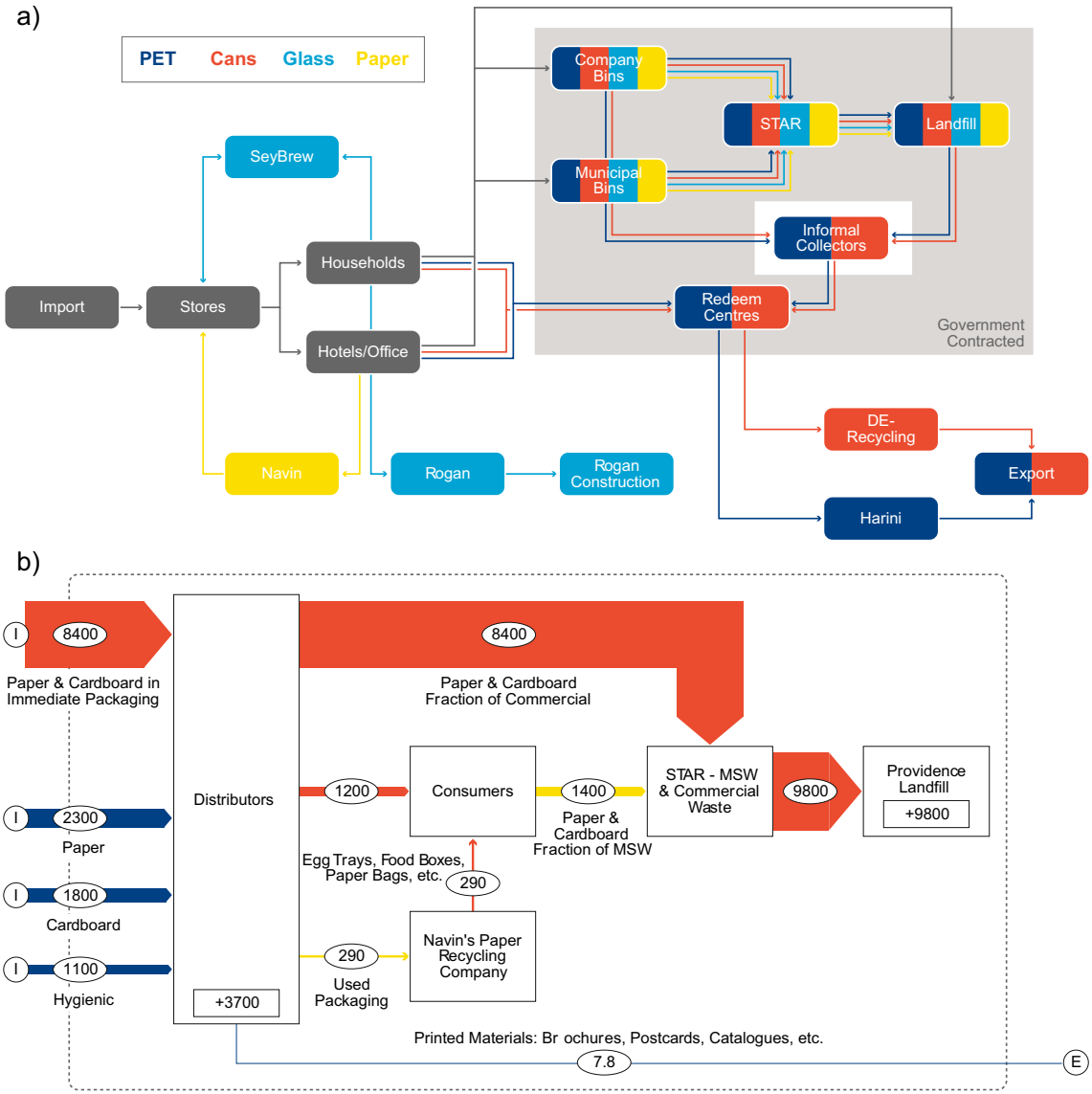

Fig. 3 **a** System diagram of the recycling scheme in the Seychelles for the waste streams PET, cans, paper, and glass, where arrows indicate the material flows and **b** 2014 material flows of paper and cardboard on Mahé with red arrows indicating high data uncertainty, yellow average uncertainty, and blue low uncertainty (numbers are in metric tons and were rounded to two significant figures; I: Import flows, E: Export flows; adapted from Lai et al. 2016)

Meinzinger et al. 2009). The material flows of paper are illustrated as an example in Fig. 3b. The material flows of the three other waste streams are available in the tdCS report (Lai et al. 2016).

