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Solid waste management in the Seychelles

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ABSTRACT

Solid waste management (SWM) is a significant challenge for the Seychelles because landfilling, the main disposal path, exacerbates the island nation's specific weaknesses, e.g., consumption of scarce land. Due to the small scale of the Seychelles economy, there is little capital available to stimulate innovations in SWM. The topic of the 2016 transdisciplinary case study (tdCS) at ETH Zurich was SWM in the Seychelles. The goal of the tdCS was to understand the current SWM system in the Seychelles and to gain insights into the obstacles and opportunities related to waste reduction.

The tdCS students, joined by students of the University of Seychelles (UniSey), split into seven groups to gain comprehensive and in-depth knowledge about the SWM system in collaboration with local stakeholders. The methods employed varied across groups, and included literature review, semi-structured interviews, and analysis of landfill data.

Existing data indicate that landfilling rates are increasing every year, and simulations suggest that up to 10 landfills could be needed in the next 25 years if current trends continue. PET and aluminum cans are primarily diverted from landfills in contrast to other waste fractions, despite a high recycling potential and willingness of consumers to source separate. Organic waste could be diverted from landfills to supply energy via anaerobic digestion. The legal framework analysis highlights significant obstacles preventing the implementation of policies and plans.

The research points out priorities for action and research and suggests that major SWM stakeholders require a government-driven, integrative approach to reduce waste in the long-term.

KEYWORDS

Policy, Seychelles, small island developing state, waste management

1 INTRODUCTION

1.1 BACKGROUND

The transdisciplinary case study (tdCS) is part of the minor "Transdisciplinarity for Sustainable Development" in the master program of the Department of Environmental Systems Science at ETH Zurich but can be selected as elective course by all master students from ETH Zurich. The general learning objectives for the tdCS can be described as follows. Students should be able to understand a case and its context from a variety of perspectives, and to extract multiple ways of framing, analyzing and developing potential solutions for the problem at hand. More specifically, students define relevant research questions in a wicked sustainability problem; select and apply tools/methods to collect, analyze, and interpret data to answer the research questions; work in an interdisciplinary team; and collaborate with stakeholders. The topic of the 2016 tdCS was solid waste management (SWM) in the Seychelles, a small island developing state (SIDS) in the Indian Ocean heavily relying on tourism for its economy. The Seychelles faces unique economic and ecologic challenges, characterized by particular vulnerability to sea level rise, land scarcity, and fluctuations in global markets. Sustainable development – at the intersection of economy, society, and ecology – is therefore crucial to the Seychelles. The tdCS was conducted jointly with the University of Seychelles (UniSey), as part of a research collaboration between the two institutions. The Ministry of Environment, Energy and Climate Change (MEEC) was major partner. The main output of the 2016 tdCS is the report on SWM in the Seychelles [1]. The present contribution relies extensively on this report, with additions based on a workshop in which the report was presented to and discussed with government representatives.

1.2 CHALLENGES OF SOLID WASTE MANAGEMENT IN THE SEYCHELLES

SWM is a major issue affecting both developed and developing economies due to the increasing amount of waste generated annually (Fig. 1). Economic growth, higher industrialization, population rise, and elevated standards of living are often correlated to increases in waste generation [2]. For economies dependent on tourism, solid waste management is considered as one of the most important environmental aspects in long- term development [3].

SWM has become a significant challenge for the Seychelles. SWM has been handled by STAR, a government-contracted company, since 1996. Presently, STAR only landfills all major fractions of waste, with the exception of polyethylene terephthalate (PET), aluminum cans, and large scrap metal. Landfilling poses environmental concerns including leaching of pollutants, methane emissions, and resource depletion. Additionally, because land is scarce and expensive in the Seychelles, landfilling will incur significant costs to the government in the future. Seychellois waste generation has increased recently due to economic development and tourism, and estimates suggest that consumption will continue to rise in the near future. Landfill construction has not kept up with waste generation: the Providence II Landfill on Mahé, the largest in the archipelago, is estimated to reach capacity in less than six years instead of the planned 10. Despite the costs, the government has not established clear targets for waste management or reduction [4,1].

A particular challenge for SWM development in the Seychelles is scale. Due to the small population of the country, there is little capital available to support SWM projects, particularly to stimulate recycling initiatives or advanced waste treatment. Additionally, the low volume of total waste generated provides insufficient quantities to have technically feasible treatment systems. The small economies of scale prevent waste businesses from generating revenues to overcome operation and investment costs. Consequently, landfilling presents a seemingly cheaper option for waste treatment, but this poses long-term sustainability issues [1].

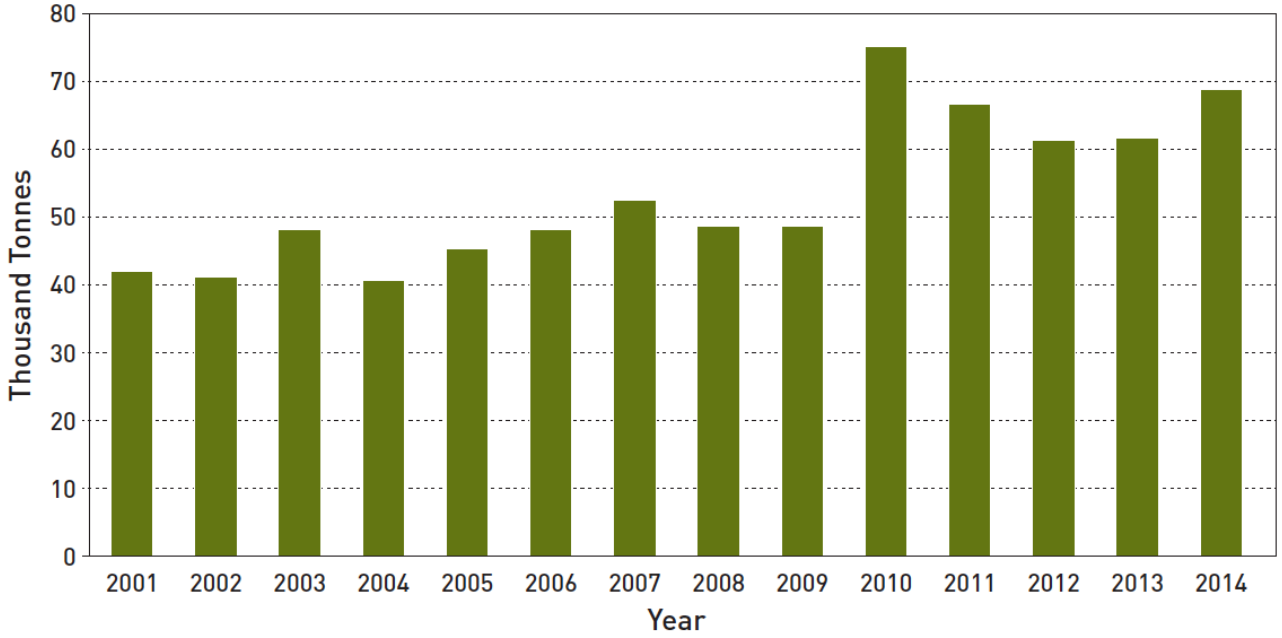

Fig. 1 Annual tonnage of waste delivered to the Providence Landfill from 2001–2014 (Source: Landscape and Waste Management Agency, LWMA) [1]

1.3 RESEARCH GAP

Despite the pressing challenges in SWM, the Seychelles lack a broad understanding of current solid SWM practices and potentials, going beyond individual consulting studies to connect the dots between different economic sectors, various stakeholders, and seemingly unrelated waste streams. Only with such a big picture can meaningful priorities be defined in order to avoid problem shifting [5] and next steps be taken in an efficient way. A broad understanding does not mean researchers should stay at the surface. On the contrary, in-depth enquiries should be possible to fill in knowledge gaps and address specific, yet pressing issues. Prior to the 2016 tdCS and to the best of our knowledge, there existed no extensive studies on the environmental impacts of landfilling in the Seychelles. Nor had a comprehensive scenario analysis or other systematic planning method been conducted to investigate the future of the Seychelles' waste management system. In this sense, a broad understanding should be set up as an interdisciplinary endeavor. Last but not least, adopting a transdisciplinary setting increases the chances of uptake of recommendations by stakeholders [6]: involving stakeholders in defining problems and formulating priorities for action and integrating stakeholder and expert knowledge into research itself.

