ETH zürich

Waste Management in the Seychelles – Pathways for Systemic Change

USYS TdLab Transdisciplinary Case Study 2018

Pius Krütli, Danny Nef, Marius Zumwald, Mélanie Haupt,
Jérôme Harlay, & Michael Stauffacher (Eds.)

USYS TdLab
Department of Environmental Systems Science
Transdisciplinarity Lab · Science-Society Interface

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Acronyms and Abbreviations

AD	Anaerobic Digestion
APEC	Asia-Pacific Economic Cooperation
AWEL	Amt für Abfall, Wasser, Energie und Luft
BMP	Biomethane Production
BSF	Black Soldier Fly
CAPEX	Capital Expenditure
CEO	Chief Executive Officer
CHP	Combined Heat to Power
EP	Exclusion Process
EPRA	Electronic Products Recycling Association
ETF	Environmental Trust Fund
IOT	Indian Ocean Tuna Ltd.
LPG	Liquefied Petroleum Gas
LWMA	Landscape and Waste Management Agency
MCDA	Multi-Criteria Decision Analysis
MEECC	Ministry of Environment, Energy and Climate Change
MoF	Ministry of Finance
MSW	Multiple Solid Waste
NBS	National Bureau of Statistics
NGO	Non-Governmental Organisation
OECD	Organisation for Economic Co-operation and Development
OFMSW	Organic Fraction of Multiple Solid Waste
OPEX	Operational Expenditure
PC	Paper and Cardboard
PET	Polyethylene Terephthalate
POU	Procurement Oversight Unit
PS	Principal Secretary

PUC	Public Utilities Corporation Ltd.
S4S	Sustainability for Seychelles
SAA	Seychelles Agricultural Agency
SBC	Seychelles Broadcasting Corporation
SCAA	Seychelles Civil Aviation Authority
SCR	Seychelles Rupee
SEC	Seychelles Energy Commission
Seybrew	Seychelles Breweries Ltd.
SFA	Seychelles Fishing Authority
SIB	Seychelles Investment Bureau
SIDS	Small Island Developing States
SPA	Seychelles Ports Authority
SRC	Seychelles Revenue Commission
SSDS	Seychelles Sustainable Development Strategy
STAR	Société de Traitement et d'Assainissement Régionale
SWM	Solid Waste Management
TdCS	Transdisciplinary Case Study
TdLab	Transdisciplinarity Laboratory
TS	Total Solids
UniSey	University of Seychelles
VS	Volatile Solids
WEPD	Waste, Enforcement and Permits Division
WMF	Waste Management Fund
WMS	Waste Management System
WMTF	Waste Management Trust Fund
WWTP	Water Treatment Plant

Preface

This report is the result of our second transdisciplinary Case Study (tdCS) in the Seychelles. It reflects a continuation of an activity on solid waste management (SWM) in the Seychelles, which we started in 2016. The challenges of SWM have not decreased since then. On the contrary, another 150,000 tonnes of waste have been dumped over the last two years, comprising approximately 40 percent of the capacity of the current landfill, Providence II, Unit 1. Thus, tackling this issue is more pressing than ever. Accordingly, the Transdisciplinarity Lab (TdLab) and the Ministry of Environment, Energy and Climate Change (MEECC) agreed to a closer study of sorting and waste treatment options.

To recall, tdCSs are problem-oriented and science-based teaching activities, aiming at understanding a real problem in its various facets to scientifically analyse it and find possible solutions. A special concern and an equally huge challenge involve attaining students' learning goals while achieving a practical result for the praxis partner, in this case, the MEECC.

The 19 ETH master's students from diverse scientific backgrounds (environmental, agricultural, engineering and spatial planning sciences) and the 14 undergraduate students (environmental sciences) of the University of Seychelles (UniSey), who joined the field phase in the Seychelles, did a great job. They provided a broad spectrum of directly useable results. During the three-week fieldwork in the summer of 2018, the students conducted around 400 interviews and surveys, spending over 3,000 work hours! The tdCS was again a success from the teaching perspective. The students learned how to proceed from a vague idea to a concrete research question; they acquired and created new knowledge on waste management in general and in the Seychelles in particular. They applied a variety of new methods; learned to work in groups, especially intercultural ones; engaged intensively with stakeholders; and learned to organise and execute a project independently and take responsibility. In short, the students experienced work practice and did so outside their disciplinary and mental comfort zones, under the pressure of obtaining practically relevant results, within a limited time and on a topic with which they were not particularly familiar initially. This demanding situation sometimes pushed the students to their limits. However, it was also highly motivating and rewarding to observe that the stakeholders intensively engaged with them and felt committed to be part of this learning journey.

We thank the large number of involved people for their kind and considerable commitment, particularly our partners from the MEECC and UniSey!

Dr Pius Krütli & Prof Dr Michael Stauffacher
Responsible heads of the Transdisciplinary Case Study of the TdLab of ETH Zürich

Acknowledgments

A special thank goes to Rahul Mangroo, Fredrick Kinloch and Mark Benoiton for their deep commitment to the case study, valuable help in guiding our research during their visit to Zürich and warm welcome upon our arrival in the Seychelles. We are also extremely grateful for the hospitality and the expertise provided to us by the University of Seychelles, particularly Dr Jérôme Harlay, who offered us ample work space and expert support throughout the field phase. Additionally, we express our appreciation to all members of the advisory board – Mark Benoiton, Cliff Conzalves, Alain Decomarmond, Tony Imaduwa, Flavien Joubert, Fredrick Kinloch, Diana Körner, Nanette Laure, Rahul Mangroo, Dr Marie-Therese Purvis and Jean Willing-Lee – for their constructive inputs to our work.

We received valuable information from our interview partners (see Table 1) and further collaborators in and outside the Seychelles, in particular Mrs Helena de Letourdis, National Bureau of Statistics, Mr Romano Wild, incineration plant in Horgen, and Mrs Heidi Brüngler, anaerobic digestion plant Werdhölzli in Zürich. They also deserve our sincerest gratitude. We thank the experts whom we consulted, including Dr Marco Cinelli from ETH Singapore Centre, Prof Dr Christian Zurbrügg from EAWAG, Prof Dr Urs Baier from ZHAW and Félix Schmidt from EPFL Lausanne, and our colleagues from TdLab Drs Ralph Hansmann, Mert Duygan, and Bin Bin Pearce. They all provided several research groups with early guidance, and we are very thankful that they shared their expertise with us. Finally, we give due recognition to the numerous members of the Seychelles community whom we interviewed – government officials, community members, store owners, recycling managers, farm owners, business owners, consultants and many more – for their time and valuable answers.

Table 1
List of interviewees. The numbers in brackets stand for the chapter in whose context the persons were interviewed.

Name	Function	Institution
Governmental Seychelles		
Alain De Comarmond (5,6)	Principal Secretary, Environment	Ministry of Environment, Energy and Climate Change (MEECC)
Denis Matatiken (7)	Special Advisor to the Minister	
Nanette Laure (7)	Director General	
Fredrick Kinloch (3,6)	Director Waste Management	
Arthur Berta (2,6,7)	Consultant	
Michelle Azemia (3)	Quality and Standards Officer	
Branda Rath (3)	Manager Hospital Support Services	Ministry of Health / Health Care Agency
Mr. Weli (3)		
Flavien Joubert (5,6,7)	CEO	Landscape Waste Management Agency (LWMA)
Rahul Mangroo (6)	Deputy CEO	
Lemmy Payet (3,4,6)	Consultant	
Karine Bonnelame (6)	Financial Controller	
Maria Jannie (6)	Coordinator	Waste Management Fund (WMF) & Environmental Trust Fund (ETF)
Helena De Letourdis (1,4)	Deputy CEO	National Bureau of Statistics (NBS)
Frankie Dupres (4)	Wastewater Engineer	Public Utilities Corporation Ltd. (PUC)
Henry Leste (4)	Wastewater Plant Operator	
Elvis Frederick (3)		
Gretelle Isaac (4)	Agricultural Statistician	Seychelles Agricultural Agency (SAA)
Mr. Berne (4)		
Tony Imaduwa (4,5,7)	CEO	Seychelles Energy Commission (SEC)
Guilly Moustache (4, 5)	Principal Officer	
Cynthia Alexander (4, 5)	Principal Officer	
Franky Laporte (3)	Project Manager	Seychelles Ports Authority (SPA)
David Bianchi (3)	Director for Strategies	
Aubrey Lesperance (4)	Principal Aquaculture Officer	Seychelles Fishing Authority (SFA)
Eric Frost (3)	Airport Manager Terminal and Landside Operation	Seychelles Civil Aviation Authority (SCAA)
Dwight Stravens (6)	Acting Chief Procurement Officer	Procurement Oversight Unit (POU)
Samuel Brutus (3)	Senior Biosecurity Officer	Biosecurity Agency
Pat Matyot (4)		Seychelles Broadcasting Corporation (SBC)
Governmental Switzerland		
Simon Schwarzenbach (1)		Amt für Abfall, Wasser, Energie und Luft (AWEL)
Hotels		
Helen Fay (4)	Learning Manager	Four Seasons Resort
Jacqueline Golding (4)	Duty Manager	Banyan Tree Resort
Gwenaël Briat (4)		
Vishal Bhagerutty (4)	Food & Beverage Manager	Berjaya Beauvallon Bay Resort
Mr. Samriddha (4)	Food & Beverage Manager	Coral Strand Hotel
Manuel Policarpo (4)	General Manager	Eden Bleu
Morias Kufa (4)	Assistant Food & Beverage Manager	
Dhanushika Ariyaratne (4)	Pers. Assistant to General Manager	Kempinski Seychelles Resort
Cederick Thomas	Landscape Manager	Constance Ephelia
Markus Ultsch-Unrath	Health, Safety & Environment, Project Manager	

Table 1
continued

Name	Function	Institution
Private Enterprises (Waste)		
Davis Uzice (6,7)	CEO	STAR and Wastea
Kandan Rengassamy (2)	CEO	Harini & Co (Pty) Ltd.
Leeroy Ernesta (2,7)	Owner	DE Recycling
Navin Naidu (7)	Owner	Navin's Recycling Paper Industries
R.S. Naidu (2)		
R. Jothinathan Naidoo (2,3)	CEO	Surya Enterprises
M. Tonner (2)		InnoRecycling AG
Rajiv Gowessoo (3)	CEO	Samlo and Sons
Maurice Waldner (5)		Hitachi Zosen Inova AG (Switzerland)
Alfred Sigg (5)		
Romano Wild (5)	Managing Director	Incineration plant in Horgen (Switzerland)
Patrick Lablache (6,7)	CEO / Private Waste Collector	3AM Services
Private Enterprises (others)		
Guynemer Corgat (4)	Owner	Fresh Way Farm
Jose Pool (4)	Owner	Jojo's Farm
Herve Morin-Adeline (4)	Managing Director	Ferox Feed
Mark Benoiton (2,4)	Environment, Health & Safety Manager	Indian Ocean Tuna (IOT)
R. Finesse (2)		Seychelles Breweries Ltd
Lekha Nair (4,5)		Seychelles Pension Fund
Sarah Romain (3,4)	Commercial Manager	Seypec
Robert Rose (3)		RMP Engineering
Shebra (2)		Hunt, Deltel & Co. Ltd
Cliff Gonzalves (2,5,6,7)	Consultant	AAI Enterprise Pty Ltd
Ian Charlette (7)	Consultant	
Vanesa Quatre (7)	Consultant	
K. Berchat (2)		Seyconsulting
Jean Weeling-Lee (6)	Managing Director	Corvina Invest. Co Ltd
Research Institutions		
Prof. Dr. Christian Zurbrügg (4)	Head of Sandec	EAWAG, Switzerland
Dr. Melanie Haupt (2,4,5)	Postdoctoral Researcher	ETH Zürich
Dr. Marco Cinelli (2)	Postdoctoral Researcher	ETH Singapore Centre
Félix Schmidt (1)		EPFL Lausanne
Prof. Dr. Urs Baier (4)		ZHAW, Switzerland
Other Organisations		
Dr. Marie-Therese Purvis (6,7)	Chairperson, Board of Directors	Sustainability for Seychelles (S4S)
Diana Körner (4)	Sustainable Tourism Consultant	Seychelles Sustainable Tourism Foundation
Lizanne Moncherry (7)	Manager Tourism Office, Victoria	Seychelles Tourism Board
Jack Esparon (6)	Ex-Operations supervisor STAR	

Executive Summary

The Seychelles faces a number of economic, social and environmental challenges. These challenges are often associated with structural peculiarities and geophysical constraints that are characteristic of Small Island Developing States (SIDS) and are often connected. For example, scarce land resources do not only constitute an important aspect of settlement development and nature conservation but also represent a crucial limiting factor for local solid waste management (SWM) in general and landfilling as the currently employed waste management strategy in particular. Landfilling also produces greenhouse gases and most likely releases leachate that raises potential environmental concerns. Besides these rather obvious problems, the current SWM has other weaknesses, some of which are structural. It is therefore evident that a more sustainable strategy must be found.

In this regard, tdCS 2018 built on and complemented tdCS 2016, with the aims of further deepening the understanding about SWM in the Seychelles and describing strategies for long-term waste management. These strategies specifically included the ways to reduce the amount of waste deposited in landfills. The study focused on possible alternatives to landfilling, as well as the structural aspects directly related to waste management. To guide the study, the following overarching research questions were proposed:

1. What waste treatment options beyond landfilling are feasible in the context of the Seychelles? What are their requirements in terms of waste input, policies and finances; what are the challenges and the opportunities of such alternatives?
2. Is there a potential to sort waste at the source that allows effective recycling and further waste treatment?

The case study was split into the following seven topics, each of which was dealt with separately by a group of students: (1) Waste Collection and Sorting: Consumers' Perspective, (2) Feasibility of Recycling: An Appraisal Methodology, (3) Hazardous Waste: Material Flows, (4) Waste Treatment I: Anaerobic Digestion, (5) Waste Treatment II: Incineration, (6) Financial Mechanisms: Money Flows, and (7) Implementation of Plans: Barriers and the Way Out. We conducted research over six months, including a three-week field phase, to address the specific subthemes within the general scope of our research questions.

The methods employed varied across groups. The research typically began with a literature review of official government documents, waste management reports from the Seychelles and other developing countries, and various other peer- and non-peer-reviewed literature. In the field phase, the groups used a variety of methods, including semi-structured interviews with stakeholders and experts, expert workshops, surveys, multicriteria decision analysis (MCDA), scenario analysis and technical and economic assessments. The ultimate goals of all these methods were to capture and synthesise stakeholder knowledge and opinions on waste management and reduction strategies to determine potential improvements.

The first substudy dealt with households and their attitudes towards waste in general and public participation in current and

future waste management systems. The surveys have shown that most interviewed households not only already perform some form of sorting but are also willing to continue or start sorting their waste, including organics. However, even if the willingness to sort waste might not be a high hurdle in the Seychelles, an appropriate sorting system that creates the necessary incentives is regarded as indispensable. The current system with the redeem centres is not used by most households and therefore might not create the right incentives to motivate people to sort their waste. Our results suggest the lack of awareness about the locations of redeem centres and, in case of awareness, their unfavourable locations as the reasons for this situation. We conclude that in the current system, the costs of sorting are too high compared with people's gain from the levy. The results of the survey involving restaurants and retailers show similar patterns.

However, sorting only makes sense if the sorted waste can be processed further and not end up on the dumping site. In this regard, recycling plays an important role. To some extent, waste recycling is already established in the Seychelles. Currently, four classes of solid waste are partly recycled or pre-processed locally, three of which are scrap metal, beverage cans and PET bottles. Nonetheless, a two-step approach that we have developed specifically for the purpose of assessing the feasibility and the potential of waste classes for recycling shows some untapped potential for recycling. This particularly applies to fraction glass, paper and cardboard, wood and probably also to other fractions.