Biogenic waste represents the largest share of waste amounts going to landfill on Mahé, so that diverting it could significantly increase the landfill lifetime. At the same time, biogenic waste represents a valuable source of energy and fertilizer, as acknowledged by the Seychelles government itself. Yet, tapping efficiently and sustainably into this resource in SIDSs requires a systematic analysis of biogenic waste supply on Mahé (Bundhoo et al. 2016). The students therefore decided to conduct an analysis of potential biogenic waste suppliers for biogas and fertilizer production to inform future strategy formulation (see section "The future of solid waste management in the Seychelles").

Glass and paper still go to a large extent to landfills. However, many stakeholders state that there is a latent potential for paper recycling through upcycling to biodegradable containers, export, or as biogas plant feedstock. As for product opportunities for glass, they range from exported glass to downcycled construction aggregate, upcycled art materials, and landfill stabilizer. Likewise, Eckelman and Chertow (2009) have found recycling glass in the construction sector to be an interesting opportunity in the island of Oahu, Hawaii. Nevertheless, members of government agencies would only like to support recycling initiatives that have a clear market potential on the local/national levels, thereby revealing a

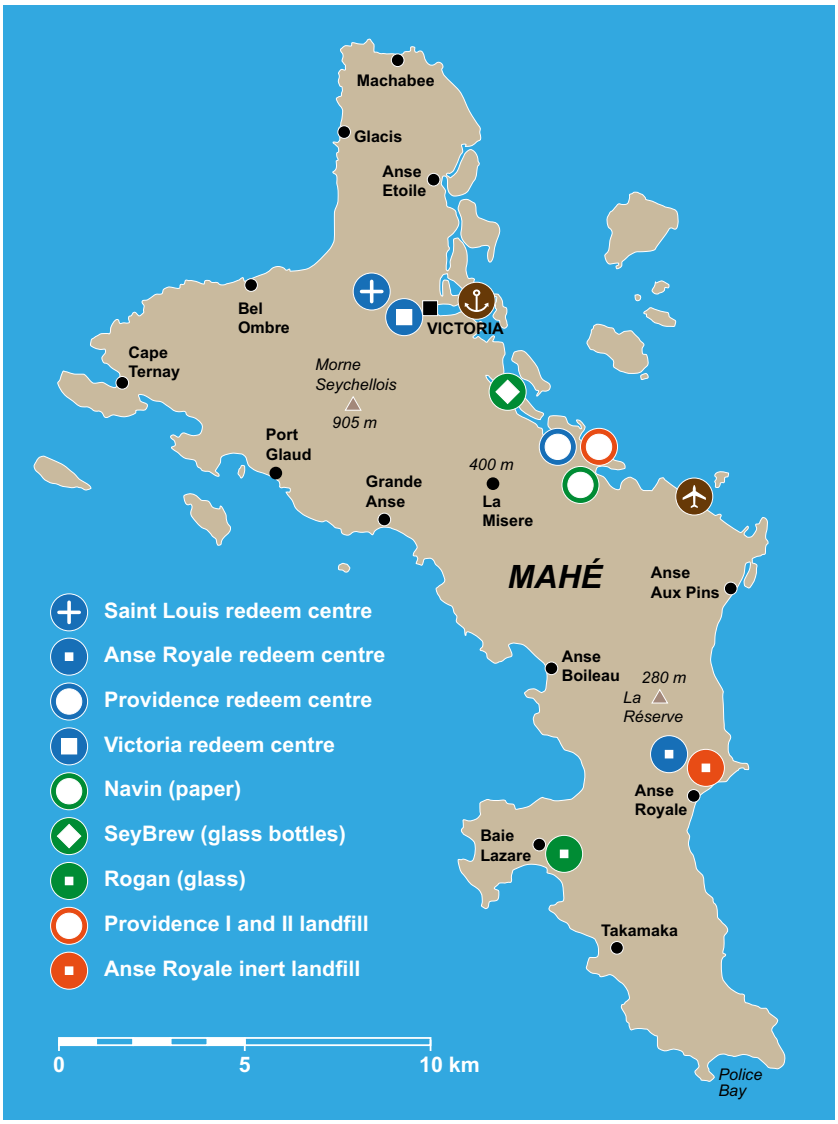

Fig. 4 Main SWM facilities on the main island Mahé

market-pull attitude in contrast to resorting to technology-push regulations (Horbach et al. 2012). As for cans and PET bottles, some stakeholders suggest that collection can be improved to increase recycling rates further. Potential can and PET collection systems named by stakeholders include collection at households, schools and businesses, collection at centralized bins, and collection of a wider range of PET and aluminum items. The household surveys showed that the public is not only supportive of separating recyclable materials as in other settings (e.g., in Macau, see Song et al. 2016), but also of purchasing recycled products. Interestingly, the majority of survey respondents think that recyclables should be collected on a monthly basis. However, such a frequency might discourage households from recycling in contrast to alternate weekly collection (AWC), where recyclables and mixed waste are collected on alternate weeks (McLeod and Cherrett 2008; WRAP 2007). The focus of stakeholders and consumers on increasing recycling rates prompted the students to conduct a scenario analysis of waste amounts deposited on the Providence II landfill as support for future strategy formulation (see section "The future of solid waste management in the Seychelles").