1.4 RESEARCH GOAL AND QUESTIONS

The focus of this case study was to understand the current SWM system in the Seychelles and to gain insights into the obstacles and opportunities related to waste reduction.

1. How does the current system operate? What are ecological risks and waste management challenges?
2. What are potential waste reduction strategies for stakeholders such as the government, consumers, and waste managers? What are obstacles preventing their implementation?
3. How could the future of waste management look like?

Answering these research questions lays the foundation for defining priorities and sketching next steps towards sustainable SWM in the Seychelles.

2 METHODS

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

One key output of the preparatory phase was the faceting of the case into seven topics. 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 the system picture below (Fig. 1). The key features used in this system picture were determined through a literature study of waste systems in SIDS 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. Accordingly, the case study was split into seven groups of 18 ETH Zurich master's students with diverse scientific backgrounds and 18 bachelor's students at the UniSey.

Researchers and teachers from ETH Zurich and UniSey guided students throughout the case study, which was supplemented by additional support from an advisory board bringing together the MEECC and administration, business, and civil society. Students intensively engaged with a variety of stakeholders from government, administration, business, NGOs, and civil society. The methods employed varied across groups, and included literature review, semi-structured interviews, and analysis of landfill data. In the following subsections, we provide an overview of methods used in the seven topics, including research questions. We also indicate which students from ETH Zurich and UniSey performed the research. Names of students are again provided in the individual Results subsections.

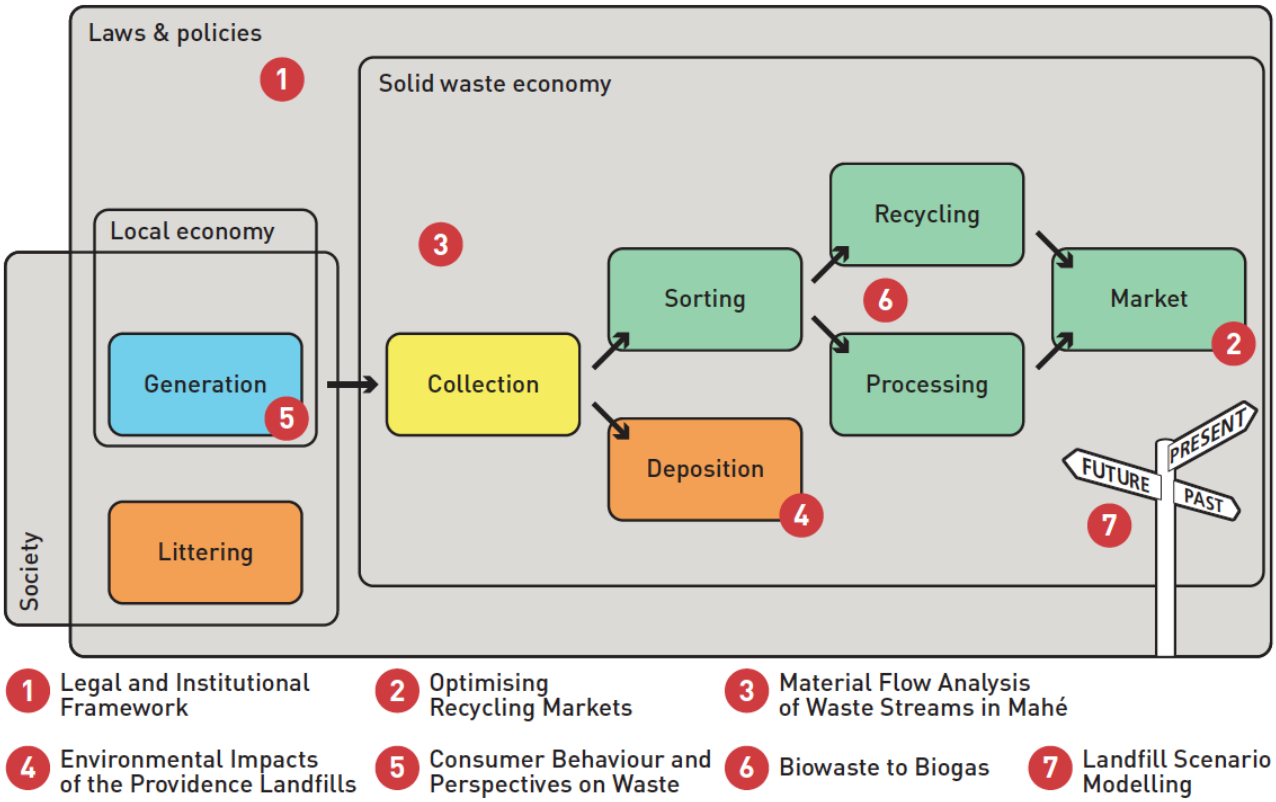

Fig. 2 Case study system picture and group breakdown [1]

2.1 LEGAL AND INSTITUTIONAL FRAMEWORK

Mégan Dine, Irma Dubois, Elisabeth Güttinger, Lisa Hämmerli, Aisha Rachel, & Olivia Pfister

The goal of this study was to provide a comprehensive analysis of the current waste management system (WMS) to clarify stakeholders' roles, particularly as they relate to jurisdiction and implementation, WMS challenges, and other existing knowledge gaps. Through a thorough investigation of strategic plans, involved governmental bodies and other stakeholders, available financial mechanisms, and institutional challenges, the research aimed to address the following research questions:

1. What are the legal and institutional frameworks of the WMS and how do they function?
2. How does collaboration between the WMS actors take place, as well as internally within these institutions themselves?
3. What financial mechanisms currently exist/are available and how can they be applied to the WMS?

The students employed two methods sequentially–document analysis and stakeholder interviews–to address the topic research questions. Accordingly, the students first undertook a thorough analysis of the various Master Plans, Acts, and Strategies to develop a preliminary understanding of the system. After acquiring initial knowledge of governmental structure, legal frameworks, and financial mechanisms from the documents, the students iteratively validated their findings with stakeholders.

Through the synthesis of information gained from stakeholder interviews, the students were able to identify significant individuals, departments, and organizations with legal authority within the waste management system and developed an understanding of how they operate in conjunction with each other. The students also discussed financing mechanisms in these interviews to gain insight into the most effective instruments.

The output of the document analysis consists of preliminary system diagrams which conceptualize the legal framework governing waste management, incorporating elements of governmental structure and financial mechanisms. Fig. 3 provides an example of such a system diagram. During the interviews, stakeholders were allowed to identify ambiguities in need of clarification. The depicted system diagram shows an overview of the management of waste pet and cans as an example (final version after multiple validation steps with stakeholders). The presumed flow of waste in the Seychelles is directed by the arrows between processes and stakeholders, from 'goods' to 'littering,' 'landfill,' and 'export.' The light blue markers represent processes, while the medium blue markers represent consumers. The dark blue markers represent other non-governmental stakeholders and are located near their relative primary spheres of influence. Finally, relevant governmental bodies are located at the bottom, where each is placed underneath its primary obligation in the WMS.