In addition to these waste classes, there are others that are unsuitable for recycling or only to a very limited extent; hazardous waste (HW) is one of them. Although HW accounts for a minor share of the overall waste stream in the Seychelles, special attention must be paid to this class of waste since if not disposed of properly, HW risks having negative impacts on human health, ecosystem integrity and finally, economic prosperity. This study yields the first good overview of how the HW situation in the Seychelles presents itself and is currently managed. Our work reveals considerable inconsistencies in information and a clear lack of complete records in the HW streams. All these findings can be drawn from the fact that the current HW management lacks clear disposal guidelines, strong enforcement and sufficient monitoring schemes.

While some waste classes are particularly suitable for recycling and in this way, provide valuable raw materials that can be returned to the market, other waste classes are not suitable. A possible alternative to landfill is conversion of this waste into energy. The study assessed the potential of two treatment options: anaerobic digestion (AD) and incineration. Both options have a huge potential to help the Seychelles meet its goals of increasing the share of renewable energy. Depending on the underlying scenario, a potential AD plant could produce enough energy to supply up to 10% of the national electricity demand. An incineration plant would contribute up to 15% of the current overall energy production. Hence, both options would help reduce the quantity of imported oil and thus the Seychelles' dependence on it. Furthermore, the products of AD have the potential to

substitute for imported fertiliser and fodder. More importantly, we find that both treatment options are feasible. Moreover, AD treatment can even be economically profitable since all calculated scenarios show net revenues, under the condition that fertiliser, one of the products of AD, can be exported. For incineration, investment and operation and maintenance costs are higher than for simple landfilling. The costs of incineration may be recovered through a combination of a tipping fee, usually paid by trade and industry, and a general waste management charge paid by households. If this is not feasible and only the omitted landfill operation costs and fossil fuel savings are considered in the calculation, approximately 65% of investment and operation costs could be covered during the expected 25-year lifetime of an incineration plant. Nonetheless, the advantage of combustion is its reduction of the volume of waste dumped to less than 20% of the current practice.

Regardless of which measures will shape the future of waste management in the Seychelles, a transparent and efficient financing scheme is needed. This is all the more important because our research reveals that the current financial system is characterised by several weaknesses in the way that economic resources are allocated, managed and monitored. The involved stakeholders lack an overarching understanding of the structures, partly because of the lack of supporting documentation and communication among the concerned parties. This results in the absence of accountability of the financial subsystems. However, we have found that some members of the Landscape and Waste Management Agency (LWMA), the Waste Management Fund (WMF) and the MEECC are aware of several of these weaknesses and are working to overcome them.

Last but not least, we emphasise that even the best and most sophisticated plans and strategies are of no use if they are not implemented in a meaningful way. We have therefore examined possible barriers to implementation and, together with key stakeholders, analysed possible measures that would help overcome them. We have found that the identified barriers across all four categories (operational, content related, structural and contextual) are highly interlinked and related to stakeholders. Furthermore, these barriers strongly depend on stakeholder perceptions; hence, their relevance is perceived in different ways. Thus, there is no single most critical barrier and no sole solution to the challenge of implementing SWM plans in the Seychelles. In this report, we discuss possible approaches and concrete actions to work on and remove barriers.

In conclusion, we have found that the population and the authorities, as well as relevant actors from the private sector, are open and willing to not only reduce waste but also take alternative paths of waste treatment. This matter is important since waste management is an ongoing activity that needs the full attention of the government and public administration in the coming years. We have also shown that these alternatives exist and are feasible in the Seychelles context. However, it is important to emphasise that their implementation must be integrated into existing structures and coordinated with other measures. By no means can their implementation be an isolated action. Only a holistic solution can efficiently and effectively address the challenges associated with waste.

General Introduction

Pius Krütli, Danny Nef, Marius Zumwald, Mélanie Haupt, Jérôme Harlay, & Michael Stauffacher

Similar to most other Small Island Developing States (SIDS), the Seychelles faces a number of challenges (Briguglio, 1995; United Nations, 2014); SIDS are small in size and remote; often comprising a huge number of islands spread over a large sea area that is difficult to manage; particularly vulnerable to climate change effects, such as extreme weather events and sea level rise; highly dependent on the international markets and vulnerable to economic shocks; and lack the capacity and the resources to properly manage basic issues, such as waste management (Eckelman et al., 2014). Therefore, sustainable development – which comprises economic, social and ecological aspects – is crucial to the Seychelles and similar SIDS and is emphasised in many significant official documents written in the Seychelles.

To understand and promote sustainable development in the Seychelles, the University of Seychelles (UniSey), the Ministry of Environment, Energy and Climate Change (MEECC) and ETH Zürich developed their collaboration in teaching and research, as called for in a long-term partnership agreement in early 2016. A transdisciplinary Case Study (tdCS) was the first implementation step of this collaboration. Since then, this collaboration has evolved, and a Sustainability Learning Lab (SLL) in the Seychelles is on the way to being built. The SLL is a learning space where people meet, share new ideas and jointly produce new knowledge and insights in the context of sustainability. The tdCS forms the structural backbone of this platform, complemented by master's and bachelor's theses, internships and further activities (Krütli et al., 2018b).

The case study was developed as a joint teaching activity of the Transdisciplinarity Lab (TdLab) at ETH Zürich and the Environmental Sciences Program at UniSey. For UniSey, the case study would be a placement provision, giving students the opportunity to conduct field research. For ETH, it is an elective seven-credit point

Box 1 – Transdisciplinary Case Studies

Transdisciplinary Case Studies (tdCSs) of the Transdisciplinarity Lab are problem-oriented, research-based seminars held in real-life situations, allowing science–praxis co-production of knowledge. Each tdCS starts from a real problem in the sustainability context (e.g., solid waste management) and includes an intensive exchange between academia and practice. A tdCS pursues a holistic approach; students from various backgrounds collaborate under a guiding question. They analyse the system of the specific issue and develop and assess solutions in close collaboration with stakeholders/experts from outside academia. Holistic appraisal methods (e.g., scenario analysis, sustainability appraisal, multicriteria assessment), and disciplinary methods (e.g., material flow analysis, cost-benefit analysis, in-depth interviews, surveys) are adopted. The TdCS is a yearly recurring seminar, alternating between Switzerland and the Seychelles.

master's course, exposing the students to a complex real-world problem addressed from multiple perspectives. Members of the TdLab, UniSey and the MEECC agreed that the case study in 2018 should (after 2016) again focus on solid waste management (SWM) in the Seychelles.

SWM poses a significant challenge for the Seychelles. Presently, all major fractions of waste, with the exception of a large proportion of PET, aluminium cans and large scrap metal, are landfilled (Lai et al., 2016). Landfilling raises environmental concerns, including leaching of pollutants, methane emissions and resource depletion (Kjeldsen et al., 2002; Adhikari et al., 2006; Nolasco et al., 2008; Laurent et al., 2014). Additionally, because land is scarce and expensive in the Seychelles, the government will incur significant costs of landfilling in the future. Waste generation has continuously increased over the last years, but landfill construction has not kept up with this increase.

In this regard, tdCS 2016 (Lai et al., 2016; Meylan et al., 2018) provided an overview of the current SWM system, potential strategies to reduce waste and options for a future waste management system. The study drew the following conclusions:

(1) Urgent actions are needed because landfilling rates suggest 7–10 other landfills with the volume of the current Providence II, Unit 1 landfill by 2040, given the current and the projected population and economic growth rates and the absence of other measures to reduce waste streams dumped into landfills.
(2) Concerted actions are necessary to tackle the various challenges of waste management; these require government leadership. It means that a clear intention to effectively implement the various strategies and masterplans is needed. Concretely, this involves actions at (a) the policy level to harmonise strategy and policy plans (e.g., eliminate inconsistencies) and (b) the operational level, which means assigning clear roles and responsibilities and formulating actionable objectives (also including a delegation of autonomy to the different administrative levels). Furthermore, insights from the study suggest the lack of long-term planning at the administrative level since some plans remain in a provisional state, hindering effective implementation.
(3) Financial mechanisms should be streamlined to avoid lengthy delays in the implementation of strategies. This process involves better collaboration between the Ministry of Finance and the MEECC. Furthermore, more transparency and earmarking in the levy system (PET/aluminium cans) would help build residents' trust in the SWM system.
(4) Genuine collaboration is required, not only among stakeholders in the public sector, but also between the actors of the public and the private sectors. The private sector essentially manages waste recycling (which helps reduce the waste to be dumped), while the government should create the framework conditions, such as physical spaces for businesses to carry out their operations or to support the private sector via financial incentives (loans, tax breaks and subsidies).

The 2018 case study was based on and drew from the results of the 2016 study. It reflected a continuation yet expanded its scope, focusing on sorting and post-sorting activities. The sorting area included hazardous waste (HW), recycling potential and perception of sorting at the household level as prerequisites for any effective waste treatment. The waste treatment

area included the treatment alternatives to simple landfilling, such as anaerobic digestion (AD) and incineration. A more in-depth study investigated the financial mechanisms and the barriers to the effective implementation of the plans. To guide the study, the following overarching research questions were proposed:

1. What waste treatment options beyond landfilling are feasible in the context of the Seychelles? What are their requirements in terms of waste input, policies and finances; what are the challenges and the opportunities of such alternatives?
2. Is there a potential to sort waste at the source that allows effective recycling and further waste treatment?

The research team involved in the study consisted of the three aforementioned research partners (ETH Zürich, MEECC and UniSey), 14 bachelor's (environmental science) students from UniSey and 19 master's students from ETH, with various environmental, agricultural science, engineering and spatial planning backgrounds. The advisory board comprised eleven stakeholders from government ministries and public administration, the private sector and civil society, who served as research guides (Table 2).

The team conducted the case study in two phases. During the semester from February through June 2018, the ETH students engaged in literature reading, back-

Table 2
Alphabetically ordered list of advisory board members and their backgrounds.

Name	Institution	Function
Mark Benoiton	Indian Ocean Tuna (IOT)	Environment, Health and Safety Manager
Cliff Conzalves	AAI Enterprise	Consultant to MEECC
Alain De Comarmond	Ministry of Environment, Energy and Climate Change (MEECC)	Principle Secretary, Environment
Tony Imaduwa	Seychelles Energy Commission	CEO
Flavien Joubert	Landscape and Waste Management Agency (LWMA)	CEO
Fredrick Kinloch	MEECC	Director, Waste Management
Diana Körner	Seychelles Sustainable Tourism Foundation (SSTF)	Consultant
Nanette Laure	MEECC	Director, General Waste, Enforcement and Permits Division
Rahul Mangroo	LWMA	Deputy CEO
Dr Marie-Therese Purvis	Sustainability for Seychelles (S4S)	Chairperson, Board of Directors
Jean Willing-Lee	Corvina Investment Co Ltd	Managing Director

ground research, research plan development and field phase preparation. About halfway through this period, the members participated in a two-day workshop involving stakeholders from the MEECC, the Landscape and Waste Management Agency (LWMA) and Indian Ocean Tuna (IOT). This preparatory phase was followed by three weeks of intensive field research in the Seychelles, a collaborative effort by both UniSey and ETH students.

The students were divided into seven groups, each representing a different element of the overall waste management system (Figure 1). The students and MEECC and LWMA representatives jointly selected the subtopics. This ensured that both the scientific interests of the students and the practical needs of the partners in the Seychelles were met.

To link the topics, we drew from the waste system framework established by our colleagues in tdCS 2016 (Lai et al., 2016); however, this framework was slightly adapted to the purpose of tdCS 2018. Law and policy were demonstrated as overarching spheres in the framework. We identified planning, financing and implementation as major issues of waste management (groups 6, 7). Waste economy, the second layer, was divided into two spheres – the national and the international markets. The flow would start with the import of goods and end in the landfill (deposition) and/or the international market (e.g., recycling stream, group 2) again. The waste generated in the national market would either undergo pre-sorting at the source (e.g. separation of HW from other waste fractions, group 3) or enter post-sorting after collection (e.g., from the

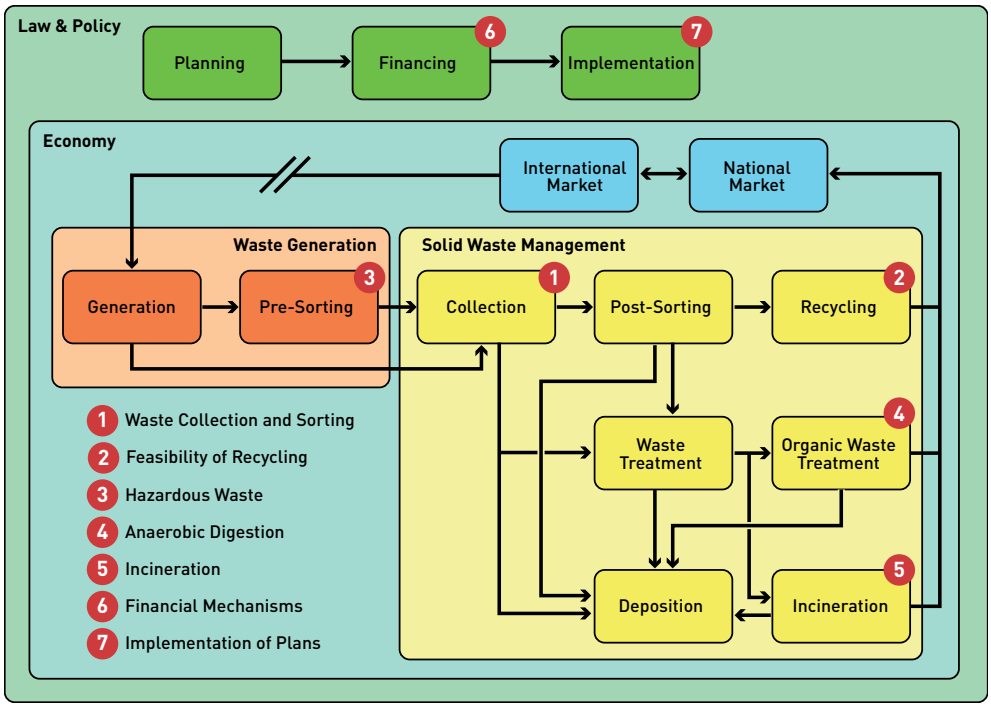

Figure 1
Case study system picture (waste system framework) and group breakdown. For details see text.

households, group 1). The collected waste would be treated (e.g., organic matter via AD, group 4 or incineration, group 5) or would end untreated in the landfill. A fraction of the treated waste would need to be dumped as well. Some fractions of sorted waste would go to recycling (in general processing before entering the national or the international market). The treatment by-products could enter the national market (e.g., as energy) or be exported (e.g., as fertiliser). Bottom/fly ashes from incineration would need to be dumped or would require special treatment (HW).

The following report presents the case study on SWM in the Seychelles. The report has been divided into seven chapters; after a short introduction, each chapter identifies an individual research group's methods, results and discussion/conclusions. The seven chapters are ordered according to the list in Table 3. A combined conclusion follows these chapters, and an outlook is drawn based on the results of both case studies 2016 and 2018. A comprehensive appendix complements this report as a separate document (see Krütli et al., 2018a).

Table 3
Description of research groups and their methods.