Consumer awareness

In a non-representative survey of consumer awareness, respondents most often named "littering", "no recycling", and "amount of waste" as problematic aspects related to waste. The interested reader can find the other named problematic aspects in the tdCS report (Lai et al. 2016). People's attitude, known to be important for a well-functioning and effective SWM (Mohee et al. 2015; Squires 2006), was hardly mentioned. Moreover, a majority of survey respondents did not realize that they pay a monthly tariff of 40 Seychelles Rupees (SCR) as part of their household bills. Such lack of awareness regarding payment of SWM services could have

made the Seychellois population less critical of this service. De Witte et al. (2006) postulated that the awareness of being charged made users more critical in the case of free versus tariff-based public transportation. Any public communication campaign (Rice and Atkin 2013) should thus start with stating clearly the current cost borne by consumers for SWM services and emphasize the importance of citizens for the success of SWM.

The survey further showed that a majority of consumers are not willing to pay the current tariff of SWM (40 SCR per month), see Fig. 5. Yet, if recommendations of these same consumers were to be implemented, 38% would be willing to pay more than the current tariff. The suggested recommendations included improvement of laws and regulations and more recycling on the one hand, and more bins, enhanced transparency, and education campaigns on the other. The latter recommendations are relatively low-cost solutions and could be implemented rather quickly. Education campaigns should target youth and take place in the school context (Zorpas et al. 2017). The results of the survey on willingness to pay (WTP) are in accordance with observations elsewhere that WTP strongly correlates with satisfaction with SWM services (Afroz et al. 2009; Jones et al. 2010).

The future of solid waste management in the Seychelles

The research question related to future waste management in the Seychelles was broken down into an analysis of options for diverting biogenic waste from landfills and the construction of landfill scenarios. Biogenic waste is one of the main components of total waste going to landfills (approx. 50% of collected waste). No comprehensive analysis has been performed so far to investigate the future of the Seychelles' waste management system and allow for systematic planning.