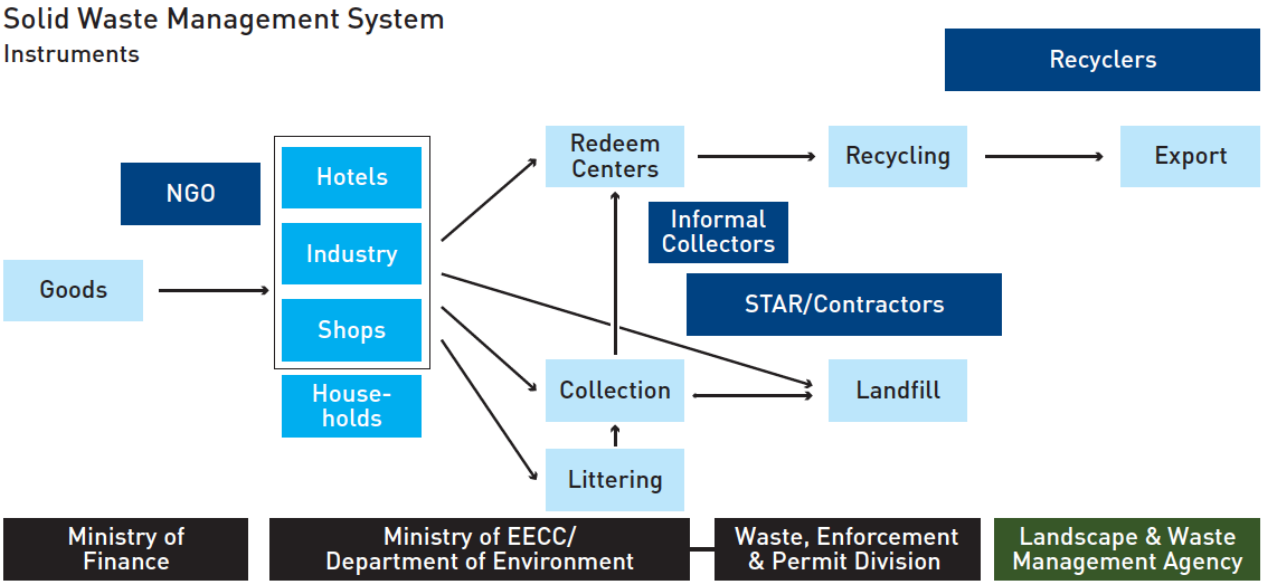

Fig. 3 Exemplary waste management system diagram (EEEC: environment, energy, and climate change, STAR: private contractor in charge of collecting waste and managing landfills on the main island of Mahé) [1]

2.2 RECYCLING MARKETS

Krystel D'offay, John Hensley, Yuna Madeleine, Marc Melliger, Jessica Moumou, & Franziska Steinberger

The goal in this facet was to provide a broad analysis of the recycling system in the Seychelles. To accomplish this objective, the students investigated past failures, current, and future opportunities, and stakeholder opinions on recycling technologies. For this study, following waste streams were investigated: PET, aluminum cans, paper, and glass. The selection was based on economic and ecologic potential, recovery rate, and current landfill deposition rates in the Seychelles. The following research questions helped guide the methods and results of this study:

1. What is the current state of the recycling systems in terms of the relevant stakeholders and recycling initiatives, past and present?
2. What options for waste separation and collection exist and how can they be improved?
3. What are perspectives on recycling and recycled products at the household level?

The primary goal was to understand the current recycling system of the Seychelles in terms of its infrastructure and stakeholders. To accomplish this, both literature and stakeholder information served to address the knowledge gaps. First, the students reviewed papers, studies and other informative material regarding past and present recycling projects in the Seychelles. Their next step was to acquire further information and opinion from stakeholders to broaden their understanding of the social, economic and political aspects of the recycling system. The students engaged in semi-structured interviews, questionnaires, and surveys with stakeholders, who included waste experts, recycling business owners, government officials, and consumers.

2.3 MATERIAL FLOW ANALYSIS OF WASTE STREAMS IN MAHE

Julio Agricole, Felix Elbert, Adelene Lai, Raina Nicette, Catherina Onezia, & Livia Ramseier

Material Flow Analysis (MFA) is an established method used to describe and interpret complex systems by accounting and visualizing the flows and stocks of goods or materials [7]. This quantification of flows and stocks provides a system-level understanding of the investigated material. MFA includes the following methodological steps:

1. Concept: Describe the system according to the underlying research questions. This means setting the system boundaries and clarifying the goods/materials and the processes to be examined in the system. The result of this step is a list with the system elements and a qualitative flow chart of the goods.
2. Data collection: Collect, measure or estimate the material flows and stocks. Describe interviews, analyse data (estimates, etc.)
3. Simulation: Calculate the remaining unknown flows through the mass-balance principle.
4. Analyze: Representing schematically the system, conducting a sensitivity analysis and interpretation of the results are the main points in this step. Key parts of the interpretation are:
    a. The identification of sources and sinks of the goods/materials.
    b. Description of processes in terms of e.g. orders of magnitude of flow turnover.

In addition to the MFA of waste streams in Mahé, all of the involved stakeholders were identified with their magnitudes of impact on the overall material flow. Conducting MFAs is a concrete way of addressing knowledge gaps related to recycling quantities and indicating infrastructure needs to inform policy-making.

The scope of the MFA was the PET, Cans (Steel and Aluminum), Glass, Scrap Metal, and Paper and Cardboard streams in Mahé. These streams were selected based on the following criteria: existing recycling programs and data availability, demand for and value as commodities in international markets, well-defined materials which do not change over time, and (economic) potential to be recycled and therefore diverted from landfills in the Seychelles. By performing material flow analyses of these streams, the students addressed the following three research questions:

1. What types of products (classified by material) enter the Seychelles and in what quantities?
2. How do materials in each stream exit the Mahé system and in what quantities?
3. How are the materials used in terms of their flows between stakeholders?

2.4 ENVIRONMENTAL IMPACTS OF LANDFILLS

Simon Baumgartner, Asha Emilien, Jasmin Fetzer, Dillys Pouponeau, Aisha Rachel, & Richard Thonig

Landfilling is the main way of dealing with waste in the Seychelles. There are currently four landfill sites in operation on three islands: one on Praslin, one on La Digue, and two on the largest island Mahé called Providence I and Providence II. The latter two landfills are located on reclaimed land situated directly along the coast. Providence II (PII) is the newest of the two, and is considered to be a sanitary landfill because unlike the other landfills it is lined with a composite plastic material to prevent leaching.

As explicitly mentioned in Section 1.2, there are no extensive studies on the environmental impacts of landfilling in the Seychelles. The very heterogeneous nature of the waste entering the landfill is of particular concern, because the high fractions of organic waste could lead to favorable chemical conditions for toxic heavy metals to become more mobile and enter aqueous systems – this can be groundwater, surface water, and finally the ocean. Because the leachate collected from the PII landfill remains untreated in practice (even though it could in theory be pumped into a leachate

treatment plant), such a situation could arise. Besides the possible ramifications on human health, the lack of knowledge regarding the environmental impacts of these landfills is all the more pressing in the long term considering the importance of the tourism and fishing industries to the Seychelles' economy.

The research seeks to address this knowledge gap using a holistic approach. The students focused on the following questions in their study:

1. Can substances in waters surrounding the Providence landfills be identified and measured to serve as evidence of landfill leaching?
2. 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?
3. How do governmental and non-governmental stakeholders perceive the state of the landfills?