Group	Description	Methods
(1) Waste Collection and Sorting: Consumers' Perspective	Household survey on the perception of the waste problem, particularly on waste collection and sorting preferences at the household level	Survey (questionnaire) involving a representative sample of 150 households from different regions and districts Choice experiment to elicit collecting and sorting preferences Face-to-face interviews with retailers and restaurant managers
(2) Feasibility of Recycling: An Appraisal Methodology	Development of a two-stage methodology to examine and prioritise potential recycling options Stages involve screening (exclusion process) and multicriteria-based assessment of options	Interviews with stakeholders and experts Literature review Multicriteria decision analysis, tested with some recycling products
(3) Hazardous Waste: Material Flows	Flow of hazardous waste based on the collection of data from various sources, such as weighbridge at Providence and Basel convention permits, import/export data	Data collection for material flows Survey involving hazardous waste producers Interviews with stakeholders and experts Modelling of waste streams Data interpretation and calculation
(4) Waste Treatment I: Anaerobic Digestion	Demonstration of the feasibility (technological and economic) of anaerobic degradation of organic material to reduce waste volume and generate energy	Landfill data analysis Interviews with waste experts/stakeholders to construct scenario Construction of organic waste stream scenarios Plant design and cost analysis
(5) Waste Treatment II: Incineration	Demonstration of feasibility (technological, economic and social) of an incineration plant to reduce waste volume, generate electricity and process heat	Interviews with experts/stakeholders Landfill data analysis Calorific value/burning capacity calculation Cost estimation Survey on incineration acceptance
(6) Financial Mechanisms: Money Flows	Analysis of the current financial system of the waste management, comprising actors, money flows and economic instruments	Literature review Interviews with local stakeholders Modelling money flows
(7) Implementation of Plans: Barriers and the Way Out	Analysis of barriers to the implementation of plans, as well as ways to overcome these barriers	Literature review Interviews with key stakeholders and experts Workshop to validate identified barriers and solutions for better implementation of plans

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1 Waste collection and sorting: Consumers' perspective

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1.1 Introduction

A well-functioning collection and sorting system significantly improves the performance of post processing activities such as incineration and recycling. More specifically, the quality of separation at source can significantly influence the quality of recycled products (Hoornweg and Bhada-Tata, 2012). Sorting can be done either before collection, i.e. at the source (pre-sorting), or after collection (post-sorting). Post-sorting is related to large energy consumption because huge volumes of waste are treated to recover the valuable fractions (Schmidt, personal communication, 09.05.2018). Furthermore, post-sorting is difficult or even impossible for certain waste streams, e.g. organic waste.

Currently on Mahé Island, households bring their waste to communal collection bins nearby, which is then collected by STAR. There are several redeem centres for PET and Cans on the island of Mahé and a levy system for Seybrew bottles. However, there is currently no sorted collection system and a large portion of PET, cans and bottles are collected by informal collectors. The informal collectors collect these waste classes from bins or landfills

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and bring them to the redeem centres to be reimbursed for their job. Overall, the sustainability of the current collection system is in question (Ally et al., 2016). Separation and recycling of wastes also diverts waste away from the landfills, increasing the lifespan of existing landfills. This reduces the amount of land required for landfills. Judging from these insights, it is important to investigate the possibility of pre-sorting in Seychelles.

A sustainable waste management system requires not only the technical prerequisites but also the involvement, acceptance and support of the public. The public perception of the waste management system is an important factor for the success of a waste management system. In the report of our colleagues' transdisciplinary Case Study 2016 (Ally et al., 2016), public interviews were conducted to investigate the consumer awareness, which revealed that the majority of respondents were aware of the problems related to waste management. Moreover, more than half of the respondents were willing to pay for a waste collection system to improve the waste situation in the Seychelles. However, the sample size of the study was rather small which does not represent population and all the regions of Mahé Island appropriately. More importantly, there was no question specifically asking about a sorting and collection system. Hence, the feasibility of pre-sorting in Seychelles in terms of public acceptance is still unclear and requires further investigation. In addition, consumer industries are another important player to establish a sound waste collection system. This is not only because of the amount of waste that they produce in a daily basis, but also because there is a potential that consumers industries act as centralised collection points for neighbourhoods. In the 2016 report, stakeholders mentioned that more centralised collection points on a community level would promote the separation of certain waste classes. Therefore, it is relevant to find out whether private companies like retailers and restaurants would be willing to act as collection points for the local community.

Grounded on the above-mentioned considerations we formulate the following research questions for our study:

1. Are households willing to sort their waste?
2. Are the consumer industries (restaurants, retailers) willing to sort and act as collection points?

As for the first research question, we aimed to quantitatively analyse households' willingness to sort by performing household survey in form of both online survey and door-to-door survey. Regarding the second research question, our goal was to collect data from target industries and qualitatively discuss the results.

1.2 Methods

1.2.1 Household Survey

To answer to the first research question, we conducted household surveys in the forms of an online survey as well as a door-to-door survey. In the survey questionnaire, we asked factual data questions to assess the current state of affairs. We asked respondents' current sorting behaviour and preferences on hypothetical sorting methods to investigate their willingness to sort. Demographic questions were asked to analyse answers afterwards. Overall, we had 54 completed online surveys and 151 door-to-door surveys (for more detail see Appendix 1.3). One of the purposes of the online survey was to obtain information before the field phase in the Seychelles so that we could revise the questions for the door-to-door survey as needed. The online survey was launched

on the 25th June 2018. Another purpose was to spread the survey among the population in a fast and anonymous way in order to raise sample size. The door-to-door survey represented the focus of the field phase. The advantages of door-to-door survey includes that it enables the designers to control the sample size of the survey (e.g. same sample size from all target regions) and that the surveyor can make sure that respondents understand the questions asked. The surveyor could also verify that demographic data given by the respondents was accurate (e.g. that the respondent does in fact live in region X). The prepared questions were initially the same for the online and door-to-door survey. After the arrival in the Seychelles we adapted the door-to-door survey slightly according to insights we had gained thus far. The survey questionnaire can be found in Appendix 1.6.

Survey design

The online survey as well as the door-to-door survey consisted both of factual data questions, demographic questions and a choice experiment. The factual data questions included the willingness to sort, knowledge about the current waste collection system and general happiness about the current waste management system (WMS). The aims of the factual data questions were to determine how widespread any form of household sorting was amongst the population on Mahé Island as well as to investigate respondents' willingness to sort in the future. Whenever the household was sorting at least one waste class we categorized the household as a currently sorting household. Furthermore, we counted the households as a currently sorting household if they mentioned any stream of waste being sorted, even if the respondents themselves said they were not sorting. For instance, even if a respondent answered that he/she is not currently sorting but the respondent collected organic waste separately for use as compost, we counted the household as a currently sorting household. The factual data questions included set response as well as two open-ended questions. The collected demographic data concerned age, gender, education level, household size and household income. We categorized the education in four levels: Primary School, Secondary School, Post-secondary School and University. The respondents could choose the range of the monthly income of their household or refuse to answer. For the online survey launched before the field phase, the ranges were <2,000 SCR, 2,000–10,000 SCR, 10,000–20,000 SCR, >20,000 SCR. However, after consultation with our UniSey colleagues and the Household Budget Survey 2013 (which was undertaken by the National Bureau of Statistics), we realized that the basic salary in the Seychelles is 5,050 SCR (Seychelles Nation (2017)). Thus the income ranges in the door-to-door survey were adjusted to <5,000 SCR, 5,000–10,000 SCR, 10,000–20,000 SCR, >20,000 SCR to account for the minimum wage. The objective of the choice experiment was to investigate respondents' preferences on sorting method based on different hypothetical sorting scenarios. Details of the choice experiment are described in a later section and Appendix 1.7.

Sampling procedure

We decided that the door-to-door household surveys would be done as a structured face-to-face interview. In collaboration with the National Bureau of Statistics (NBS) we developed a sampling strategy. The aim of this sampling strategy was to conduct the survey in a representative way.

We chose the sampling locations to represent the four main regions of Mahé Island, namely the Northern region, Western region, South-Eastern region and Central region (see map in Appendix 1.2). The respective collected samples for each region are shown in Table 1.1. For each of these four regions we selected two districts. In

Table 1.1
Sampling of door-to-door household survey (not including online survey).

Region	District	Collected sample	Target sample
North	Beau Vallon (BV)	20	22
	Bel Ombre (BO)	19	21
Central	English River (ER)	20	18
	Mont Fleuri (MF)	15	17
West	Anse Boileau (AB)	18	19
	Grand Anse Mahé (GM)	21	17
South-East	Takamaka (TA)	15	14
	Au Cap (AC)	23	23
		N_{total}=151	N_{total}=150

each district we aimed to collect the necessary responses from two enumeration areas (EA's) (see EA maps in Appendix 1.2). The enumeration areas are defined by the NBS and used for data collection. The EA's include about 45 to 75 houses. Depending on the district there are 20 to 40 EA's per district. The main factors influencing the choice of EA's was the distribution density of the households and the topography. We chose areas of higher densities. In some cases, the owner of the house was not present, or the person did not want to participate. We counted these cases as active rejections.

Together with the NBS we determined the required target sample sizes for each EA in proportion to the number of inhabitants in each district. However, in most of the cases the collected samples differ from the target sample.

Data collection

During the door-to-door survey, we aimed for the head of household. However, sometimes the respondents were not the head of household because the head was not at home or the head of household asked another member of the household to respond to us instead. We conducted the survey in Créole or in English, depending on the preference of the respondents. The ETH students conducted the English surveys whereas the UniSey students conducted the surveys in Créole. The respondents of the online survey had also the choice between English and Créole (translated by UniSey students). For spreading the online household survey, the UniSey students and a participant of the advisory board meeting shared the link to the survey on social media.

Data analysis

After the data collection, we analysed data both qualitatively and quantitatively. Our household survey included two open-ended questions, namely reasons for not sorting waste and current behaviour regarding organic waste. However, we tried as much as possible to categorise answers into several categories if possible. In order to discuss results objectively, we used mosaic test and Wilcoxon-Mann-Whitney test. For example, we applied Wilcoxon-Mann-Whitney test to investigate the effect of education level on satisfaction level with the current waste management system.

Choice experiment

Theoretical background of choice experiment

The discrete choice modelling method, also called choice experiment (CE) allows us to investigate respondents' preferences on hypothetical situations that do not yet exist (stated-preference data) by letting respondents repeatedly choose one alternative from several alternatives. The advantage of investigating stated-preference data is that the experiments can be designed to contain as much variation in each characteristic of an alternative as the researcher thinks is appropriate (Train, 2002). Among other approaches to analyse stated preference data such as Likert scale based method, the advantage of CE is that combinations of alternatives make it difficult for respondents to respond strategically and therefore we can reduce bias. We assume that a respondent chooses an alternative that maximizes the respondent's utility, which indicates a satisfaction towards an alternative. Utility is assumed to be expressed as a linear sum of characteristics of an alternative.

Design of question set and method of analysis

The choice experiment used in our survey was designed based on a paper of Aizaki (2015). The first step in CE design is to identify characteristics and levels of each characteristic to generate our hypothetical collection systems. The characteristics are: fractions of sorting; collection frequency; monthly costs. Fractions of sorting are identified as it clearly has an impact on utility of users of a collection system. We selected three waste classes, namely PET, Cans and organics to define three levels. Although we recognize the existence of redeem centres in Mahé, it is important to investigate the possibility of sorting at source given that current sorting system is dependent on informal collectors. Organics is selected since presorting is the only way to sort this waste class effectively and can be used for anaerobic digestion. Collection frequency is determined as the second characteristic although households can bring their waste to a collection bin whenever they want to. It is mentioned that floating bins are a serious problem in Seychelles although there is a daily or twice a day collection (Gonzalves, 2017). Therefore, we included this characteristic to find out whether households regard collection frequency as an important aspect of a collection system. Finally, we introduced monthly costs for a household to investigate the effect of cost to households' utility. Three levels are determined based on Seychellois' willingness to pay for current system identified by Ally et.al (2016). Characteristics and their levels are listed in Table 1.2.

In the next step, question sets used in our survey were designed by using factorial design and blocking method. In short, the advantages of applying these methods were to determine question sets in a way that respondents need to answer to only several question sets and still enables researchers to see effects of characteristics. Montgomery (2017) explains the detailed methodology of the design. In our CE, nine different choice sets were created and blocked into three blocks. Each block has three choice sets. During the survey, respondents received only 1 block with 3 question sets in each of which they were asked to choose one hypothetical collection system which they prefer the most out of three alternatives (See Figure 1.1 for an example question set). Com-

Table 1.2
Characteristics and levels for each attribute used for our Choice Experiment.

Characteristics	Levels	Description of levels
Fractions of sorting	3	'No sorting' vs 'PET and Cans' vs 'PET, Cans and Organic'
Collection frequency	3	'Monday, Wednesday and Friday' vs 'Everyday (Mon–Fri)' vs 'Everyday (Mon–Sun)'
Monthly costs	3	0 SCR vs 50 SCR vs 100 SCR

Example	Alternative 1	Alternative 2	Alternative 3
Method of sorting	No sorting	Cans & PET are collected separately	Cans, PET & organic are collected separately
Days of collection	Monday, Wednesday & Friday	Everyday (Monday to Friday)	Everyday (Monday to Sunday)
Monthly costs for your houshold	SCR 0	SCR 50	SCR 100

Figure 1.1
Example of a question set (Respondents were asked to choose one of three alternatives, which they prefer the most. In total each interviewee had to answer three question sets).

plete question sheets used in our survey can be found in Appendix 1.7. We distributed blocks to respondents in a way that we have equal number of answers from all blocks. We analysed collected data by applying conditional logit model (CL). CL allows us to quantify a degree of contribution of each level of characteristics to respondents' utility. Theoretical background of CE and CL can be found in Appendix 1.4. Among 151 door-to-door interviews, we conducted 144 CE since sometimes respondents rejected to answer CE or had disability such as blindness, which made it impossible to conduct CE.

Door-to-door Household Survey Demographics

In total, we contacted 269 households across Mahé Island. We were able to collect data of 151 households. Out of the 151 households seven respondents did not want or were not able to answer the choice experiment. We encountered 118 rejections whilst performing the door-to-door survey. This equates to a response rate of 56%. Some households rejected the interview because they did not have time or a head of household was not available. Interviews were taken in the period of July 4th –11th 2018.

In Table 1.3, the demographic data of all our samples in the door-to-door household survey is shown.

Overall the share of female respondents is higher than the share of male respondents (59% vs. 41% respectively). Median of respondents' age is 57, which is significantly older than 36 given by Bureau of Statistics. Moreover, more than 30% of the respondents belong to the age groups older than 65, which means that the respondents were rather old in the door-to-door survey. Since most of our surveys took place during the week and during the working hours we encountered a lot of retired people because the younger people were at work. Nevertheless, the elderly people usually were the head of household. Regarding the income level 48.3% of the respondents have a monthly income over 10,000 SCR. 27.2% of the participants did not answer this question. It is important to remark that the monthly income includes the salaries of all the members of the household together. The income per capita might be much smaller for large households than for small households. Most of the respondents attended Secondary or Post-secondary school (68%). 17% of respondents attended Primary school level and University make up 15%. According to the Bureau of Statistics, the Dependency Ratio in Seychelles is 428 and is defined as the sum of those aged <15 years and >65 years per 1000 inhabitants. We assumed that all members of the household that are aged <15 years and >65 years are not working members of the

Table 1.3
Demographics of the door-to-door household survey (N=151).

Gender (n=151)	Female		Male	
	59%		41%	
Age group (n=148) (Mean age = 54.19) (Standard deviation = 17.81)	<30	30–50	50–70	>70
	12%	26%	42%	20%
Educational level (n=146)	Primary	Secondary	Post-secondary	University
	17%	30%	38%	14%
Monthly household income (SCR) (n=110)	<5,000	5,000–10,000	10,000–20,000	>20,000
	9%	25%	34%	33%

household. Thus, we calculated the number of non-working household members per household member from our data. However, some non-working members in the households could be aged 15–65 years, such as children attending secondary school, post-secondary school and university. This means that our Dependency Ratio should be higher than the one reported nationally. We calculated the Dependency Ratio of our sample at 456.

Of the 151 surveys collected, 42% were conducted in English and 58% were conducted in Créole.

Online Household Survey Demographics

We started the online survey on 25th of June and closed it on 14th of July 2018, so the duration of the survey was 19 days. During this time, in total 54 respondents participated in the survey. Table 1.4 contains the demographic data of the participants of the online survey.