Figure 6 shows the average ranks of the potential suppliers of biogenic waste on Mahé for biogas production through anaerobic digestion (AD). A higher average rank on Fig. 6 indicates a higher potential of the supplier. Indian Ocean Tuna Ltd. (IOT, fish processor), PUC (Public Utilities Corporation), Seybrew (brewery), and hotels or restaurants providing waste oil supply the feedstock with the highest potential. Ranked below the industrial companies and waste oil producers are farmers which provide manure. The suppliers with lowest average ranks are those generating food and green waste. Industrial companies tend to have feedstocks that achieve high ranks in the amount of waste going to landfill as well as in the amount of volatile solids (VS) produced. Kitchen oil receives a high ranking in the biogas yield category because it yields 1285 m^3 of biogas per ton, which is double or more the value achieved by other waste streams. However, all suppliers of waste oil achieve low ranks in seasonal variation, waste quality, and quantity indicator categories. Studies in the literature show that the addition of small amounts of grease to the influent can lead to a drastic increase of the overall biogas production (Lansing et al. 2010). However, if the share of oil used for AD becomes too high, biogas yields decrease again. Fats are degraded relatively slowly, and the use of co-substrates to increase degradation rates also increases maintenance costs (Czepuk et al. 2006; Deublein and Steinhauser 2011). Manure from farmers achieved high rankings in the VS generation category, but had a low ranking in the 'amounts currently landfilled' criterion, as manure is not currently dumped in the landfill. The biogas yield of manure is below average compared to the other alternatives. Green and food waste from hotels and restaurants have the lowest average ranking. While it has a high biogas yield compared to the average, these waste streams have a low VS production, represent small amounts currently landfilled, and are far away from the Providence Landfill. Additionally, kitchen waste with high salinity and fat contents can pose serious problems to AD (Yang et al. 2013). A sensitivity analysis showed that variability in the rankings is low when using low, mean, or high literature values for VS and biogas yields. In conclusion, some waste types represent a promising AD feedstock and others not, regardless of their providers.

Figure 7 shows the impacts of a business-as-usual (BAU) scenario and individual storylines of waste disposal on the landfill in terms of reduced amounts. On the plot, each storyline surface represents the amounts of waste reduced

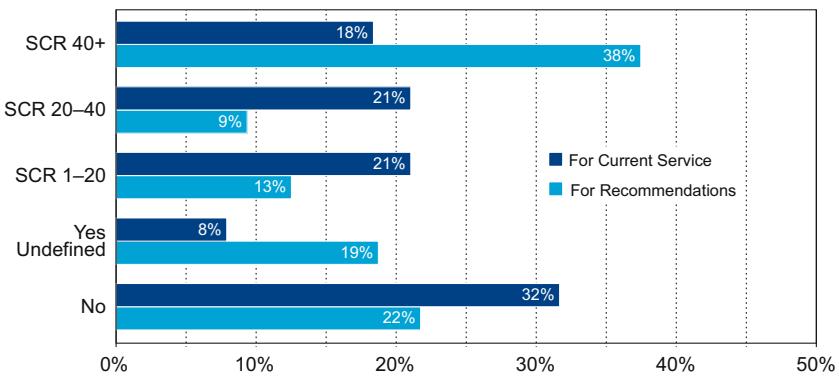

Fig. 5 Amount per month which people are willing to pay for the current system and for a service integrating the proposed recommendations. Percentages refer to the total number of people who expressed their willingness to pay ($N = 26$ for current service; $N = 25$ for improved services according to their recommendation) (adapted from Lai et al. 2016)