In their study, the students employed a dual approach to assess the possible environmental impacts of the Providence I and II landfills. Inorganic compound parameters of water samples taken from areas surrounding the landfills were measured in tandem with stakeholder interviews. Despite their relevance, the measurement of the outgassing of any of gases contributing to climate change and of organic pollutants were not part of the scope of the study. The students sampled water at 10 different sites in and around the landfills of Providence I and II. These sites consisted of various outlets from the leachate pre-treatment plant (LPTP) of Providence II, coastal waters, ponds, and groundwater

2.5 CONSUMER'S PERSPECTIVE

Zarah Ally, Lynndina Essack, Danny Nef, & Vera Ziltener

The motivation of this study was to understand the perception and awareness of consumers on waste management. The students formulated their motivation into two research questions to guide this study:

1. How do consumers perceive waste management in the Seychelles?
2. What are decisive purchase criteria from the perspectives of consumers and retailers?

The students conducted semi-structured interviews using three different interview guides which each addressed a different topic or perspective related to the study:

1. Consumer awareness;
2. Consumer purchasing criteria; and
3. Store employee perceptions of consumer satisfaction.

For the sake of synthesis, the students grouped answers given to open-ended questions into appropriate categories. For instance, cans, PET bottles, and paper fall under the category 'Recyclables', while the category 'Packaging' comprises plastic bags, food packaging not including Styrofoam take-away boxes, and cardboard packaging.

2.6 POTENTIAL FOR BIOGAS PRODUCTION

Rossetta Alcindor, Lara Kalisch, Sophie Morel, David Müller, Till Schmid, Andrin Schulthess

The aim of the present study is to determine the potential of a successful biogas plant based on feedstock suppliers and customers of its end products. The technology considered was anaerobic digestion (AD) [8]. The students defined the following research questions to guide their work:

1. Which suppliers offer high potential feedstock for an anaerobic digester?
2. What is the demand for the end products?

To answer the research questions above, the students collected and analyzed both quantitative and qualitative data. First, the students analyzed landfill data to learn about the biogenic waste currently deposited in the landfill and large-scale suppliers of biogenic waste to the landfill. The students then conducted technical expert interviews in Switzerland and identified potential biogenic waste suppliers and customers of AD products in the Seychelles. Interviews with local experts in the field, suppliers, and customers provided the knowledge base required to conduct a Multi-Criteria Analysis (MCA) [9] of different feeds/suppliers. Ultimately, the students ranked feeds/suppliers and qualitatively analyzed potential suppliers and customers.

2.7 LANDFILL SCENARIO MODELING

Rosabella Mangroo and Marius Wälchli

No comprehensive scenario analysis or other systematic planning method has been conducted so far to investigate the future of the Seychelles' waste management system. Therefore, the goal of this study was to estimate possible amounts of waste deposited on landfills up to 2040 as a result of different developments. The following research questions guided the scenario analysis:

1. What could the total amount of waste landfilled over the next 25 years be under a "business as usual" (BAU) scenario?
2. What events, policies, and other developments affect landfilling rates?

To address the two topic research questions, the students conducted a scenario analysis that relied on literature, expert knowledge, and other information to generate models that provide possible, future outcomes of the waste landfilled up to 2040. The students selected this 25-year time horizon because of indications from the Seychelles Strategic Plan: Sustainability Appraisal report [10]. The scenario analysis consisted of two steps. First, the students built a model of waste generation in the Seychelles as a function of population and economic growth. Second, using the Storyline-and-Simulation (SAS) approach [11,12], they investigated the impact of different storylines, e.g., with respect to treatment of biogenic waste, on the amount of waste landfilled in the future.

3 RESULTS

In this section, we present the most important and striking results which informed the conclusions presented in Section 4.1. All results can be found in the tdCS report [1].

3.1 LEGAL AND INSTITUTIONAL FRAMEWORK

Mégan Dine, Irma Dubois, Elisabeth Güttinger, Lisa Hämmerli, Aisha Rachel, & Olivia Pfister

The government has 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. Tab. 1 highlights the unclear allocation of responsibilities with respect to implementation, contracting, and enforcement control as well as other issues such as the outdated nature of key documents.

Tab. 1 Summary of legal and administrative implementations (EPA: Environmental Protection Act, LWMA: Landscape and Waste Management Agency, SSDS: 2012–2020 Seychelles Sustainable Development Strategy) [1]

Analysis Criteria	International treaties	EPA	SSDS	SWM Policy	SWM Plan	Strategic Plan
Lawfully mandatory	Yes, partly integrated in the national law	Yes	No	No	*Outdated*	No
Liability	No, partly integrated in the national law (EPA)	Yes, Art. 3 1. (2) "This acts binds the Republic"	Endorsed by cabinet	Validation workshop	*Outdated*	*Not clear*
Position in the legal framework	Guidance/ national law depending on ratification process	Environment law	Overarching document, strategy	Guideposts for strategy development and implementation (SMW Policy)	Guidance for LWMA and MEECC	Guidance for LWMA
Responsibility of implementation	MEECC	MEECC	SSDS Secretariat under MEECC (p. 22)	LWMA key in implementing this policy (p. 29)	*Unclear*	LWMA
Contracting authorities	UN COP, UNEP	MEECC	MEECC	MEECC	*Unclear*	MEECC
Enforcement control	MEECC	MEECC	Mentioned for each objective. For waste, mostly LWMA	*Unclear*	*Unclear*	*Unclear*
Coherency between documents	Partly included in the EPA	Legal framework basis for implementation of SSDS	Links at each objective mentioned, Convention	Builds further on the SWM Plan. The actions are consistent with SSDS.	Was consistent with the existing environment Management plan for the Seychelles 2000–2010. Consistent with EPA 1994, overlaps between SWAC and MEECC	Policy and Implementation Framework 2015

3.2 RECYCLING MARKETS

Krystel D'offay, John Hensley, Yuna Madeleine, Marc Melliger, Jessica Moumou, & Franziska Steinberger

The current recycling scheme concerning PET bottles, aluminum cans, paper and glass is displayed in Fig. 4. All material streams enter the Seychelles through import because local production is on a small scale, if existent, and is

therefore negligible. Typically, the goods are sold, consumed and deposited. Deposition is the primary point at which infrastructure for recycling begins to be needed. The primary deposition sites are municipal and commercial bins, Redeem Centres and littering.

According to stakeholders, the government-contracted company STAR collects waste from the municipal and commercial bins and brings it unsorted to the landfill. Some have stated that even if hotels and companies separate their waste, the segregated fractions are ultimately mixed together upon collection. Stakeholders say that previously, the government and STAR attempted to separate the waste. However, some stakeholders argue that STAR is not compensated enough to separate the waste, and others argue that segregation stopped when stockpiles of the separated waste were left unused.

Paper and glass fractions remain at the landfill. Secondary streams from typical deposition are managed by Navin's Paper Company, Rogan's Construction Company and Seychelles Brewery (Seybrew) for paper, glass, and glass waste, respectively. These recycling businesses provide deposition alternatives that divert a small fraction of the waste from typical deposition streams. Seybrew's products re-enter the market through recycling while Navin's Paper Company upcycles and Rogan's Construction Company downcycles the waste. Many stakeholders state that there is a latent potential for paper recycling through upcycling to biodegradable containers, export, or as biogas plant feedstock. Members of government agencies would only like to support recycling initiatives that have a clear market potential. There is currently no formal collection scheme for glass, nor large-scale usage of recycled products from glass waste in the Seychelles. Stakeholders identified different collection strategies: (i) levy/refund system at Redeem Centres, (ii) recycler-operated collection, (iii) bottling company-sponsored collection, and (iv) government-contracted collection. As for product opportunities, they range from exported glass to downcycled construction aggregate to upcycled art materials to landfill stabilizer.