The age structure of the online survey shows that about 65% of the participants are younger than 30. There is a clear trend that the participants are rather young in this part of the study. As is the case in door-to-door survey, around 60% of the respondents were female. Most of the respondents had a monthly household income of more than 10,000 SCR. However, almost as many respondents did not know the household income or did not give an answer to this question. The educational level shows a very distinct pattern. All the participants have at least a post-secondary education, with most having attended a university. This is probably because the online survey was spread from our UniSey colleagues.

1.2.2 Consumer Industry Interviews

For the consumer industry we focused on the industries that are regularly frequented by the residents and by tourists. Since the focus was on households, we were able but to cover a small selection of 9 restaurants and 8 retailers in our survey. In total, we contacted 17 and 18 restaurants and retailer shops, respectively. The response rate was approximately 50%, see Table 1.5.

The information we wanted to gather from these surveys was the following:

- The current waste and sorting behaviour of the business.
- Willingness to sort and act as a collection point in the future.
- Composting activities.

This information was gained by using semi-structured surveys (see Appendix 1.5). We performed face-to-face surveys in the restaurants/shops very similar to the

Table 1.4
Demographics of the online household survey (N=54).

Gender (n=54)	Female		Male	
	61%		39%	
Age group (n=54) (Mean age = 28.61) (Standard deviation = 10.29)	<30	30–50	50–70	>70
	65%	28%	7%	0%
Educational level (n=54)	Primary	Secondary	Post-secondary	University
	0%	0%	43%	57%
Monthly household income (SCR) (n=32)	<5,000	5,000–10,000	10,000–20,000	>20,000
	6%	13%	38%	44%

Table 1.5
Sampling of Consumer Industry Interviews (N=17).

Business Type	Target Sample	Collected Sample	Rejections
Restaurants	10	9	8
Retailers	10	8	10

Table 1.6
Categories of businesses surveyed.

Business		Category	Number
Restaurants	Size	< 30 seated	4
		> 30 seated	5
Retailers	Type	Electronics	2
		Clothing	2
		Food	2
		Hardware	1
		Boating Equipment	1

door-to-door surveys that we employed for the household. The surveys were conducted by individual interviewers or by pairs of interviewers from the 12th to the 16th July 2018. The position of the respondents in the business was owner, manager or assistant manager of the businesses we interviewed. We guided the conversation to gain our target information but also took notes of other information gained during the conversation. Most of the retailers were interviewed in the English River district of Victoria. The restaurants were spread between the districts of Anse Royal, English River, Beau Vallon and Grande Anse Mahé. The number of different size restaurants and different types of retailers interviewed is indicated in Table 1.6. We had an even distribution of smaller and larger restaurants as well as a wide variety of retailers. The data collected during the interviews was evaluated and analysed manually since the sample size was not that big. We counted the number of statements relating to the willingness to sort (Yes, No), to the current situation of sorting in the business (Yes, Yes, but only organics and No) and to the willingness to sort as a collection point. Regarding the collection points we had three categories (Yes, No and Yes, but...).

1.3 Results

In this section we present major results of the door-to-door and the online household survey and the consumer industry interviews.

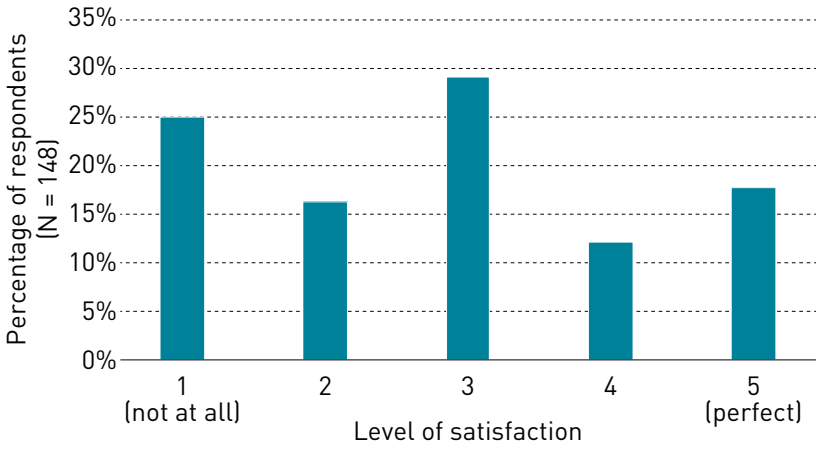

Figure 1.2
Overall satisfaction with the current waste management system for the door-to-door survey.

1.3.1 Door-to-door household survey

Results of the door-to-door survey include: satisfaction of the respondents with the current waste management; the current sorting behaviour of respondents, including regarding their organic waste; the respondents' use of the PET and can redeem centres; preferences of respondents based on the choice experiment; and the public awareness of the waste management system in Seychelles.

Satisfaction level

The average satisfaction with the current waste management system is 2.81 on a 1–5 scale (1=not at all satisfied, 5=totally satisfied), with a standard deviation (SD) of 1.40. Figure 1.2 shows the response pattern regarding households' satisfaction with the current waste management system. About 30% of the respondents are plus-minus satisfied with the current system. This could also be interpreted as

them not having a clear position on how satisfied they are. A considerable number of respondents (41%), however, are rather or not at all satisfied while 29% are rather or completely satisfied with the current waste management system. There was no statistically significant difference in the level of satisfaction when comparing gender, education level and region.

Some respondents elaborated further on why they were (dis)satisfied. Some who were dissatisfied mentioned that the collection bins were too far away/too inconvenient to use. This opinion was also expressed about the redeem centres. Others mentioned that the frequency of collection was too low. Another reason was that the current system was perceived as not being environmentally friendly. Those who were satisfied mentioned that they were happy to be able gain extra income from the sale of PETs and/or cans. Further indicated that the current system was very convenient because once their waste was in the collection bins, they did not need to worry about it anymore. Others perceived that the current system was more environmentally friendly and/or a lower public health risk than if every household dealt with its waste independently.

Current sorting behaviour

In terms of the current sorting behaviour of households, 64% of the respondents stated they were already sorting at least one stream of waste and diverting it from landfill, as indicated in Figure 1.3. These respondents usually sorted their waste for several reasons. PET bottles and cans, for example, were usually separated for the following reasons: the first is for financial gain, where the household sold its PET bottles and cans to the redeem centres or to informal collectors at a reduced price. These were also separated to prevent informal collectors from digging through the rubbish bins (several respondents expressed concern over the health hazards informal collectors would otherwise be exposed to) as well as to protect the environment. Similarly, organics were separated for hygienic reasons such as prevention of distasteful odours from the collection bins, prevention of rats in the house and garden or discouraging stray dogs from overturning the collection bins to get at food waste. Some organics, such as food waste, were also sorted to feed pets (dogs, cats, tortoises). Garden waste that was separated was usually used for compost or was burned.

Around 22% of the respondents replied that they would be willing to sort in the future, even though they were not currently sorting (Figure 1.3). Reasons for lack of sorting included the lack of a system that maintained the purity of the sorted waste streams or that they would only be willing to if provided with enough rubbish bins. Others responded that there was not sufficient incentive for them to sort their waste. Almost 14% responded that they do not and would not be willing to sort their waste in the future (Figure 1.3). The reason that they had in common with the former 22% of the respondents is that they do not have the time/space to perform the sorting. Occasionally respondents also mentioned that the government had promised a decent waste system and thus believe that sorting is the government's responsibility and not theirs. The reasons stated for not sorting are summarised in Figure 1.4. This indicates that most of those who do not sort because of a lack of sorted system are those who are willing to sort. However, most of those who do not have the time or have no incentive to sort are those also not willing to sort.

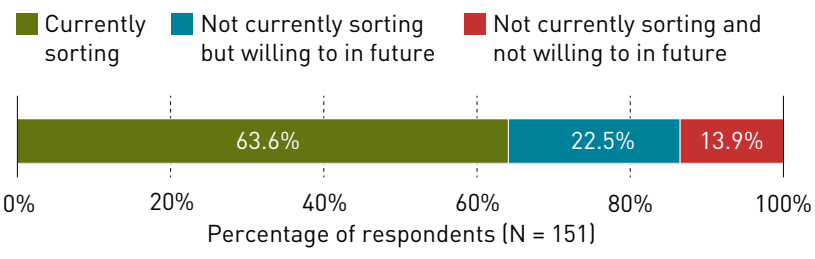

Figure 1.3
Percentage of respondents willing to sort.

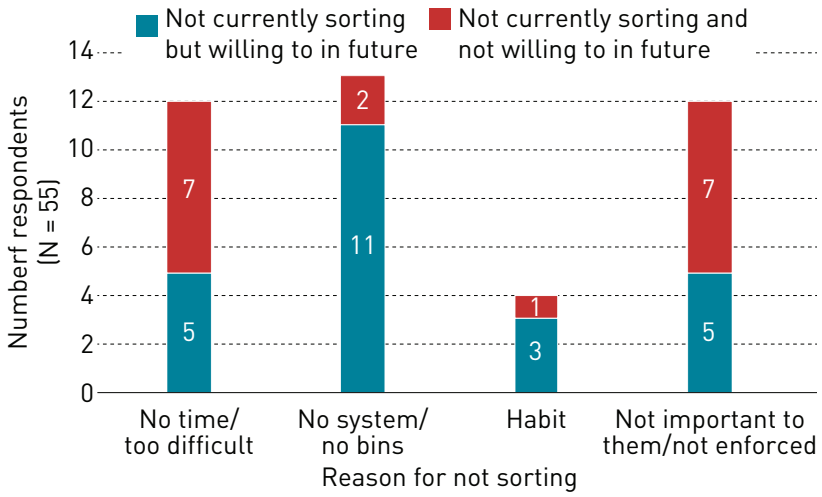

Figure 1.4
Reasons for not currently sorting waste.

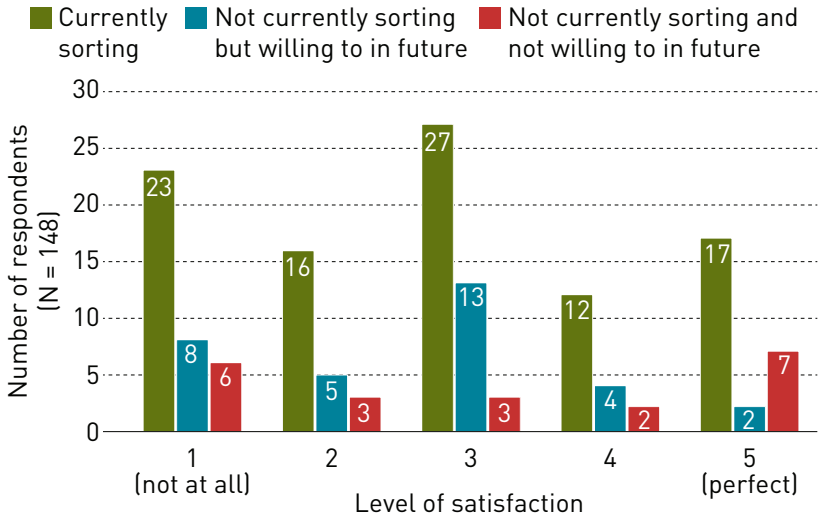

Figure 1.5
Overall satisfaction with the current waste management system according to sorting behaviour.

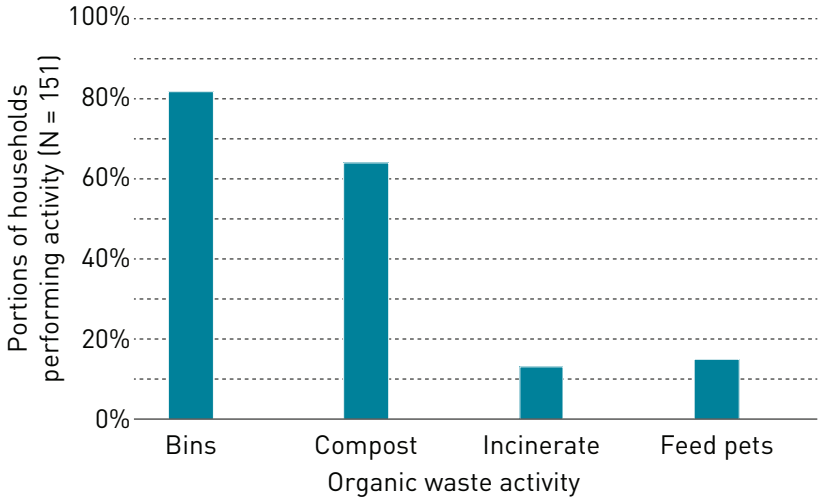

Figure 1.6
Behaviours for disposal of organic waste in households (N = 151) , multiple answers possible.

Thus, at least 86% would be willing to sort their waste in the future, depending on how the waste management system develops.

When considering the willingness to sort of a household versus their satisfaction with their current waste management system, as shown in Figure 1.5, then one can see that those not willing to sort tend towards the extreme ends of the satisfaction levels. Only 21 respondents said they are not willing to sort. This might not be a representative sample of this subset of respondents and could thus have generated a different pattern. On the other hand, those not currently sorting but willing to tend to be more neutral.

Sorting of organics

When we asked specifically about the household behaviour with regards to the organic waste produced by the household, there were four main behaviours mentioned. These were to dispose of organic waste in the collection bins, composting, incineration of the waste or feeding some of it to pets (such as dogs and tortoises). It is important to note that most households performed some combination of these; such as composting garden waste but disposing of the remaining organic in the collection bins. Figure 1.6 shows the most prevalent behaviours for households to dispose of organic waste. Whereas 64 of the households perform some form of composting, which they use for their own garden, 82 of the households use the collection bins to dispose of some or all of their organic waste (N=151, multiple answers possible). 13 incinerate a portion of their waste and 15 feed a portion to their pets (N=151, multiple answers possible). This total is greater than the sample size because, as mentioned before, some households dealt with their organic waste in multiple ways.

Redeem Centres

Table 1.7 contains the responses of the households when asked about their use of the redeem centres for PET bottles and cans. 66.6% of respondents either sell or give away their PET bottles to the informal collectors. Another 14.7% sell their collected PET bottles to the redeem centres themselves while approx. 18% of respondents have not heard about the redeem centres and levy system in place for PET bottles and cans. Similarly for aluminium cans, only 12% of all the respondents sell their cans to the redeem centres themselves while 70% make use of the informal collectors. Several of the respondents who sell or give away their PET bottles/cans to informal collectors mentioned that the redeem centres were too far away from them (most of the respondents knew only about the redeem centre in Providence). They said they spent more money bringing in the PET bottles and cans than they would get for them. Many also mentioned that they would bring their collected items to a redeem centre themselves if the centres were closer or more conveniently situated.

Table 1.7
Use and awareness of redeem centres. 'Yes' indicates that respondents are currently using a redeem centres themselves whereas 'No' means that respondents do not use it. 'I don't know' means respondents did not know the existence of redeem centres. (N=151).

	Respondents use of Redeem Centres		
	Yes	No	I don't know
PET bottles	14.7%	66.6%	18.7%
Cans	12.0%	70.0%	18.0%

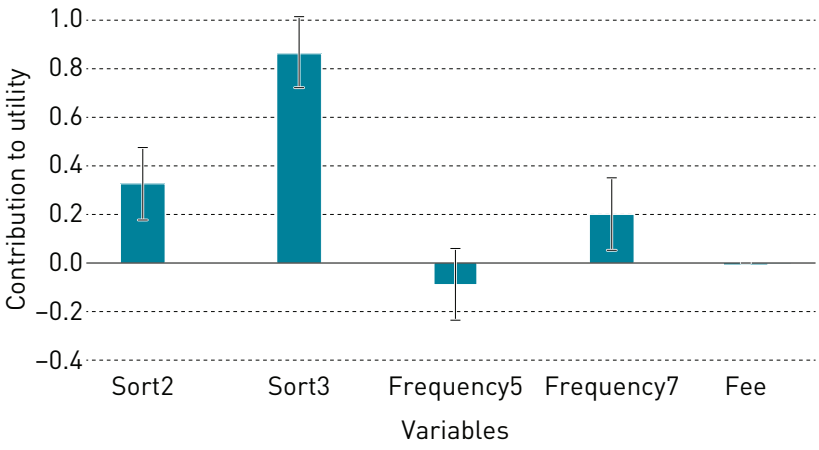

Figure 1.7
Plot of utility per attribute. sort2 = sorting of only PET and cans from household waste; sort3 = sorting of PET, cans and organics from household waste; frequency5 = bins are collected every week day; frequency7 = bins are collected every day; fee = contribution to the utility. (N = 144).