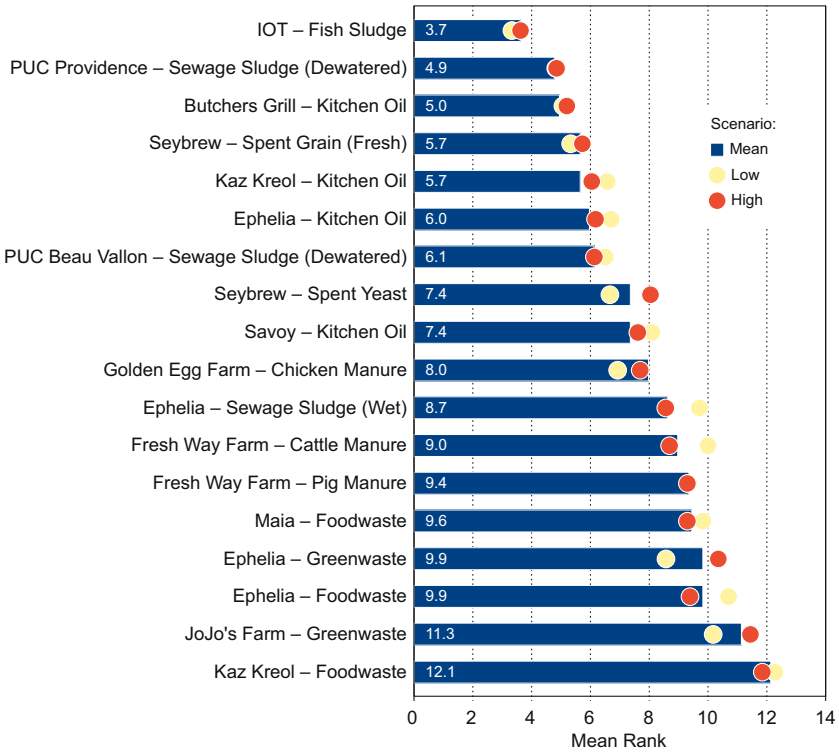

Fig. 6 Mean rank of each supplier of biogenic waste according to the MCA criteria, with "low," "mean," and "high" values for VS and biogas yield, respectively (the higher the rank, the higher the potential of the supplier) (Lai et al. 2016)

thanks to the storyline. In the BAU scenario, landfilling rates of each waste stream for each year are a function of landfilling tonnages of that waste stream in 2015, population growth, and GDP growth and therefore reflect current trends of waste landfilling. The BAU scenario corresponds to the total colored surface on the plot and suggests that a total landfilling capacity of approx. 3.5 million tons would be needed between 2015 and 2040. This is multiple of the capacity of Providence II. Storyline 1 corresponds to a steady decoupling of economic growth and waste generation. The decoupling goes from 0 to 20% in 2040. The 20% value is based on observations in OECD and EU-27 countries which have implemented waste reduction strategies in the past (Inglezakis et al. 2012; Mazzanti and Zoboli 2008; OECD 2011). Storyline 2 reflects the implementation of AD for biogenic waste. Storyline 3 is the introduction of cardboard and paper recycling. Finally, Storyline 4 proposes the ban of some plastic imports and the export of a broad range of plastic wastes. The combined storylines could allow keeping landfill rates at the levels of the year 2000 and accumulated waste going to landfill would be dramatically reduced to approx. 1.2 million tons between 2015 and 2040.

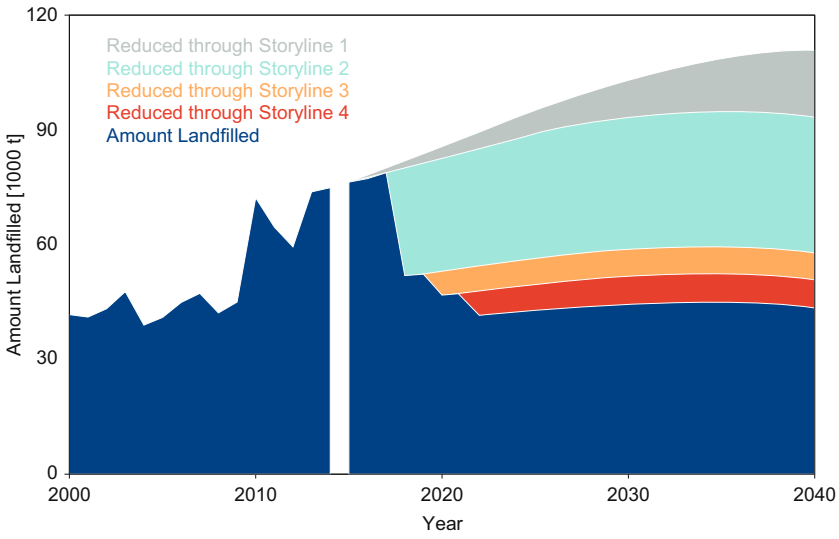

Fig. 7 Annual amount landfilled under low economic and population growth scenarios as a function of storylines (Lai et al. 2016)