The informal sector collects large proportions of PET and cans from the bins, littering, and landfill. The informal collectors are financially compensated when they bring these items to the Redeem Centres, which in turn distribute them to DE-Recycling and Harini to be processed and exported to countries such as Mauritius, Russia, China and India, according to stakeholder interviews. There are four Redeem Centres on Mahé and one each on Praslin and La Digue. Many stakeholders argue that the current levy system implemented for PET and aluminum can recycling is well-functioning. This is because large fractions of waste are diverted from the landfill and the system is financially self-sustaining. Some suggest, however, that collection can be improved to increase recycling rates further. Potential aluminum and PET collection systems include collection at households, schools and businesses, collection at centralized bins, and collection of a wider range of PET and aluminum items.

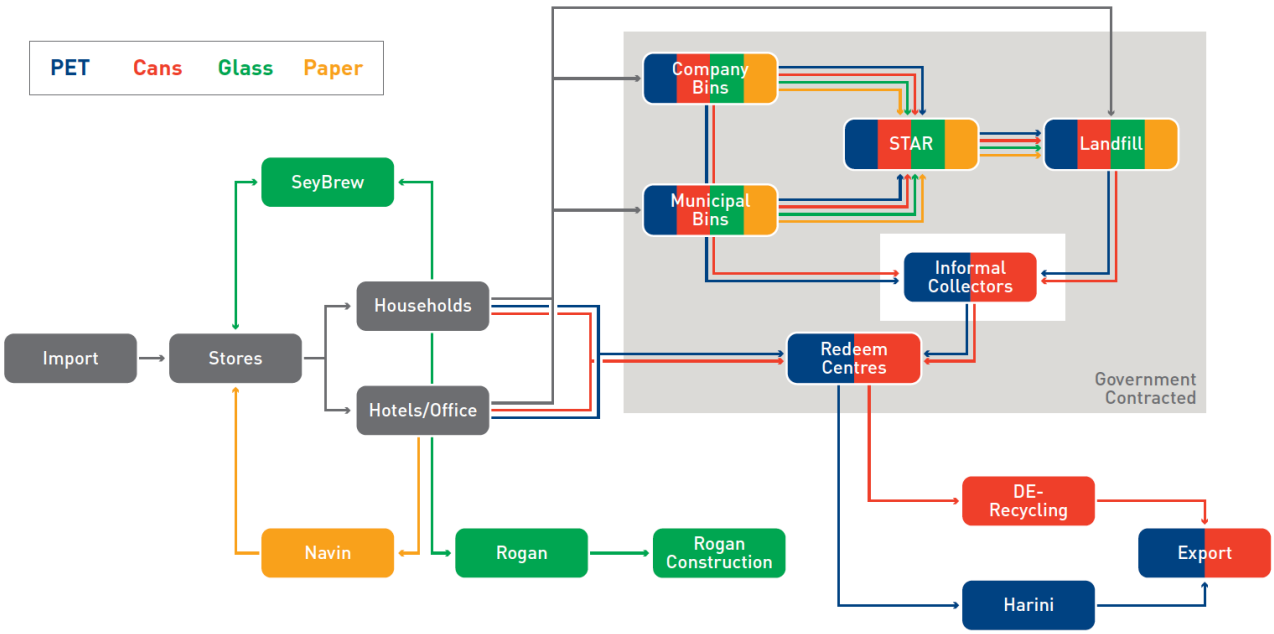

Fig. 4 System diagram of the recycling scheme in the Seychelles for the waste streams, PET, aluminium cans, paper and glass. Arrows indicate the material flows [1]

The household surveys showed that the public is not only supportive of separating recyclable materials, but also of purchasing recycled products. Interestingly, the majority of survey respondents think that recyclables should be collected on a monthly basis.

3.3 MATERIAL FLOW ANALYSIS OF WASTE STREAMS IN MAHE

Julio Agricole, Felix Elbert, Adelene Lai, Raina Nicette, Catherina Onezia, & Livia Ramseier

The material flow and other data analyses give quantitative data to show that PET and aluminum cans are primarily diverted from the landfill, while other waste fractions, notably glass, paper, and organic waste, have high landfilling rates despite a high recycling potential. In particular, organic waste has the highest contribution to landfill composition, which could be substantially reduced while contributing to the energy supply via anaerobic digestion. As example of the students' research, we present the paper and cardboard (PC) case to highlight the benefits of an MFA (Fig. 5).

Unlike the other materials described so far, PC have neither a levy (PET and cans) nor international market value (Scrap Metal). Furthermore, PC cannot be attributed to a specific waste class like glass can be to Inert Waste. As a result, there is virtually no recycling of paper and most of it is landfilled as fractions of other waste streams. There is one private business which recycles PC to products such as egg trays and takeaway plates, but it operates on a very small scale. The landfill is therefore by far the greatest sink of PC in the system.

3.3.1 IMPORT OF PAPER AND CARDBOARD

The students assumed all PC is imported into the Seychelles and that there is no local production. PC enters the Mahé system in two ways. The first is that PC can be imported as a finished product, to be used for commercial or home use. These types of import are accounted for by Customs under the internally acknowledged Harmonized System (HS) codes 47, 48, and 49. For this MFA, the students subdivided corresponding paper imports into three categories based on type and recyclability:

1. Paper, mass < 150gm/m^2 (Category 1)
2. Cardboard, mass > 150gm/m^2 (Category 2)
3. Hygienic Paper, e.g., napkins, diapers, kitchen paper (Category 3)

Categories 1 and 2 have recycling potential if uncontaminated by organic substances such as oils. Category 3 PC must be landfilled or be treated at a waste water treatment plant. It will eventually be decomposed into carbon dioxide, methane and water.

The second way paper enters Mahé is as the immediate packaging of various products. The students expected the quantity of PC estimated under HS 47–49 to grossly underestimate the actual total amount of PC imported into the Seychelles. This is because there are a wide range and large quantity of products, including but not limited to electrical appliances, food, furniture, and glassware, which are packaged in PC when imported into the Seychelles. In other words, businesses such as supermarkets and electronics stores receive their imported stock in PC packaging. The students therefore estimated that the PC fraction of Commercial Waste equals the imported quantity of PC in immediate packaging because businesses dispose of mostly PC, according to stakeholders.

3.3.2 CONSUMPTION OF PAPER AND CARDBOARD

Consumers use PC products for a wide range of purposes, including for packaging, hygiene, decoration, businesses, and education. A lot of paper remains in the system as stock in the form of printed materials, office records, and books because students observed that in many offices, records are kept as hard copies and not in electronic form. However, because of the humid climate in the Seychelles, paper is expected to have a relatively short lifetime and high turnover rates.

3.3.3 EXPORT/END-OF-LIFE OF PAPER AND CARDBOARD

The majority of PC (>93%) is landfilled. The students estimated that STAR collects most PC in Commercial Waste and MSW, of which the fractions of PC are estimated by stakeholders and the literature to be 50% and 5.9% respectively [13]. Approximately 2% of the total quantity of PC imported is recycled by Navin's Paper Company. Navin's Paper Company processes PC, creating products that re-enter the market as egg trays, paper bags and other goods. However, some stakeholders believe that the majority of the paper collected by Navin's Paper Company remains as stock because their operations are relatively irregular. A small fraction leaves the system as exports of printed materials such as postcards, brochures, and leaflets (<1%).

3.3.4 SUMMARY OF MATERIAL FLOW ANALYSIS OF PAPER AND CARDBOARD

Practically all the paper and cardboard which enters the Mahé system remains within the Mahé system boundaries, with the largest long-term sink being the Providence Landfill. The only recycler of paper operates on a very small scale and

even then, processing of PC is on an irregular basis. PC does not have its own classification in the waste system and is therefore disposed of as fractions of other waste streams.