Choice experiment

We visualized the significance of the characteristics as well as standard error as a form of contribution to utility in Figure 1.7.

Signs and relative values of coefficients explain how different variables influence respondents' utility. The values of *sort2* and *sort3* indicate the contribution of each sorting method to respondents' utility with respect to no sorting (Figure 1.7). In the same manner, the values of *frequency5* and *frequency7* imply the contribution of each collection frequency to the utility with respect to 'collections are done on Monday, Wednesday and Friday'. The value of Fee indicates the contribution of increase of monthly cost by 1 SCR to the utility.

The sorting method (*sort2* and *sort3*) and the monthly cost (fee) turned out to be statistically significant determinants of choice. Coefficients *sort2* and *sort3* show that respondents prefer to sort their waste. The relatively large value for *sort3* when compared to *sort2* indicates the respondents' strong willingness to sort organic waste. This could indicate that sorting of organics is a major priority for respondents. It could also indicate the respondents' preference to have a sorting system that includes organic waste in addition to PET and Cans sorting. The coefficient for fee is slightly negative, indicating the intuitive fact that respondents' utility decreases as the monthly cost increases. However, it can be said that monthly cost has little impact on respondents' utility given that coefficient value for fee is much smaller than coefficients for *sort2* and *sort3*. The

insignificant coefficients *frequency5* and *frequency7* might indicate that the frequency of collection is not important for the respondents. However, assuming that the frequency of collection is important to the respondents, this could indicate a lack of consensus among the respondents with regards to the preferred collection frequency. A further reason for the lack of significance is that the choice experiment limited the choice to two specific scenarios with specific days of collection rather than asking for preferred frequency independent of the days of the week. Values of all coefficients and standard errors, significance level of each coefficient, and goodness of fit are shown in Appendix 1.4.

Indication of public awareness

At least 77% of respondents knew that the waste collected by STAR was mainly destined for the landfill. We say 'at least' because when asking them if they 'know what happens to [their] waste after collection', several respondents were hesitant or thought at length before giving a response. From some discussions it was clear that the fact that we asked the question made the respondents second-guess their knowledge. Some went as far as to elaborate systems that currently do not exist in the waste management system (such as a post-sorting scheme, managed by either the government or STAR, with all the sorted categories being recycled rather than landfilled). Thus, we say 'at least' because there might be several respondents who know, but after second-guessing their knowledge responded that they did not know.

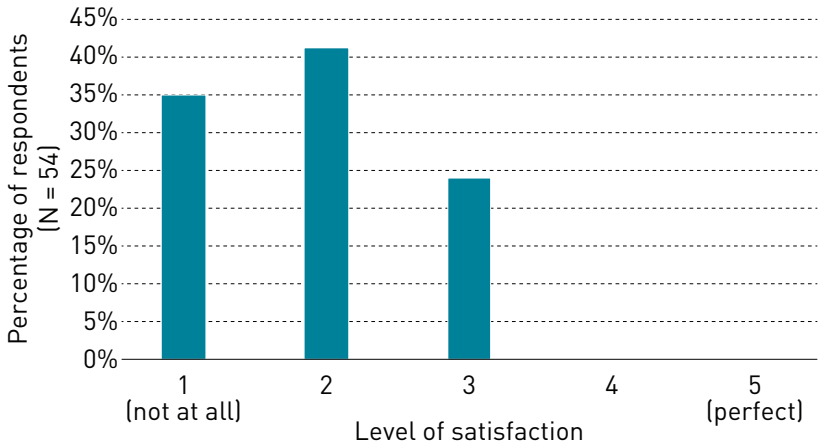

Figure 1.8
Overall satisfaction with the current waste management system for the online survey.

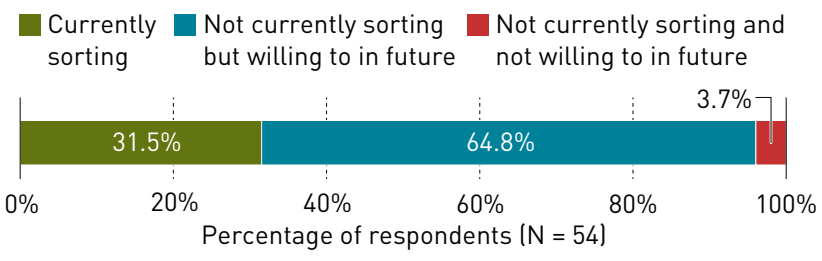

Figure 1.9
Percentage of respondents willing to sort.

1.3.2 Online household survey

Satisfaction level

For the respondents of the online survey, the average satisfaction level with the current waste management system is 1.89 on a 1–5 scale (1=not at all satisfied, 5=totally satisfied), with a standard deviation (SD) of 0.77. No respondent has a satisfaction level larger than 3. The distribution of the result is shown in Figure 1.8. Further analyses also indicated that gender seems to have no effect on satisfaction level for the respondents of the online survey.

Willingness to sort

As is indicated in Figure 1.9, a bit more than 31% of respondents are already sorting and nearly 65% are currently not sorting at all but willing to start sorting whereas almost 4% answered that they are not willing to sort.

Comparison between door-to-door survey and online survey

The average age of respondents of the door-to-door survey (54 years old) turned out to be much older than that of online survey (28 years old). Since we aimed for a head of household during door-to-door interviews whereas online survey was spread through social media, this age

difference is reasonable. Results of satisfaction level and willingness to sort were considerably different between two surveys average satisfaction level from door-to-door survey (2.81) is much larger than that of the online survey (1.89). Also, only 3.7% of the respondents from the online survey are not willing to sort in the future whereas 13.9% answered the same on door-to-door survey. Indeed, results of Wilcoxon-Mann-Whitney test significant difference both on satisfaction level and willingness to sort between two surveys with the significance level at 1%.

1.3.3 Consumer Industry Interviews

Restaurants

In total we interviewed nine different restaurants on Mahé Island. Four out of the nine restaurants did not currently sort at all. The remaining restaurants sorted mainly organics. Since none of these restaurants showed composting activities, most of the organics were used for animal feed or given away to neighbouring interested households. The motivation for sorting the waste consisted of public image, environmental protection and hygienic reasons inside the restaurant. The restaurants without any sorting activity stated that there are not any facilities and bins to sort, that not enough space is available and that the system does not work properly. Other restaurants explained that they do not have the motivation to sort, that the legal regulations are missing or that no sorting is just their habit. However, whenever we asked whether they were willing to sort if the system worked well, all the nine interviewed restaurants stated that they were willing to sort in this case. The frequency of collection was quite high for all the restaurants. The waste was collected at least three times a week for all the restaurants. Five out of nine restaurants indicated a collection frequency of seven times a week. According to the statements of some of the restaurant managers the high collection frequency should prevent the waste from starting to smell inside the restaurant, which could have negative impacts on the costumers. The majority of restaurants worked together with STAR and most of them paid for the waste collection. In general, the reactions to the idea of functioning as collection points for the public were rather negative. Six out of nine restaurants would not be willing to act as a collection point. They argued that acting as a collection point for the public would have negative impacts on the image and were afraid that the waste inside the bins would start to smell. One manager of the restaurant stated that he is not willing to pay for another person's rubbish. Another manager mentioned that it would create restlessness if people rushed in and out all the time. Some restaurants, however, would allow costumers only to dispose their waste in the bins owned by the restaurants. Three restaurants would be willing to act as collections point but only if exclusively dry waste would be disposed in the bins.

Retailers

During the analysis of the interviews with the retailers we gained the insight that most of the retailers generally do not produce a lot of waste. Six out of eight interviewed storekeepers explained that the majority of the produced waste is packaging waste, paper and cardboard. According to some of the interviewees the amounts of the residual waste are so small that it is not worth it to sort out the different waste streams. Another storekeeper reasoned that he does not have the time to sort the waste. Other reasons mentioned were the habit of no sorting, no existing laws or no sorting system in place. Since the interviewed stores do not accumulate a lot of waste the frequency of collection was correspondingly low for the retailers. Four out of eight interviewed storekeepers said that the waste is collected only once a week. The most often mentioned collector company was STAR. One store even stated that only informal collectors collect the waste. Five out of eight storekeepers stated that they would be willing to offer bins for the

public. However, four out of the five storekeepers, who would be willing to offer bins, would not allow household waste, which is slightly contradictory. Another store would be willing to act as a collection point but does not want to be responsible for the entire community. The two storekeepers who did not want to act as a collection point mentioned that they would only allow customers to dispose their waste in their bins.

1.4 Discussion

The goal of this study was to determine public participation in the current and future waste management systems. As mentioned earlier in the report, public participation is a crucial factor that can determine the success or failure of a waste management system.

1.4.1 Key Findings of Household Survey

Willingness to sort

Most of the households surveyed (64%) already perform some form of sorting and a further 22% would be willing to sort in future. Few (14%) said they are not willing to sort. Interestingly, 42% of the households were composting a portion of their organic waste in their private garden and 10% of the respondents said that they feed their pets with a part of the organic waste fraction. This is a surprising insight since the stakeholders from Government were convinced that Seychellois people are not ready to sort organics. Furthermore, they told us that there is no need for compost because the agricultural sector is not prominent in the Seychelles; yet several households were performing home composting and using the compost for their own gardens. This also indicates that former public awareness campaigns aiming to encourage home composting were somewhat successful. However, during the surveys we got the impression that many respondents were not aware of the fact that separating organics is a kind of sorting waste. Some respondents would state that they do not sort but if the respondents indicated that they did sort at least one waste stream later during the interview, we adjusted the answers for the survey accordingly. Also, unlike with the door-to-door survey, most respondents of the online survey stated that they do not and/or are not willing to sort their waste. This could indicate that the respondents do not perceive their own sorting behaviour.

From the choice experiment, we revealed that households prefer to sort their waste rather than throwing all the waste classes in the same bin. As for the sorting of PET and cans, considering the fact that many of respondents were already using redeem centres directly/indirectly or giving away their PET and Cans to informal collectors, our result is not surprising. However, results also showed that respondents preferred the sorting method 'PET, Cans & Organics are collected separately' over 'PET, Cans are collected separately'. The aforementioned fact that over 40% of respondents are already performing some sort of organic sorting can be a possible explanation for this result. Also, several respondents who already perform organic sorting mentioned to the odour from organics as a reason of sorting. Overall, sorting organics might not be a high hurdle in Seychelles as indicated by the results. However, an appropriate sorting system, which provides the respective incentive to sort (e.g. sorting spots nearby), needs to be in place. Regarding the frequency of collection, we did not find any significant preference. Since in our choice experiment the frequency of collection was connected to specific days (e.g. Monday, Wednesday and Friday) some of the respondents replied that they would prefer other days of the week for collec-

tion. Surprisingly some of the respondents would prefer a lower frequency of collection. They argued that their household does not have enough waste for a daily collection. A possible explanation for this answer could be that some of them did not understand that the collection would be on a community level from a shared collection bin. Furthermore, the separation of organics could have influenced this choice. In their opinion, bins without organic waste in it have lower odour emissions and do not have to be emptied every day. In terms of the monthly costs for the household we found out that the people prefer not to pay a monthly fee. However, it is important to remark that the fee for the waste management system is already now indirectly included in the taxes. According to the PUC (Public Utilities Corporation) every household pays the water bill on a monthly basis. The water bill is an environmental charge and comprises 15 SCR per month (see Chapter 6, Financial sustainability: current structures and potential steps forward, subchapter *'Environmental Trust Fund (ETF)'*). Obviously most of the people are currently not aware of this automatic financial contribution to the waste management system. As a possible consequence, many people chose alternatives with low costs.

1.4.2 Other Findings of the Household Survey

The satisfaction level with the current system is spread throughout all 5 categories. Most respondents were either indifferent (scale 3) or chose the extremes of very unsatisfied (1) or very satisfied (5). Fewer respondents where only slightly dissatisfied (2) or slightly satisfied (4). This could indicate either that there is a wide range in the quality of the service delivery or that the ideal system of the respondents can vary significantly. The data was also analysed to see if there were significant differences between the region and education level (based on a Wilcoxon-Mann-Whitney test) and the age of the respondents (by visual inspection of plots). There was no difference between the satisfaction levels of the respondents when comparing their education level and the region. Similarly, there was no difference seen in the satisfaction level when comparing the age of the respondents. A visual inspection was performed to see if there was a difference in satisfaction with regards to the gender of the respondents. It is important to remember that 60% of respondents were female and 40% male, thus if there were a tendency among the female respondents then this will dominate the overall behaviour. Although minor differences were observable, a Wilcoxon-Mann-Whitney test revealed that these differences are not significant. Thus, the satisfaction level of respondents is independent of education level, region, age and gender.

Comparison between door-to-door survey and online survey showed significant difference on answers to satisfaction level and willingness to sort. The different mind-set between the younger generation and the older generation might provide some explanation since the average age of online survey (29 years old) is a lot lower than that of the door-to-door survey (54 years old). Another possible reason is the education background since the majority of respondents of the online survey (57.4%) have university level whereas only 14.1% have university level in door-to-door survey. However, it is also important to note that there might be a difference caused by using two different data collection methods.

Most of the households surveyed do not directly make use of the redeem centres. From performing the surveys, it is apparent that there is a lack of awareness regarding the locations of the redeem centres. If the redeem centres were more convenient to use, many respondents mentioned that

they were more likely to make direct use of the redeem centres. The distance to the redeem centres was an often-mentioned reason why the households do not use the redeem centres directly. In addition, some households told us that the financial gain they would get out of the levy would be minimal or even negative. Also, some of the respondents avoided the piling up of empty PET bottles by giving it to informal collectors. Thus, more accessible location of redeem centres or having more redeem centres spread across the island could increase the number of households making direct use of the redeem centres. However, the redeem centres have assisted in diverting a large portion of the PET bottles and cans from the waste stream in Seychelles.

1.4.3 Consumer Industry Interviews

The interviewed restaurants and retailers differed in their willingness to sort and their sorting behaviour. All of the interviewed restaurant keepers stated that they would be willing to sort under certain conditions. The willingness to sort depended strongly on the presence of adequate facilities and on sufficient space for sorting activities. Compared to retailers however restaurants tended to sort more than retailers. Among the restaurants with sorting activities the most often mentioned waste stream was the organic part because decomposing organic fractions start to smell after a while. Hygiene seems to be of great importance for restaurants. Most of the interviewed restaurants highlighted that odour emissions are not tolerated at all because the customers react very sensitively to non-hygienic conditions. This is also the reason why restaurants prefer to have a daily collection of their waste. The retailers did not show a distinct sorting activity. Important to remark is that the retail shops usually do not produce a high range of different waste classes. Most of the interviewed retail shops produced only packaging waste. Therefore, they had no need for sorting. For most of the restaurants the idea of acting as a collection point was not an option. The fact of having waste close to food was a delicate topic for the restaurant keepers and therefore we did not encounter any restaurant keeper who was willing to be involved in the public waste collection system. Slightly more open to that idea are retail shops. However, we could not identify a strong willingness of either restaurants or retail shops to act as collection points accessible to the public. Nonetheless more businesses and businesses of other sizes should have been interviewed for a distinguished analysis.

1.4.4 Limitations and future research

During our research we managed to collect 151 door-to-door surveys from several districts across Mahé Island. Due to time constraints we could not conduct more surveys from the remaining districts on Mahé Island. However, we made sure to cover several districts from each ‘subregion‘ of Mahé Island: Northern region, Central Region, Western region, and South-Eastern region. The ratio of respondents between the districts surveyed was approximately that of the population from those districts.