Limitations of the case study and further research

One of the main limitations of the study is the lack of reliable quantitative information on waste streams due to poor data as highlighted by the MFA of paper presented in section "Fate of waste streams". Such information is a necessary condition for the sound planning of SWM activities (Arena and Di Gregorio 2014; Meinzinger et al. 2009) and the reliable quantification of recycling potentials, e.g., to substitute imports of primary materials, one of the starting points of the tdCS. To cope with often poor and scarce data, approaches have been recently developed and applied to individual cases to assess the reliability of an MFA as a function of input data quality (Schwab and Rechberger 2017). Reliability assessments not only provide decision-makers with quantitative uncertainty indicators, but also help orient data collection efforts towards those MFAs least reliable. Further research on waste streams could include a cost-benefit analysis yielding the optimal collection rates, i.e., rates at which the economic benefit of diverting waste from the landfill is largest compared to the effort to collect recyclables (Hanley and Slark 1994; Lavee 2010).

All case study consumer and household surveys were non-representative of the total Seychelles population; therefore, their results should be taken as indications rather than as legitimate bases for policy-making. Moreover, some potentially insightful aspects were not covered, e.g., the awareness of consumers of how their solid waste is managed. Yet, surveys altogether might not be the best approach to elicit information such as recommendations for SWM improvement or WTP. In Switzerland for instance, draft regulations (not only in SWM) undergo a consultation procedure, in which stakeholders including civil society, industry, and public sector state their opinion on the draft and suggest their own changes to legislation (Duygan et al. 2017). This approach enables the confrontation of preferences backed by arguments of both practice experts and non-experts. Alternatively, deliberative processes combine consultation of and recommendations by citizens with expert inputs at the demand of these same citizens. The purpose of deliberative processes is to strike a balance between societal interest, rational decision-making, and technical expertise (Arriaga 2014; Petts 2001).

The surveys focused on the willingness to pay by consumers. Yet, as argued in section "Institutional and financial frameworks", it might be more meaningful to make affluent groups pay more for waste management, including tourists through a bed fee. It would thus be interesting to know what is the WTP of the (i) Seychelles tourist industry and (ii) tourists in the Seychelles for SWM. Such a study in the Seychelles or other similar touristic resorts has, to our knowledge, not been conducted, but case studies demonstrated the existence of tourists' willingness to pay for environmental protection in general (e.g., in Thailand, see Dodds et al. 2010).

Due to the lack of data and resources to collect such data, the study lacks key indicators of waste management. Waste generation per capita would have allowed benchmarking the Seychelles against other islands (Eckelman et al. 2014). Such benchmarks could help waste authorities argue for more prevention when talking to the broader public or government. Various recycling metrics, such as the end-of-life recycling rate, give a very concrete sense of how closed or linear an economy is and are a crucial indicator when it comes to measuring progress (Haupt et al. 2017). Once such indicators are available, one can venture further into more aggregate indicators. The MFAs of cans, glass, paper and cardboard, and PET bottles do not indicate what the environmental impacts of these material systems are, yet would provide the basis to conduct a life cycle assessment yielding such single scores (Laurent et al. 2014a, b). Other aggregate indicators have been developed especially for waste management such as the landfill water pollution index (LWPI, Talalaj and Biedka 2016) or sustainability potential analysis (SPA, Lang et al. 2007). LWPI and SPA could be useful in the Seychelles and other SIDSs. In turn, the application of such indicators to the SIDS context could help refine them.

Conclusions and outlook

Conclusions

Overall, the systemic approach applied in the 2016 tdCS points out fields where action and additional, focused research is needed. The multiple disciplines involved and close interaction with stakeholders demonstrate the potential of student projects to establish on-site data collection and provide key SWM insights in a context with serious lack of information and of resources to fill the research gaps. The results suggest that major SWM stakeholders require a government-driven, integrative approach to better manage waste in the long term. Conclusions from the results of the seven subprojects can be made at three levels, which might be relevant to other SIDSs facing similar SWM issues.