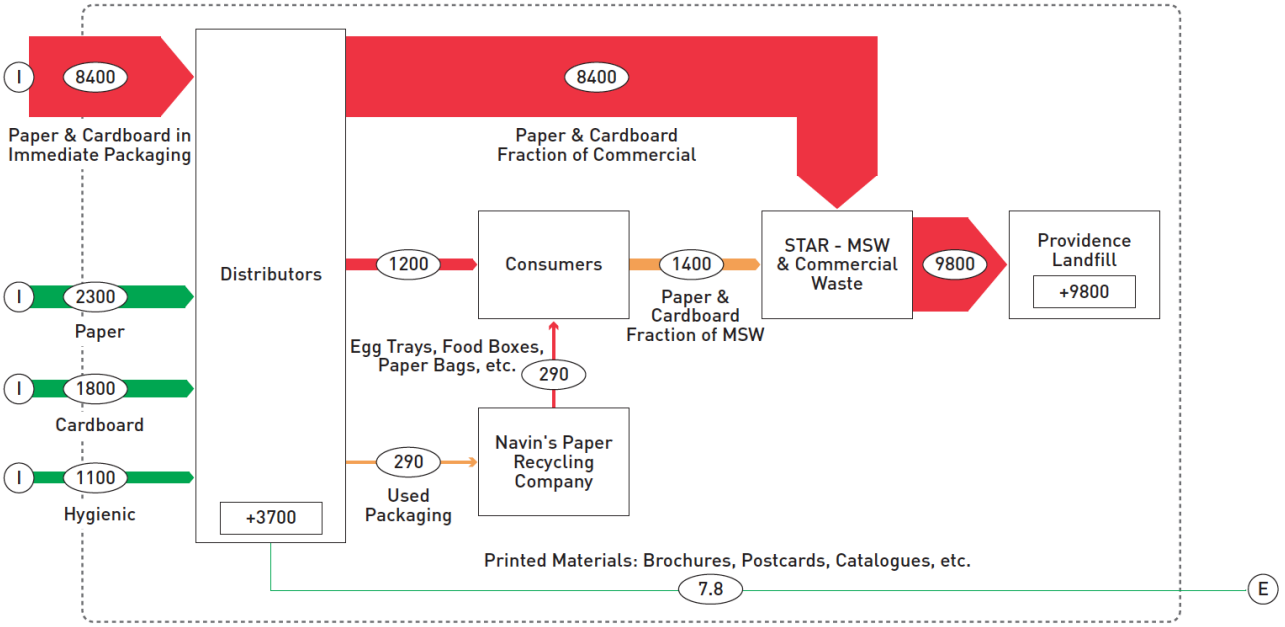

Fig. 5 System flow of paper and cardboard in Mahé. Numbers are in tons and were rounded to two significant figures. I: Import flows. E: Export flows. The colors of the arrow reflect uncertainty assumptions: red: high uncertainty, orange: moderate uncertainty, green: low uncertainty [1]

3.4 ENVIRONMENTAL IMPACTS OF LANDFILLS

Simon Baumgartner, Asha Emilien, Jasmin Fetzer, Dillys Pouponeau, Aisha Rachel, & Richard Thonig

Tab. 2 show the arsenic (As) concentrations measured using ICP-OES. All values depicted are after the subtraction of the average blank value. The italic values exceed the WHO drinking water guidelines. Empty cells mean the measured concentration was 0 mg/L. Most elements do not show critical concentrations at any site. Some samples exceed the drinking water standard with respect to the elements aluminum (Al), As, chromium (Cr), and lead (Pb); however, these are not very problematic concentrations. Exceptional is sample P-3 from the leachate tank with relatively elevated concentrations. This was expected because the tank is designed to deliberately collect the leachate. The groundwater Sample 6 at the scrap metal yard had elevated concentrations of As, iron (Fe) and zinc (Zn), suggesting that those elements are not completely removed during percolation through the landfill. However, the proximity to the scrap metal yard could explain these elevated heavy metal concentrations. Since the students only could take one groundwater sample, they could not conclude if it is representative of the whole landfill. Sample 8 originates from the older pond between the landfill and ocean and shows elevated element concentrations as well (mainly Al, As, Co, Cr, Fe, Ni, P and S). The pond probably acts as a barrier and sink for substances leaching from the landfill.

The heavy metal content of the water samples is much lower than expected of the landfill, considering its high proportion of biogenic waste. The low heavy metal concentrations are most probably caused by the relatively high pH values that prevent heavy metals from going into solution. The proximity to the ocean could be the cause for these high pH values, as could the reducing conditions which keep the pH high.

The measured water samples were in the same range as the reference samples taken from the coast at Anse Forbans, which is located on the east coast of Mahé, south of the landfill where there are fewer industries nearby. In the reference samples from Anse Forbans the students detected As (range of 0.01–0.018 mg/L), Cr (0.001 mg/L), and S (range of 81–86 mg/L).

Tab. 2 Concentrations, measured with ICP-OES, after blank subtraction of heavy metals showing values exceeding WHO drinking water guide lines (in italic; empty: 0 ppm) [1]

Name	Al [mg/L]	As [mg/L]	As [mg/L]	Cr [mg/L]	Pb [mg/L]
	396.152 nm	188.980 nm	193.696 nm	283.563 nm	220.353 nm
P2-0407-1		0.006		0.002	
P2-0407-2		0.007		0.001	
P2-0407-3	*0.534*	*0.369*	*0.303*	*0.185*	*0.011*
P2-0407-4		0.009	0.002	0.002	
P2-0407-5		0.004		0.002	0.002
P1-0407-6		*0.018*		0.002	
P1-0407-7		0.004			
P1-0407-8	*0.0635*	0.080	*0.017*	0.043	
P1-0407-9		0.008			0.002
R-0407-1		*0.011*		0.001	
limit values DW (WHO)	(0.1-0.2)	0.01	0.01	0.050	0.01

The most worrying statements from local fishermen and other governmental and non-governmental stakeholders concern the disposal of the leachate from the Providence II landfill. Currently, it is simply being stored in ponds on the older Providence I landfill without any form of treatment. It seems that no long-term strategy is in place, despite ever-increasing rates of waste generation. It can be concluded that the interviewed stakeholders did indeed observe changes in the environmental conditions close to the landfill. However, these changes are only in part attributed to adverse effects of the landfill, as impacts also believed to arise from nearby land reclamation activities.

3.5 CONSUMER'S PERSPECTIVE

Zarah Ally, Lynndina Essack, Danny Nef, & Vera Ziltener

In this subsection, we present the results of the survey on the willingness to pay for waste collection services. First, the students asked interviewees whether they pay for the present waste collection service (Fig. 6). Most respondents stated that they are currently not paying for this service. 68% of respondents said that they would be willing to pay for the current service if they were asked to do so. When asked whether they would be willing to pay for a service which incorporated a recommendation they named (e.g., more bins or transparency), more than three quarters (79%) of respondents said yes. Most people are willing to contribute up to 40 rupees (SCR) per month (42%) for the current service, while 38% said that they would be willing to pay more than 40 rupees per month for the improved service.