During this study we did not conduct surveys on Praslin and La Digue due to time constraints. Also, the populations on Praslin and La Digue are significantly smaller than that of Mahé.

We performed 58% of the interviews in Créole as it was generally the preferred language of the respondent. It is impor-

tant to remember that there could have been a loss in data due to the translation from Créole to English and vice versa. In addition, it could have occurred that the respondents did not understand the question in the way it was intended, regardless whether the interview was conducted in Créole or English.

For future studies, it would be interesting to also record whether households have gardens and/or pets (in which case also what kind of animals) as this could play a role in sorting behaviour. Specifically recording which wastes were already being sorted would also improve the analyses. With regards to the demographics of household income, increasing the number of options and reducing the ranges of the options would have provided better data to allow for analyses to see if the average household income per household member had a significant effect on waste/sorting behaviour. Important are a specified minimum and maximum income range that are unlikely to be selected (for example as a minimum to have 0 – 1000 SCR). It would also be interesting to know if there were certain aspects of the waste management system that prompted the respondent's level of satisfaction.

A further limitation that could be addressed is that the respondents were asked for their general satisfaction with the waste management system. This makes it difficult to assess the reason why they chose one of the options. Some people might have thought only about the daily collection by STAR whereas other people gave their opinion on the entire waste management system including the landfilling practices.

The online survey could have incorporated more 'yes/no' questions that could have made data analyses more efficient. Such questions are also less likely to be misunderstood, especially when translated into Créole. The 'yes/no' questions can also be used to gather more detailed additional data about the respondents' behaviour that we would otherwise get during the conversation when performing the door-to-door surveys. One of the significant limitations with the online surveys was that we could not verify the data with the respondent. One such instance is, for example, whether the respondent was currently sorting. During the door-to-door survey we could verify this during the interview and adjust the data recorded but we had no way of doing this for the online survey, as it was anonymous.

As for the CE, it would be interesting to always add current waste collection system as an alternative since it enables us to investigate whether households are willing to change current collection system to another one.

From the household survey, it is evident that the behaviour of sorting some waste is already widespread. Especially the separation of at least some organic waste fractions was common among the surveyed households. Overall willingness to sort is even more widely spread. Thus, we believe that introducing a sorted collection system would be successful, as long as it is designed effectively and enforced appropriately. This is further supported by the findings of the choice experiment, where we have also seen that sorting increases the utility of the household. The remaining portion can be encouraged to adopt sorting through economic incentives (such as paying an extra fee for not sorting waste). Peer-pressure and community pressure may also possibly encourage more households to start sorting.

1.5 Conclusion

As expected, the choice experiment found that paying reduces the utility to the household. However, preferring not to pay does not mean that the households are not willing to pay. The TdLab case study of 2016 found that people are willing to pay to maintain their ideal waste management system.

1.6 References

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2
Feasibility of recycling: An appraisal methodology

Ramon Hess, Bianca Curcio*, Tobias Minder*, Sheril De Commarmond***

2.1 Introduction

Recycling is part of the '3Rs' (Reduce, Reuse, and Recycle) and one of the core principles of the Seychelles' Solid Waste Management Policy 2014–2018. Recycling serves the direct diversion of waste from landfills and the substitution of raw materials in the production of goods (Martens and Goldmann, 2016). Furthermore, recycled products potentially substitute certain imported products on the national market, and may thereby reduce the overall amount of waste. Recycling includes the different processing options downcycling, recycling and upcycling. These three terms refer to the value of the product, which decreases, remains the same, or increases subsequent to the recycling process (Martens and Goldmann, 2016). Due to not only economic but also to technical issues with certain materials, all three process options are preferably performed in large centralized facilities or may be outsourced to other countries. Therefore, the export of waste from SIDS as recyclable commodities could represent another pertinent approach for the Seychelles (D'offay et al., 2016; Leney, 2006). Additionally, exporting recyclable commodities to the international market also reduces the accumulation of disposed material on the islands. This

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leads to a prolongation of the life-time of Seychelles' landfills, which is especially crucial as previous calculations clearly revealed a need for additional landfills in the next 25 years if dumping rates remain the same or increase (Mangroo and Wälchli, 2016).

To some extent, waste recycling is already established in the Seychelles. Currently, four classes of solid waste are partly recycled or pre-processed locally, three of which are scrap metal, beverage cans and PET bottles. They are mainly processed in Providence and hen exported. The fourth class consists of paper and cardboard (PC) that has been recycled on Mahé for about 20 years. Egg trays, as an example of a recycled product from paper and cardboard, are in demand on the national market and, has because of this, successfully replaced imported egg trays. However, the introduction of other recycling products, such as paper bags and take away boxes, have not been successful so far.

In the past years, awareness of the importance of sustainable waste management has improved, and the collection and processing of waste has increased significantly in the Seychelles (Lai et al., 2016). However, the majority of the resource waste is currently dumped on the landfill – waste, that potentially could be used for recycling activities.

The aim of this study was to examine and prioritize potential recycling options. For this reason, we developed a tool that provide a thorough and easy way to carry out evaluations of the feasibility and effectiveness of both current and new recycling streams. The tool is comprised of two steps. In the first, a guideline helps to roughly identify potentially feasible recycling options and thus exclude options with a low potential. In the second next step, remaining recycling options are assessed in more detail with the aim to further describe their potential for recycling, considering criteria on waste input, technology, national and international markets, and the implementation on the national and international markets. We structured our research guided by the following research questions:

- Is there a potential for further-waste recycling in Seychelles?
- What are the key criteria for recycling options to be successful in Seychelles?
- Which recycling alternatives have the highest potential

2.2 Methods

In the following sub-sections, we present an overview of our project including its boundaries and our methodological system picture. We then present the development and verification of the criteria used in our method. Finally, we present the Multi-Criteria Decision Analysis (MCDA) as a method to assess recycling alternatives.

2.2.1 Methodology

Mahé is the Seychelles' most populated island and the focus of this study. Other islands of the archipelago are not covered within the scope of this project. In our analysis, we consider recycling options within the Seychelles and export of recycling goods. Our assessment represents current conditions for potential recycling options in the Seychelles but does also include other variables that may change over time. A recycling option consists of a waste material and its associated processing. We excluded organic waste in this assessment, as it was part of another group's responsibilities (Chapter 4: Waste treatment I: Anaerobic digestion).

In a recycling system, the generation of waste is followed either by a processing of the waste into commodities or by a recycling of waste into secondary products (Figure 2.1). In the first case, the waste material is locally processed to a commodity and then exported to the interna-

tional market. All further recycling steps are performed in the destination country and hence outside of the Seychelles. In the second case, the waste material is locally recycled to a secondary product, which subsequently may either be distributed in the national market or exported to international markets. We define a secondary product as a good that is manufactured from recycled material and not from primary resources. As indicated in Figure 2.1, both a commodity and a secondary product are considered as a product.

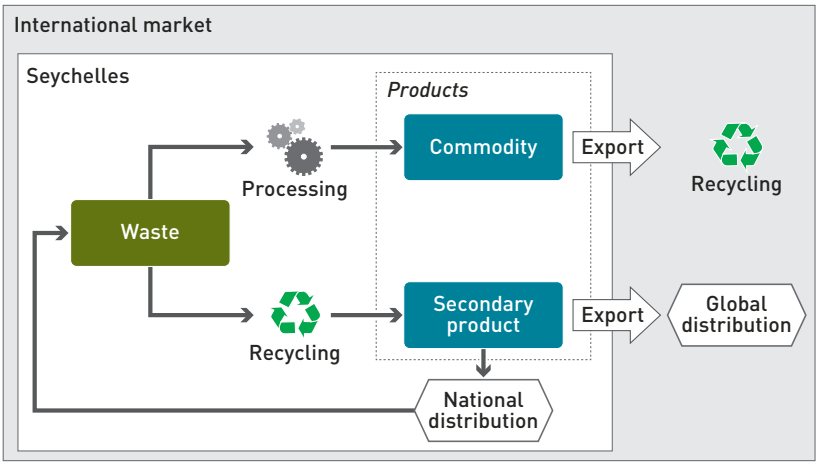

Figure 2.1
The recycling system in Seychelles. Source: Own representation.

To assess the feasibility of recycling options, we created a methodology consisting of two parts: the Exclusion Process (EP) and the Multi-Criteria Decision Analysis (MCDA) (Figure 2.2). With the EP, we tested whether the recycling options meet a defined set of preconditions. If this was not the case for a certain recycling option, we considered the recycling potential for this option as too low for further consideration and hence excluded the option from a further assessment. Possible reasons for this were economic, environmental, social, or technical constraints, which could possibly prevent an economical recycling under current conditions. The remaining recycling options were considered to have a potential for recycling and henceforth were called recycling alternatives. In a next step, we assessed the potential of these recycling alternatives with a MCDA. We then translated the results into a ranking of alternatives according to their recycling potential. In doing so, we distinguished between the recycling potentials for the national and the international market.

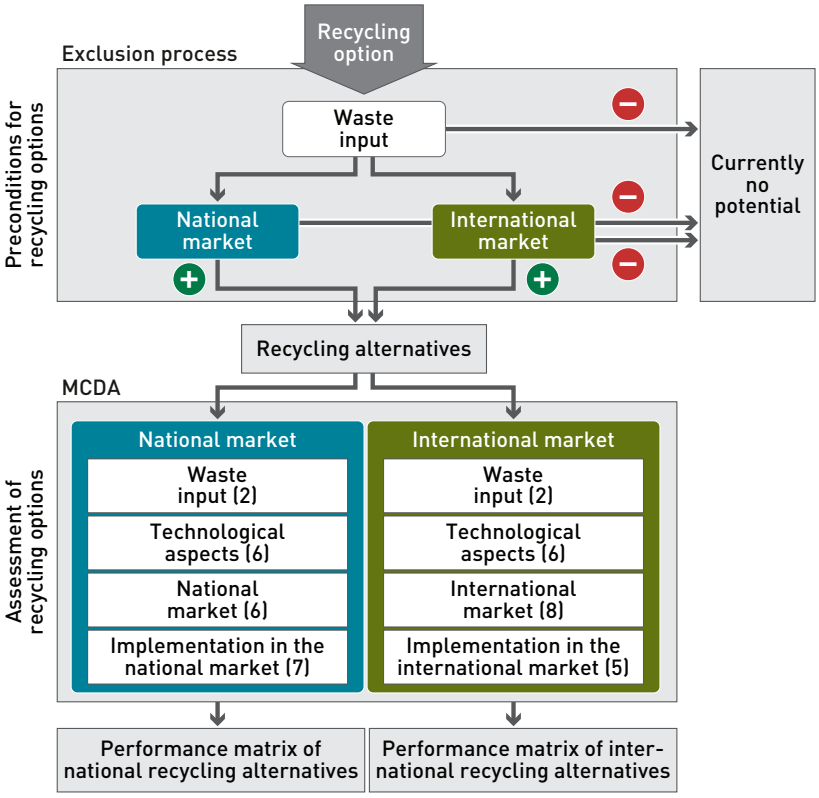

Figure 2.2
Overview of the assessment including the two methodology, the Exclusion Process and the Multi-Criteria Decision Analysis (MCDA) and for both, the national and international market. (Numbers of criteria in the MCDA categories are marked in brackets).

2.2.2 Development and verification of the criteria

Both the EP and the MCDA consist of a set of criteria assigned to different categories. The criteria are the basis for the evaluation of the recycling options and the assessment of the recycling potential of the recycling alternatives.

Our criteria are based on relevant aspects of Solid Waste Management (SWM) and recycling techniques and are aligned with the local context of the Seychelles. The information needed for the identifica-

tion of criteria was provided by four main sources: external experts, local experts, stakeholders and the literature. Together with waste management experts, we identified the key challenges and crucial elements in recycling techniques. For the identification of our criteria, we also used insights from market analysis methods (Marktabklärung, 2002), product development recommendations (Meier, 2005), and technical aspects of recycling (Martens and Goldmann, 2016). For each criterion, we added a clarification including a definition of the terminology used.

We developed the criteria in an iterative process as shown in Figure 2.3. Expert interviews with SWM specialists (M. Haupt from ETH Zürich, M. Tonner from InnoRecycling AG) regarding the existing recycling system in Switzerland helped us in our first criteria verification to cover important decision-making factors. We received additional methodological support from Mr. M. Cinelli (ETH Singapore Center), who is an expert in Multi-Criteria Decision Aiding and sustainability assessments.

A core element of our work was the adjustment and verification of our criteria with local stakeholders and experts in the Seychelles (Figure 2.3). Through interviews, we captured various perspectives on the recycling system and specific recycling products in order to understand the current context. A full list of all interviewed experts and interviews can be found in the Appendix 2.1 and 2.3 respective.

Simultaneously with the verification process, we gathered information for the assessment of the recycling options and recycling alternatives. Additional interviews with local recyclers and experts as well as site visits built the foundation for our assessment (Appendix 2.1 and 2.3). We obtained further information from the literature. In case stakeholders or the literature search did not provide enough information on the respective criteria, we completed the rating to the best of our ability. These criteria are highlighted in the analysis (the respective files are available on request).

2.2.3 Exclusion process: Preconditions for recycling options

The exclusion process (EP) aims to exclude recycling options that are not plausible under current conditions. This approach allows for a quick preliminary assessment of the necessary conditions and potential risk factors specific to the

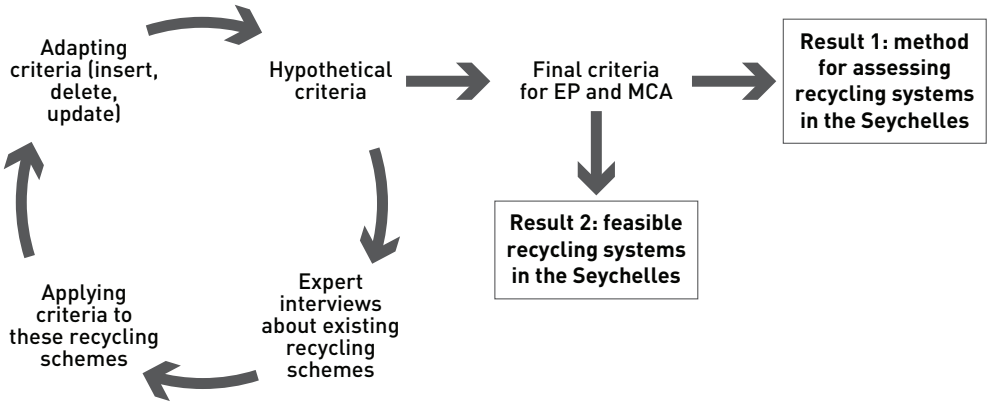

Figure 2.3
Iterative process used for the development of the criteria for both the EP and MCDA methods.

Seychelles. Further, it quickly and efficiently reduces the amount of possible recycling options, allowing more time for reviewing the most plausible and promising ideas and thus picking the low-hanging fruits first. The EP consists of a number of hard criteria. We transformed these criteria into questions that can be answered with either 'yes' or 'no'. After we have identified and developed the criteria (Figure 2.3), we verified each of them. For this, we developed a process consisting of four steps (Figure 2.4). For each exclusion criterion (1), we provide a reasoning (2) which explains why a certain criterion is suitable as a precondition for the functioning of recycling options. The reasoning is built on data and facts and, in cases where pertinent sources were lacking, on assumptions. We verified the assumptions (3) in the course of site visits, stake-holder interviews or by literature search (4).

The robustness of each criterion depends on the strength of the respective reasoning and the plausibility of the verification, which varies depending on the criterion. This represents a limiting factor that could cause some recycling options to be excluded despite being potentially viable. By making this process transparent, we make it possible to further develop or adapt the criteria if more information becomes available or if circumstances change.