The first level is executive action. The Seychelles government must establish clear waste management responsibilities based on a sustainable waste strategy. In other words, it must define who is responsible for executing what tasks. Considering the body of government texts on SWM, it seems that many efforts have been put so far on strategies and higher-level legal prescriptions, e.g., the Environmental Protection Act. Yet, waste management entails many tasks of technical and administrative nature, which in turn vary strongly depending on the waste streams. Hence, the government must design technical advice for the implementation of waste management to guide stakeholders in their day-to-day business. In this task and in others designed to transition towards sustainable SWM,

there are indications that the government can expect support from the population.

The second level of conclusions relates to multi-stakeholder collaboration, which is indispensable to tackle the biggest challenges the Seychelles face in SWM. Source separation at households and business should be promoted through appropriate collection infrastructure and information campaigns. This, however, makes sense only if the separated fractions find a corresponding recycling or waste treatment stream. Accordingly, further in-depth studies on waste sorting schemes must be strongly linked to studies focusing on post-sorting activities such as recycling, anaerobic digestion, gasification, or combustion (Pan et al. 2015). Recycling and downcycling opportunities for waste streams could be first validated and tested in pilot projects. Here, local NGOs, with their field experience, are potential partners. Clear and well-accepted goals should be defined before implementing or supporting an AD system. Finally, all stakeholders will have to collaborate to face the greatest SWM challenge in the Seychelles, that of implementing multiple measures to divert waste from landfills and avoid burdening future generations of Seychellois with the weight of remediation. Yet, even if all measures stakeholders think of are taken, further landfills—on reclaimed land—will be needed by 2040 unless additional treatment options such as combustion are implemented.

Regular and long-term monitoring of water bodies surrounding Providence II should be prioritized in order to preserve fishing resources and keep the natural environment intact. Organizations collecting or treating waste must report material inputs and outputs to allow for planning. Providing waste businesses with standardized reporting sheets can facilitate reporting activities, often considered by businesses as a tedious task. Material flow analysis can help accelerate and streamline the processing of collected data and become a useful planning tool for authorities.

Outlook

In a half-day workshop following completion of the case study report, government representatives were presented with the conclusions and discussed with the tdCS coaches short- and long-term priorities for action, based on the results and conclusions of the case study. These priorities included the creation of data management systems and lower-level regulations (e.g., a strong waste management regulation), a feasibility study on AD, and expanding the number and scope of redeem centers.

The workshop participants agreed that next steps should be taken in the realm of policy and research. The government should hire a waste director who would ultimately be responsible for waste management in the Seychelles. His or her first task could be to lead and coordinate the review and revision of the waste legal framework (strategies, plans, laws, etc.), in consultation of stakeholders from administration, business, and civil society. Moreover, the government representatives believe that a number of proposed ideas deserve implementation as pilot projects, the main goal of which is learning in a real-world setting (e.g., glass downcycling, waste-to-protein, paper to construction material). Research is needed to better understand past failures, for instance that of a project of downcycling packaging glass to construction material. A cost-benefit analysis of biogenic waste landfilling vs. anaerobic digestion could inform all stakeholders on the true cost of AD by considering the future costs of carbon dioxide and methane emissions from landfills. The knowledge integrated in the tdCS and other studies could help set up an industrial symbiosis map, which would inform prospective waste businesses and other stakeholders on the location, amounts, and qualities of waste supplies as well as potential users of waste treatment products. Industrial symbiosis maps are particularly useful in the case of digestate use in agriculture. Finally, given the encouraging results from the consumer surveys, the government is interested in conducting more representative surveys.

A promising approach for solid waste management in small island developing states

The novelty of the systemic approach lies in the emphasis given to the preparatory phase and its faceting into subprojects to make research as relevant and context-specific as possible and increase the chances of up-take of findings. The approach provided policy-makers with an extensive base for discussion and debate of priorities and next steps. The case study demonstrated the approach's feasibility in the SIDS context thanks to the commitment of students with various disciplinary backgrounds and their coaching by experienced researchers and teachers. It could be applied in other small islands—independent states (i.e., SIDS) or as parts of larger states—to test and evaluate it in different contexts, possibly improve it, and obtain a better understanding of what makes SWM challenges so special in small islands.

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