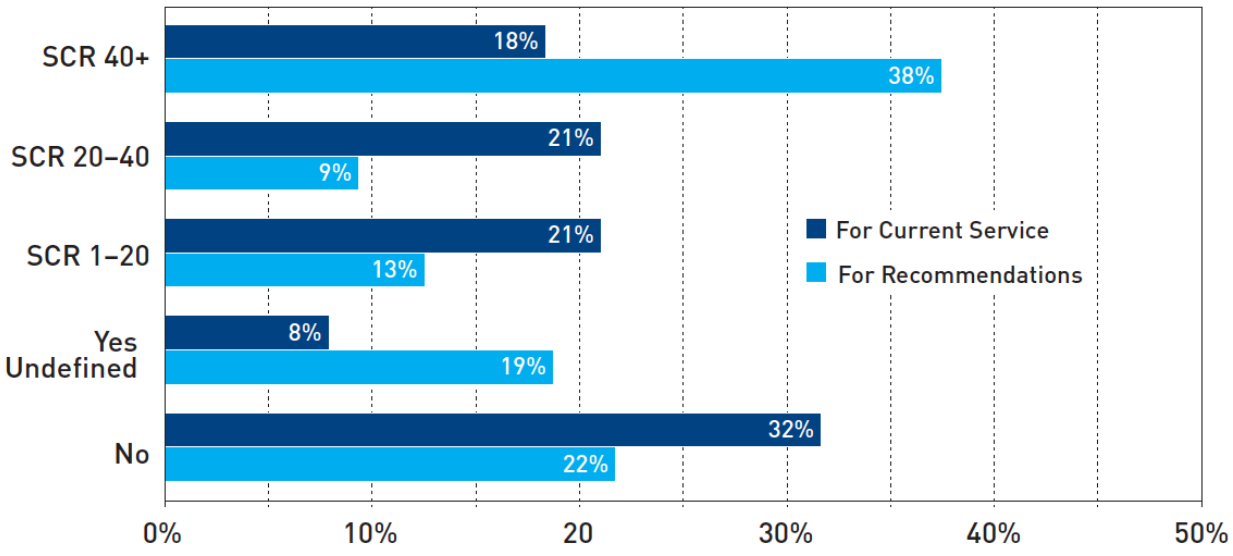

Fig. 6 Amount per month which people are willing to pay for the current system and for a service with the proposed recommendations. Percentages refer to the total number of people who expressed their willingness to pay (N=26 for current service; N=25 for improved services according to their recommendation) [1]

3.6 POTENTIAL FOR BIOGAS PRODUCTION

Rossetta Alcindor, Lara Kalisch, Sophie Morel, David Müller, Till Schmid, Andrin Schulthess

Fig. 7 shows the results of the MCA conducted on the potential suppliers of biogenic waste identified on Mahé. The seven criteria included amounts currently landfilled, biogas yield, complexity of pre-treatment, and volatile solids (VS). For each criterion, the suppliers were ranked. Hence, a lower score on Fig. 7 equals a higher rank, and therefore higher potential of the supplier. The industrial companies Indian Ocean Tuna Ltd. (IOT, fish processor), PUC (Public Utilities Corporation), and Seybrew (brewery), and hotels or restaurants that provide waste oil as a feedstock provide the feedstock with the highest potential. The next most promising suppliers are farmers which provide manure. The least promising are food and Green Waste.

With the exception of spent yeast from Seybrew, all industrial companies have feedstocks that achieve low scores in the amount of waste going to landfill, as well as in the amount of VS produced. IOT fish sludge has a particularly low VS production rate of 52% total solids (TS). Because they have low biogas yields, fish and sewage sludge achieved low rankings in this indicator category, while spent yeast and spent grain are ranked highly, just after the yield of oil. Kitchen oil receives a high ranking in the biogas yield category because it yields 1'285 cubic meters 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 and in waste value indicator categories. Some of the suppliers, especially Butcher's Grill, are located near Providence, which contributes additionally to the high rank. Only Butcher's Grill Restaurant can provide a large amount of oil, the other suppliers only provide minor amounts which would substantially lower the usability of this feedstock. In addition, it has to be noted that the possible amount of kitchen oil used in AD is limited. 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 [14]. 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 [8,15]. Manure from farmers achieved high rankings in the VS generation category, but low rankings in the criterion of amounts currently landfilled. This is because 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 overall ranking. While it has a high biogas yield compared to the average, these waste streams have a low VS production, small amount currently deposited on the landfill, and are far away from the Providence Landfill. A sensitivity analysis showed that variability in the rankings is low when using low, mean or high literature values for TS, VS, and biogas yield. Nevertheless, the highest ranked suppliers retained their original rankings despite changing variables in the sensitivity analysis, meaning that they are insensitive in the context of the students' analysis.

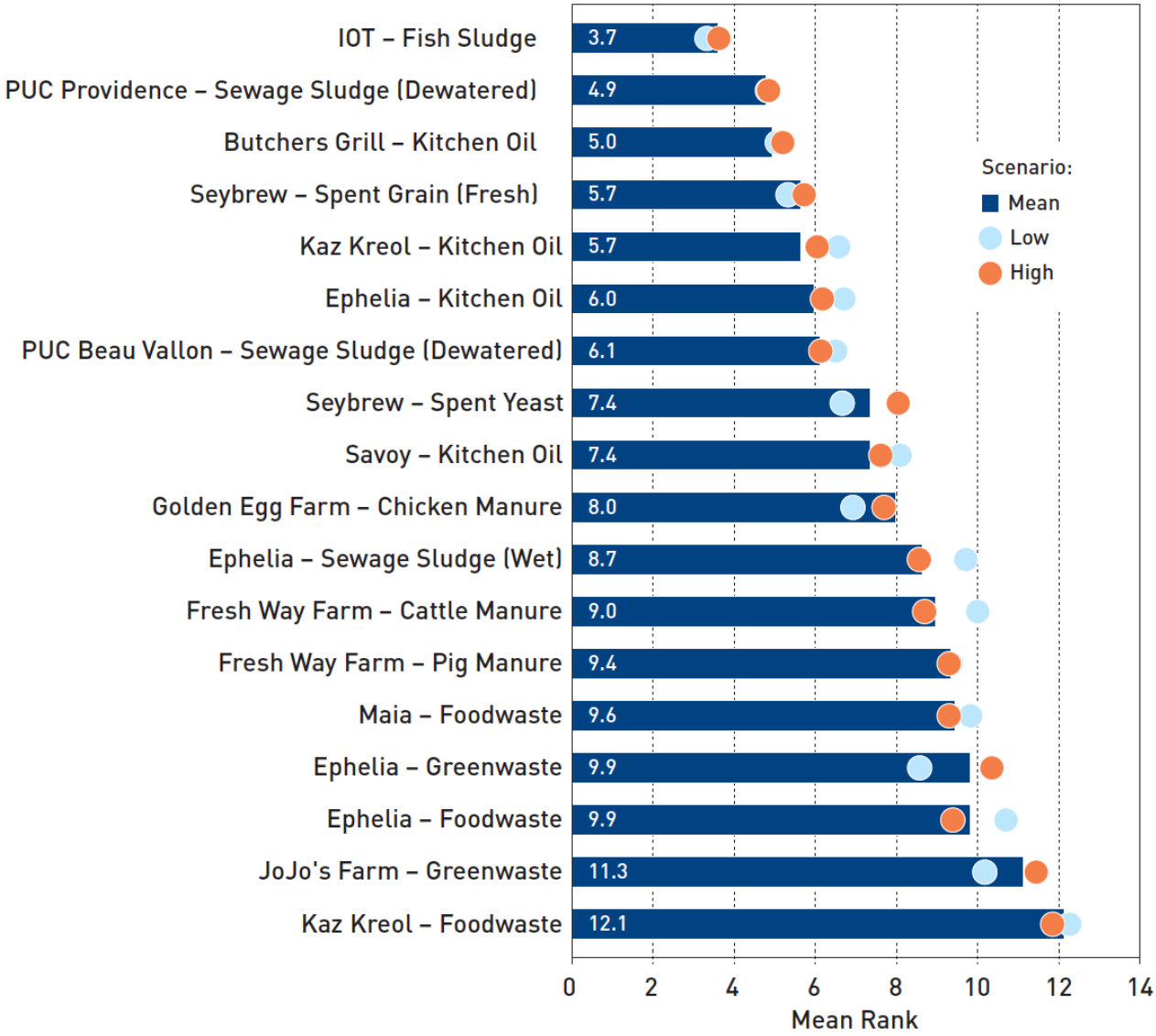

Fig. 7 Mean rank of each supplier according to the MCA criteria, with "low," "mean," and "high" scenarios due to low, mean, and high literature values for VS, TS, and biogas yield, respectively (the higher the rank, the higher the potential of the supplier [1]

3.7 LANDFILL SCENARIO MODELING

Rosabella Mangroo and Marius Wälchli

In a business-as-usual scenario, the model suggests that up to 10 landfills could be needed in the next 25 years if current waste generation trends continue. Fig. 7 shows the impacts of individual storylines on the landfill in terms of reduced amounts. The storylines have been developed jointly with stakeholders. 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 of observations in OECD and EU-27 countries who have implemented waste reduction strategies in the past [16-18]. 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. Combined, the measures entailed in the storylines could allow keeping landfill rates at the levels of the year 2000.