2.2.4 MCDA: Assessing recycling alternatives

In this section, we present the MCDA method, the measurement of the criteria, and the criteria-based evaluation process of the different recycling alternatives that were not excluded in the course of the EP. Finally, we provide information on the mathematical analysis that we used in our MCDA.

MCDA as a method

A MCDA is used to address complex problems with various features, e.g., conflicting objectives, data and information in different forms, large uncertainties, and different interests. The tool enables better understanding of the decision problems and facilitates efficient and rational decision making. The evaluation using a MCDA is performed in five steps. More details on the conducted procedure is explained in the following sections. Essentially, the first step includes a clear definition of the problem, followed by the identification of alternatives. At this stage, the evaluation criteria are formulated using key issues and objectives. Subsequently, in step two, evaluation criteria are weighted according to the relative importance of the criteria. The third step includes the construction of the evaluation matrix and the evaluation of alternatives. Then, in step four, one of the multi-criteria methods appropriate for the problem and the data is selected.

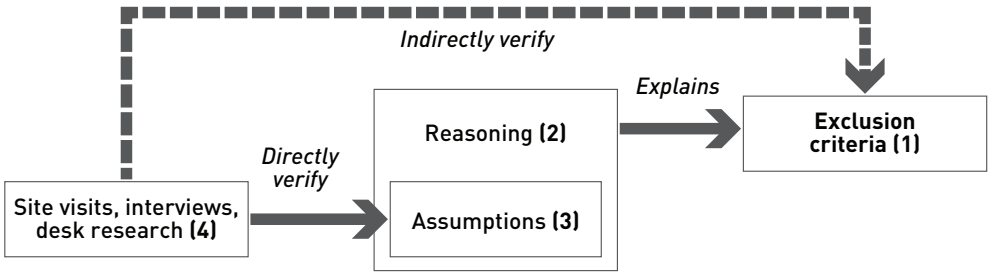

Figure 2.4
Methodology for developing the criteria of the Exclusion Process.

In the fourth and final step, alternatives are ranked (Mateo, 2012). In the following sections we further elucidate the applied assessment.

Criteria and linked questions

As described in Section *'Development and verification of the criteria'* the criteria were developed in an iterative process using different sources of information. In the MCDA, we elaborated the criteria for both the national and the international market. To ensure a consistent application of the criteria, we defined the terminology of each criterion and specified the qualitative measurables. For assessing each criterion, we defined an individual scale using a five-point Likert scale as suggested in other assessments of waste management indicators (ElSaid and Aghezzaf, 2017). We kept the polarity of the scale constant with 1 as the least and 5 the most favorable score for a criterion. However, if one of the following two conditions applied, we did not further assess the criteria in the MCDA. First condition: We assigned a critical criterion to the Exclusion Process. This happened, if one of the evaluation questions was answered with 'No'. Second condition: We could not obtain the necessary knowledge for the weighting.

As demonstrated in Figure 2.2, the MCDA consists of the following categories: i) waste input, ii) technological aspects, iii) national and international market characteristics and iv) implementation in the national and international market. Due to the scope of the project, we could not include additional important categories such as legislative or business management aspects. While each MCDA, national and international, consisted of an equal number of criteria in total, their number varied within the categories as also indicated in Figure 2.2.

Evaluation of the alternatives

We described the local context for each criterion of the respective product alternative, using the knowledge we gained from interviewing local recyclers and experts as well as from our literature search. This knowledge also served as the basis for the rating on the defined five-point Likert-scale. The definition of the terminology ensured the inclusion of the defined aspects into the rating of each criteria. To ensure a consistent evaluation of the qualitative measures, the same two members of the team conducted the rating.

Mathematical analysis

We used the following two methods to analyze our data: the 'Average Score' and the 'ELECTRE III Method'. The fact that all criteria were weighted equally, and no threshold was included, simplified the analysis. A comparison between products for national and international markets is not feasible, as the criteria in the assessment of the national and international market vary.

Average Score

We calculated for each product alternative the average scores (ordinal from 1–5, specified in the Appendix 2.2) of the following categories: waste input, technical aspects, market, and implementation in the market. This facilitated the identification of strengths and weaknesses of the respective alternative within the categories. Additionally, we calculated the overall average score, which represents the recycling potential of the respective recycling alternative. Based on this value, we ranked each recycling alternative.

ELECTRE III Method

In addition to the Average Score Method, we applied the ELECTRE III Method. This approach allowed us to compare alternatives on the criterion c_i against each other. To compare two alternatives, a and b, the ELECTRE-like marginal index $g_j(a,b)$ needs to be calculated. The index shows whether the first alternative *(a)* is as good or clearly better than the second alternative *(b)* (Greco et al., 2016). With the help of two experts (M. Cinelli and M. Kadziński) the index was calculated as follows:

$$g_j(a,b)=\begin{cases}1, \text{ if } a \text{ is as least as good as } b \text{ on } g_j,\\ 0, \text{ if } a \text{ is as worse than } b \text{ on } g_j.\end{cases}$$

The index *G(a,b)* then consists of the sum of the marginal indices $g_j(a,b)$ on all criteria as demonstrated in the equation below.

$$G(a,b)=\frac{\sum_{j=1}^{m} g_j(a,b)}{m}$$

, where *m* is the number of criteria (Cinelli and Kadziński 2018)

For example, the index *G(a,b)* = 0.7 implied that alternative *a* is at least as good or strictly better than the alternative *b* on 70 % of the criteria.

To compare an alternative against all other assessed alternatives an aggregation function is applied (Kadziński et al., 2016). In our case, a greater score represented a better performance, which was calculated by the sum of differences. The index *G(b,a)* (alternative *b* was compared to alternative *a*) was subtracted from the index *G(a,b)* (alternative *a* is compared to

$$\sum_{b\in A'\setminus\{a\}} [G(a,b)-G(b,a)]$$

alternative *b*):

This resulted in the average performance of a product against all other products. A greater score represented a better performance.

2.3 Results

In this section, we present the result of our research (methods development and application). First, we present results from the EP, followed by the results from the MCDA.

2.3.1 Exclusion Process (EP)

In the following, we present the 13 criteria of the EP together with their reasoning and verified assumptions. We then demonstrate the application of the EP for 28 recycling options.

Criteria

The exclusion criteria are a set of preconditions necessary for a recycling system to operate economically feasible. We transformed the criteria into questions and organized them in three clusters (Table 2.2): (1) waste input (N=5), (2) national market (N=5) and (3) international market (N=3). Criteria from the cluster 'waste input' were testing for constraints concerning the usefulness of a certain waste class for recycling or export. If one of the questions was answered with 'no', a recycling option was considered unsuitable for current recycling or processing in the Seychelles. Thus, the recycling option was excluded immediately and not tested in the MCDA. Each recycling option was tested in both clusters of national and international market. The criteria cluster 'national market' looked at local recycling and distribution of secondary products in the national market. The criteria in the cluster 'international market' finally looked at recycling options to export as commodity or secondary product to the international market. If a recycling option dropped out at both, the national and the international market, it was not further considered.

Table 2.2
Criteria of the exclusion process and their verification organized in three clusters: waste input, national market, international market.

No.	Exclusion Criteria	Reasoning	Assumptions	Verification
		Cluster 1: Waste input		
1.1	Is the waste class industrially recycled anywhere in the world?	If 'no', recycling is not established and therefore not feasible for SIDS.	None	None
1.2	For this particular waste class, is there recent and plausible data on the amount produced in Seychelles?	If 'no', the feasibility cannot be assessed due to lack of material flow data.	The economy and the technical feasibility depend on the amount of waste produced.	The interviews strongly support this assumption.
1.3	For hazardous waste: Can some of the non-hazardous parts be mechanically removed to be used for recycling?	Extraction of non-hazardous parts requires special and often high-tech facilities. The amount produced in in SIDS is often too small to operate such a facility. If the criteria is answered with 'no', no other part of the hazardous waste can be used.	Dealing with small amounts of hazardous waste is not economic.	Interviews provided the information that, if hazardous parts are identified in the scrap metal, government officials are called to take care of them.
1.4	For bulky (high-volume) waste: Can the volume be reduced fast and efficiently?	If 'no', either the costs for storage is very high, or not enough land is available for leasing. Storage is required whenever processing cannot keep up with the supply of the waste at certain times.	1) It is difficult to get access to land to do recycling in Seychelles. 2) The supply of waste classes can fluctuate (go up and down).	1) Interviews show that at certain times, the supply of waste indeed varies and one national recycler only accepts waste input amount according to the national demand for the secondary product. 2) Interviews indicate that land or space for recycling is often a limiting factor.
1.5	For waste that is damaged by long-term storage: Can it be processed fast and efficiently?	If 'no', elaborate measures would need to be taken to preserve the quality.	The climate in Seychelles (high temperature and humidity) can damage some of the materials.	Interviews show that for some waste classes this is relevant – they lose value through storage – while for others it is not relevant. Some recyclers or pre-processors of waste can increase the processing.

Table 2.2
continued

No.	Exclusion Criteria	Reasoning	Assumptions	Verification
		Cluster 2: National market		
2.1	Does national policy in Seychelles allow to produce, sell and use the secondary product in Seychelles?	If 'no', market access is not possible under the current law.	None	None
2.2	Does the production of the secondary product substantially decrease the amount of waste?	If 'no', resources should be used for more effective waste reduction.	Waste reduction is a governmental priority.	Stakeholder workshop ETH 2018/04/20, Advisory board meeting 2018/07/02
2.3	Are there competitors offering similar products, including conventional, non-recycled products?	If 'no', there is currently no market for such a product.	Similar products are substitutable.	None
2.4	Are there waste processing facilities on the global market that are suitably sized (not over-sized) for the amount produced in Seychelles?	Facilities for processing a certain waste class should not be oversized because Seychelles is a small country and produces little waste in absolute terms. If 'no', small scale recycling is not feasible.	If the recycling facility is over-sized, recycling is not cost-effective.	Interviews indicate that for some recycling or pre-processing, the current processing capacity is not fully exploited. This harms the economy of the business.
2.5	From past experience, is the product likely to be socially accepted by the public?	If 'no', the product might not be accepted by the market.	Recycled products might not be liked for sensitive applications, e.g. health.	One recycler confirmed that hygienic issues need to be considered for recycled products.
		Cluster 3: International market		
3.1	Is an international trade for the product already established?	If 'no', trading the product in small amounts (as is given in Seychelles) is not feasible.	The Seychelles produces too little commodities to establish its own market.	None
3.2	Is the value of the product larger than US$ 109 per ton?	The cost for shipping overseas needs at least to be covered.	The cost for shipping overseas is per volume approx. 109 US$ for the most commonly used shipping company.	We derived this number from one company's container cost. It amounts to the average of US$ 2495 (PET to Ukraine) and US$ 1425 (scrap to India). One standardized container can be loaded with 18 tons of material.
3.3	Are there waste pre-processing facilities on the global market that are suitably sized (not over-sized) for the amount produced in Seychelles?	Facilities for pre-processing a certain waste class should not be oversized because Seychelles is a small country and produces little waste in absolute terms. If 'no', small scale recycling is not feasible.	If the recycling facility is over-sized, recycling is not cost-effective.	Interviews indicate that for some recycling or preprocessing, the current processing capacity is not fully exploited. This harms the economy of the business.

Evaluation of recycling options

Table 2.3 shows the recycling options that were tested in the EP for either the national market (N), the international market (I) or both. If the recycling option was excluded in the EP, the main criterion for the exclusion is provided as well as a short reasoning.

Subsequent to the evaluation of options, we assessed the recycling options that have passed the exclusion process using the MCDA.

2.3.2 Multi-Criteria Decision Analysis (MCDA)

In this section, we present the results of the MCDA for the five recycling alternatives in the national as well as the seven recycling alternatives in the international market. Finally, we present the results from the ELECTRE III analysis of the MCDA.

Criteria

In the MCDA, we assessed and compared all recycling options that have passed the exclusion process. We call

Table 2.3
Testing different products with the Exclusion Process (EP). N = national, I = international market.

Recycling option	Market tested	EP passed	Exclusion criterion	Reason
Beverage cans from scrap metal	I	✓		
Building insulation from PC	N	×	2.3	no market, no insulation needed
Building material from wood	N	×	1.4	volume reduction not possible
Cardboard boxes from PC	N	✓		
Charcoal from wood	N	✓		
Construction material from glass	N	×	2.2	amount too small
Decoration from glass	N	×	2.2	amount too small, niche product
Egg trays from PC	N/I	✓		
Fuel pellets from plastic, wood and tyres	I	✓		
Furniture from wood	N	×	2.2	amount too small, niche product
Heavy scrap from scrap metal	I	✓		
Household decoration from PC	N	×	2.2	amount too small, niche product
Household goods from plastic	N	×	2.2	amount too small
Household goods from plastic	N	×	2.2	amount too small, niche product
Hygienic paper from PC	N	×	1.5	quality issues
Jewellery from glass	N	×	2.2	amount too small, niche product
Landfill cover from glass	N	✓		
Lead batteries from e-waste	I	×	1.2	not enough data
Mixed light scrap from scrap metal	I	✓		
New bottles from glass	N	×	2.4	too small-scale to be economic
Paper bag from PC	N	✓		
Paper export from PC	I	✓		
Paper from PC	N	×	1.5	quality issues
PET flakes from plastic	I	✓		
Regranulate from plastic	I	×	3.3	amount too small
Shavings from wood pallets	I	×	3.2	value too low
Shredded plastic (not PET) from plastic	I	✓		
Sorted light scrap (Al, Cu/CuZn) from scrap metal	I	✓		

these options recycling alternatives. We applied the MCDA separately for the national and the international market. Both analysis consist of 21 criteria in four categories: waste input, technological aspect, market, and implementation in the market. In the following, we present the criteria in the different categories together with the linked question, the definition of terms, and the qualitative measurable evaluated along a five-point Likert scale. Further information on the used qualitative measures is presented in the Appendix 2.2.

Waste Input and Technological Aspects

As shown in Table 2.4, the first eight criteria are focusing on the waste input and the technological aspects of the processing. The underlying reason for this is that the processing requires a certain quality of the collected waste. We rated the waste quality in terms of the material homogeneity and absence of (anthropogenic) contamination. Furthermore, various technological factors influenced the success of the pre-processing and the processing of the waste class to the product. In the Seychelles, the amount of input resource and

Table 2.4
Criteria, linked question, definition of terminology and the qualitative measurable in the categories Waste Input and Technological Aspects.

Category	Criteria	Linked questions	Definition of terminology	Qualitative measurable
Waste input	Feasibility of collection and sorting	How *simple* is the collecting and sorting of the waste for the product?	*Simple* if low work intensity and low costs of infrastructure	1 = not simple, 5 = simple
	Sufficient collected waste quality	Can the product be manufactured with the *quality* the waste after collection and sorting?	*Quality* if separated waste class is homogeneous enough for further processing	1 = quality not given, 5 = quality given
Technological aspects	Sufficient waste input quantity	Can a *sufficient* amount of waste be collected in Seychelles for local pre-processing of the product?	*Sufficient* if the local pre-processing technologies in place can operate under the given context	1 = not sufficient, 5 = sufficient
	Complexity of pre-processing	How *simple* is the dismantling or pre-processing of the waste input resource to manufacture the product?	*Simple* if low human capacity required to understand the technology of pre- processing	1 = not simple, 5 = simple
	Economic feasibility of pre-processing	Are disassembly or pre-processing steps *economically feasible* in Seychelles?	*Economically feasible* if the energy consumption is low, infrastructure necessary not too expensive and the labor costs not too high	1 = not feasible, 5 = feasible
	Availability of pre-processing quipment	Is required equipment for the pre-processing of the product already *available* in the Seychelles?	*Available* if already existent and accessible in Seychelles to operate profitable processing	1 = not available, 5 = available
	Impact of waste fluctuation	Do input resource *fluctuations* have a *negative influence* on the processing of the product?	*Fluctuations* occur if waste supply is irregularly *Negative influence* occurs if changes in process output result due to varying waste input streams	1 = high influence, 5 = no influence
	Technical maintenance	How *easy* is the technical maintenance of the processing of the product?	*Easy* meaning a low maintenance effort, if the management complexity, labor cost, time intensity and frequency of maintenance events are low as well as the expertise needed is accessible	1 = not easy, 5 = easy

its fluctuations, but also the complexity of the process, economic aspects and the required maintenance of the equipment may affect the feasibility of a recycling system. Additionally, we assessed whether the necessary equipment is already available in the Seychelles, which would facilitate the implementation of a recycling alternative.