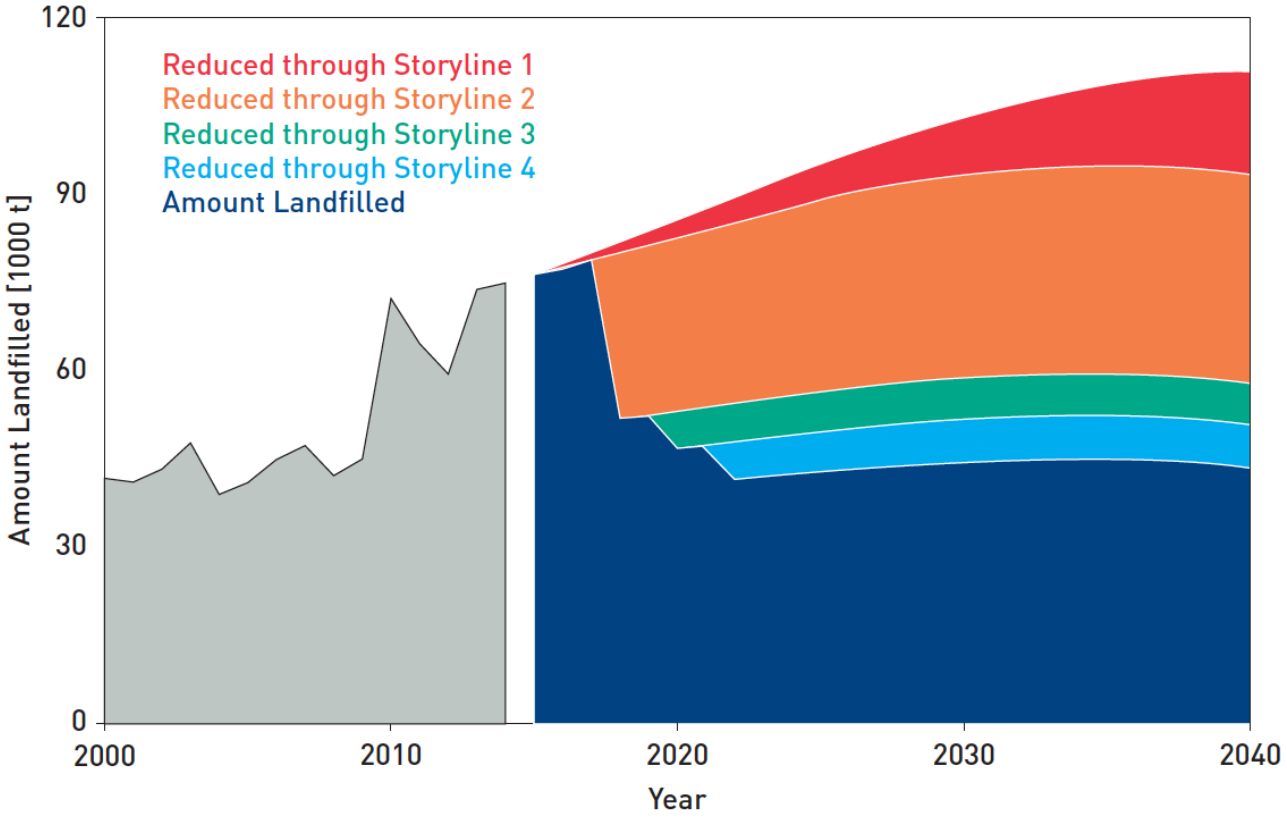

Fig. 8 Annual amount landfilled under the low economic and population growth scenario in Storyline 1–4 Aggregation [1]

4 CONCLUSIONS AND OUTLOOK

4.1 CONCLUSIONS

Overall, the holistic approach applied in the 2016 tdCS points out fields where action and/or additional, focused research is needed. In particular, the results suggest that major SWM stakeholders require a government-driven, integrative approach to reduce waste in the long-term. Conclusions from the results of the seven individual studies can be made at three levels.

The first level is executive action. The Seychelles government must establish clear waste management responsibilities. 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 waste management, there are indications that the government can expect support of 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. Recycling and downcycling opportunities for waste streams could be first validated and tested in pilot projects. Here, local NGOs, with their field experience, could become instrumental. Clear and well-accepted goals should be defined before implementing or supporting an anaerobic digestion 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 to future generations of Seychellois with the weight of remediation. Yet even if all of these measures are taken, at least two more Providence-sized landfills will be needed by 2040.

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 business with standardized reporting sheets and setting minimum amounts to be reported can facilitate reporting activities, often considered by business as tedious tasks. Material flow analysis can help accelerate the processing of the collected data and increase its usefulness to the authorities.

4.2 OUTLOOK

In a half-day workshop following completion of the case study report, government representatives and researchers from ETH Zurich discussed the short- and long-term priorities for action. The following list was presented:

- Help in developing policies and objectives in order to create lower-level regulations (e.g., a strong waste management regulation). The latter already exists for chemical waste. Also, for this, it is necessary to go back to the Seychelles Sustainable Development Strategy 2012-2020 (SSDS) and see what objectives there have not yet been fulfilled.
- Feasibility study on anaerobic digestion.
- Data management system: How to put in place the necessary system to get good material flow analyses in order to take the appropriate strategic decisions. As a first step, MEECC needs to know what kind of data it wants.
- Who does what? What are the other players? Waste management is one of the many systems in Seychelles which are plagued with fragmented laws.
- Beef up the redeem centers. They started with PET bottles as collection in small shops was found to be impossible, moved on to cans, and will probably soon implement glass collection. In any case, the priority is to collect recyclables through the redeem centers. One option to beef-up the redeem centers would be to create more of them in addition to the 5 existing ones. According to MEECC, this system is flexible. Overall, the collection system should be able to meet objectives in a practical and effective way.
- Since MEECC follows the 3R principle (Reduce, Reuse, Recycle), the plastic packaging ban has priority.

The workshop participants agreed that next steps should be taken in realm of policy and research. The government should hire a waste director who would ultimately be the responsible for waste management in the Seychelles. His first task could be to lead and coordinate the review and revision of the waste legal framework (strategies, plans, laws, etc.) with consultation of stakeholders from administration, business, and civil society. Finally, a number of ideas are out there that 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 the glass downcycling project. 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 landfill remediation. The knowledge integrated in the tdCS and other studies could help set up an industrial symbiosis map, which would inform prospective waste business and other stakeholders on the location, amounts, and qualities of waste supplies as well as potential users of waste. Industrial symbiosis maps are particularly useful in the case of digestate use in agriculture. Given the encouraging results from the consumer surveys, the government is interest in conducting more representative surveys. On a more general note, the same holistic approach could be applied in other small islands – independent states (i.e., SIDS) or parts of larger states – to test it in different contexts and possibly improve it and get a better understanding of what makes SWM so special in small islands.

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