As described earlier and illustrated in Figure 2.2, the recycling system consists of secondary products for both the national and international markets and as commodities for the international market. Due to different properties of the national and the international market, the criteria were compiled separately for each market. In the following, we present the categories 'national market' and 'international market' as well as 'implementation in the national market' and 'implementation in the international market'.

MCDA in the National Market

The assessment of the market is of major importance for recycling. The crucial criteria for the national market are shown in Table 2.5. Recycling is only implementable, if there is a market demand for the output product. Aspects, such as the long-term perspective of the market,

Table 2.5
Criteria, linked question, definition of terminology and the qualitative measurable in the MCDA categories of the National Market and Implementation in the National Market.

Category	Criteria	Linked questions	Definition of terminology	Qualitative measurable
National market	Availability of market	Is there currently a *market* for the product?	*Market* if a demand for the product is present	1 = no market, 5 = market present
	Long-term availability of market	Will the *market* for the product *remain* in the *long-term* perspective?	*Market remains* if a demand for the product is available and constant *long-term* if constant for 20 years	1 = maintenance of market unclear, 5 = maintenance of market secure
	Sufficient market absorption	Can the *market absorb* the locally processed quantity of the product?	*Market* if a demand for the product is present, *Absorption* if there is a demand for at least the entire manufactured product quantity	1 = no absorption, 5 = full absorption
	Stability of market demand	Is the market *demand* for the product *stable*?	*Stable* if the *demand* for the product follows a long-lasting trend and there are little demand fluctuations	1 = not stable, 5 = stable
	Stability of market price	Is the market *price* for the product *stable*?	*Stable* if the *price* for the product follows a long-lasting trend and there are little price fluctuations	1 = not stable, 5 = stable
	Possibility of financial viability	Have best practices in other countries with *similar contexts* shown *financial viability* of the product?	*Similar context* is given in other SIDS and insular states dealing with recycling *Financial viability* if either a positive financial benefit or in case of no benefit at least self-sustaining characteristic of the recycling system occurs Influencing factors might include infrastructure, collection scheme, labor costs, market access for the product etc.	1 = no financial viability, 3 = self-sustaining, 5 = net positive benefit

the absorption rate but also the demand and price stability, are crucial when evaluating a product alternative. Furthermore, best practices of other countries with similar contexts to the Seychelles serve as a benchmark for recycling projects.

In addition, the local context, such as the public perception and social acceptance, may affect a successful implementation of recycling alternatives. These aspects may be positively or negatively influenced by previous recycling initiatives in Seychelles. As a further element, existing infrastructure for the distribution of already existing products can facilitate the implementation. Furthermore, the criteria include the assessment of the impacts of the introduction of recycling alternatives on each of the three sustainability pillars: social, economic and environmental.

MCDA in the International Market

The criteria of the MCDA category 'international market', presented in Table 2.6, show similarities to the ones in the 'national market'. The analogous criteria include the long-term expectation of the demand, the absorption rate of the product alternative and the demand and price stability. In addition, we used best practices in the respective recycling business

Table 2.5
continued

Category	Criteria	Linked questions	Definition of terminology	Qualitative measurable
Implementation in the national market	Public perception	How is the *public perception* of the product on the market?	*Public perception* includes whether the consumer has knowledge about the product, accepts it (consummation and use), past experiences with the product (positive/negative)	1 = negative perception, 3 = neutral, 5 = positive perception
	Social acceptance	Is the product *socially accepted*?	*Socially accepted* if there are no ethical, religious or social norms affecting the consume, the application or the use of the product	1 = not accepted, 5 = accepted
	Past recycling experiences	What *local experiences* exist from earlier recycling projects for the product?	*Local experience* from previous recycling initiatives, identified challenges, lessons learnt	1 = negative, 5 = positive
	Distribution by existing retailing systems	Can common *retailing systems* be used to distribute the product?	*Retailing systems* include the existing infrastructure to distribute the product in the market and make it accessible for the consumer	1 = no usage, 5 = usage
	Social impacts	Does the product cause negative *social impacts*?	*Social impacts* for workers and consumers occur after the introduction of the product and affect the wellbeing of other businesses, cause loss of workplaces or increase the informal sector.	1 = high impact, 5 = low impact
	Economic impacts	Does the product cause negative *economic impacts*?	*Economic impacts* for other businesses, workers and consumers occur after the implementation of the product and affect the wellbeing of other businesses through competition, loss of workplaces'	1 = high impact, 5 = low impact
	Environmental impacts	Does the product cause negative *environmental impacts*?	*Environmental impacts* include contamination of land, air or water including toxic compounds and heavy metals	1 = high impact, 5 = low impact

Table 2.6
Criteria, linked, definition of terminology and the qualitative measurable in the MCDA categories of the International Market and Implementation in the International Market.

Category	Criteria	Linked questions	Definition of terminology	Qualitative measurable
International market	Accessibility of global trade	How *accessible* is the *international market* for the product?	*International market accessible* if there are potential logistic routes in terms of distance, cargo business already in place, other national trading activities including import activities.	1 = international trade not accessible, 5 = international trade accessible
	Long-term availability of market	Will the *market* for the product *remain* in the *long-term* perspective?	*Market remain* if a demand for the product is available and constant *Long-term* if constant for 20 years	1 = maintenance of market unclear, 5 = maintenance of market secure
	Sufficient market absorption	Can the *market absorb* the locally processed quantity of the product?	*Market* if a demand for the product is present, *Aabsorption* if there is a demand for the entire produced quantity of product	1 = no absorption, 5 = full absorption
	Stability of market demand	Is the *demand* for the product *stable*?	*Stable* if the demand for the product follows a long-lasting trend and there are no demand fluctuations expected in the next 20 years	1 = not stable demand, 5= really stable demand
	Stability of market price	Is the *market price* for the product *stable*?	*Stable* if the price for the product follows a long-lasting trend and there are little price fluctuations	1 = not stable, 5 = stable
	Possibility of financial viability	Have best practices in other countries with *similar contexts* shown *financial viability* of exporting the product?	*Similar context* is given in other SIDS and insular states dealing with recycling *Financial viability* in terms of either a positive financial benefit or in case of no benefit at least self-sustaining characteristic of the recycling system Influencing factors might include infrastructure, collection scheme, labor costs, market access for the product etc.	1 = no financial viability, 3 = self-sustaining, 5 = net positive benefit
	Technical limitation of logistics	Does the *logistics* of the product to the market represent a *technical limitation*?	*Logistics* include transportation from the recycling center to the market using shipping, air cargo or transportation by trucks *Technical limitations* if the logistic options are not accessible, the energy consumption is too high, or shape, size or value of the product does not suit the chosen logistics	1 = technical limitation, 5 = no technical limitation
	Financial limitation of logistics	Does the *logistics* of the product to the market represent a *financial limitation*?	*Logistics* include transportation from the recycling center to the market using shipping, air cargo or transportation by trucks *Financial limitations* are given if the energy consumption is high during the logistics, the value of the product is in no relation with the occurring transportation cost	1 = financial limitation, 5 = no financial limitation

Table 2.6
continued

Category	Criteria	Linked questions	Definition of terminology	Qualitative measurable
Implementation in the international market	Past recycling experiences	What *experiences* exist from earlier recycling projects for the product?	Local *experience* from previous recycling initiatives, identified challenges, lessons learnt	1 = negative, 5 = positive
	Distribution by existing retailing systems	Can common *retailing systems* be used to distribute the product?	*Retailing systems* include the existing infrastructure to distribute the product in the market and make it accessible for the consumer	1 = no usage, 5 usage
	Social impacts	Does the product cause negative *social impacts*?	*Social impacts* for workers and consumers occur after the introduction of the product and affect the wellbeing of other businesses, cause loss of workplaces or increase the informal sector.	1 = high impact, 5 = low impact
	Economic impacts	Does the product cause negative *economic impacts*?	*Economic impacts* for other businesses, workers and consumers occur after the implementation of the product and affect the wellbeing of other businesses through competition, loss of workplaces'	1 = high impact, 5 = low impact
	Environmental impacts	Does the product cause negative *environmental impacts*?	*Environmental impacts* include contamination of land, air or water including toxic compounds and heavy metals	1 = high impact, 5 = low impact

to assess the feasibility of our product alternative. We identified additional criteria to cover the features of an export product. We evaluated the market access in international settings by potential spatial and logistic limitations. Moreover, technical and financial factors due to additional logistic infrastructure are relevant evaluation criteria in the MCDA of the 'international market'.

The criteria in the category 'implementation in the international market' are analogous to the criteria in the category 'implementation in the national market'.

Evaluation of recycling alternatives

We performed the MCDA for a total number of twelve recycling alternatives, which include five secondary products for the national market and seven commodities for the international market. The results are based on stakeholder and expert interviews and literature research and were calculated as described in Section *'Mathematical analysis'*. In essence, the categorical scores are mean values and represent the performance of a recycling alternative within one category. The total average is the mean value of all 21 criteria of one alternative and describes its recycling potential from 1–5.

In the following section, we first present the results of our MCDA for the national and the international market. The evaluated alternatives are listed in the order of their total average potential. Secondly, we describe the recycling alternatives' performance in the four categories waste input, technological aspects, national market, and implementation in the national market. We sort the alternatives by waste input material. The original files of the MCDA including the disaggregated values in the different categories are available on request.

Recycling alternatives in the national market

For the national market, the recycling alternatives cardboard boxes and crushed glass as a landfill cover scored best (Table 2.7). Followed with a slightly lower average score, egg trays and charcoal performed with a potential of 4.38 and 4.33 respectively. Paper bags as the fifth assessed product alternative, has a score of 3.71 and thus reaches the second lowest score of all assessed alternatives.

Waste input material glass

An estimated amount of 2,200 tons of glass is imported annually, whereof 1100 tons are immediate packaging of beverages and 600 tons are imported as empty bottles by the local brewery (Agricole et al., 2016). Apart from the refilling system at the local brewery, most scrap glass is deposed at the Providence landfill or the inert landfill in Anse Royal. In October 2018, the authorities will introduce a levy system on glass bottles (2 SCR / bottle) (Advisory Board). According to our current knowledge, the glass will then be crushed and used as a landfill cover as a long-term SWM strategy (A. Berta, personal communication, July 06, 2018).

Waste input and technological aspects

The already existing collection system of the brewery bottles could be extended relatively easy to collect other glass bottles. The alternative crushed glass reached an average score of 5.00 in the category waste input (Table 2.7). Crushing machinery is already partially available in construction companies as well as in the private sector and certain know-how on its maintenance is available (Agricole et al., 2016). Therefore, crushed glass reached an average score of 4.50 in the category technological aspects.

National Market and Implementation

The demand for landfill cover is constant because of the increase in waste generation in the Seychelles and the necessity of a sustainable landfill management in the future (Mangroo and Wälchli, 2016). The average score in the category market resulted in 4.67 (Table 2.7). Currently 8,000 tons of coral sand are used

Table 2.7
Average scores (1–5) of the potential of the recycling alternatives for the national market ([1]currently existing recycling products) in the four categories waste input, technological aspects, national market and implementation in the national market. A high score represents a high potential, the coloring in grayscale facilitates the visualization of the different average scores.

Waste input material	Glass	Paper and cardboard			Wood
National market	Crushed glass	Cardboard boxes	Egg trays[1]	Paper bags	Charcoal
Waste input	5.00	5.00	4.50	4.00	4.00
Technological aspects	4.50	4.00	4.33	4.00	4.67
National market	4.67	4.67	4.00	3.00	4.67
Implementation in the national market	4.14	4.71	4.71	4.00	3.86
Total average	4.48	4.52	4.38	3.71	4.33

as landfill cover per month, which does not represent a sustainable resource (F. Joubert, personal communication, July 12, 2018). Crushed glass could serve as a substitute and hence reduce the pressure on this natural resource. Due to negative experiences in earlier glass crushing initiatives (D'offay et al., 2016), the public perception of crushing glass influenced the recycling potential in the category implementation reaching an average score of 4.14 (Table 2.7).

Overall, with a score of 4.48, crushed glass as a substitute of corral sand on the landfill showed the second highest potential of the recycling alternatives in the national market (Table 2.7).

Waste input material paper and cardboard

The large amount of imports in Seychelles leads to a significant amount of packaging material made from paper and cardboard (PC). In waste class 1 (municipal and commercial waste) 7 % of the waste accounts for cellulose household and product packings and 4 % for cellulose distribution packings. In the waste of hotels, commercials and the industry (waste class 2) the share of cellulose household and product packings and cellulose distribution packings is 6 % and 12 %, respectively. In the mixed waste (waste class 5) the cellulose distribution packings represents 31 % and the cellulose household and product packings 2 % (Source confidential). The recycling of PC is therefore an option to reduce the PC share on the landfill, which poses significant environmental impacts such as the release of methane into the atmosphere. There is currently no official collection system for PC in place. However, some businesses started separating this waste class and to bring it to a local recycler. A small share of the waste stream (1 ton daily) is currently recycled and turned into egg trays, which have been sold on the national market for many years. Previously, the recycler has also introduced other PC products such as paper plates, paper bags, meat and vegetable trays, take-away boxes and lunch boxes. Currently, none of these products are on the market due to the competition of imported goods or social acceptance.

Waste input and technological aspects

The input quality of the waste is crucial for PC recycling. The aspect of using the product for food carrying purposes enhances the quality requirements. The separation at the source would be essential to ensure the absence of contamination and a sufficient quality for our assessed recycling alternatives. Cardboard boxes and egg trays need a lower waste input quality for their production than paper bags. This was visible in the average scores in the category waste input: 5.00, 4.50 and 4.00 respectively (Table 2.7). Crucial technical challenges voiced by stakeholders were mainly of financial nature and concerning the production costs. The highest share of production costs is due to the electricity demand. An electricity intense process is required for the drying of the material for paper bag as well as in cardboard production. This led to a lower average score of paper bags (4.00) and cardboard (4.00) compared to egg trays (4.33), which are dried without the need of additional heat production.

National Market and Implementation

Cardboard boxes, egg trays and paper bags showed different average scores in the category market. Yearly, an amount of 1.849 tons of Cardboard is imported and mainly used as packaging material for export goods. The national demand for cardboard boxes is therefore as stable as the export industries in the Seychelles. This was represented in the recycling potential of 4.67 (Table 2.7). Egg trays, which have an average score of 4.00, currently in demand on the national market. Nevertheless, there are imported low quality egg trays available for a lower price than locally produced ones. Paper bags on the other hand,

showed the lowest potential for the market, with an average score of 3.00. The reusable bags, which are currently sold, are a strong competitive product. According to the assessment of our criteria in the Section *'Implementation in the national market'*, the cardboard boxes and egg trays achieve an equal average score of 4.71 (Table 2.7). They both face few limitations from public perception or social acceptance, as these products are currently already in use. The introduction of paper bags could be challenging due to a low social acceptance resulting from negative experiences in previous projects with paper bags. These considerations led to an average score of 4.0 in this category.

Overall, within the waste class PC, cardboard boxes showed the highest potential with a total average score of 4.52, followed by egg trays with an average score of 4.38. Paper bags (3.71) showed the lowest performance of all assessed PC recycling products.

Waste input material wood

15.7 % of all the waste on Mahé is wood including construction waste and other wooden waste (Mangroo and Wälchli, 2016). Especially industries and trading companies have a high share of wooden pallets, which are currently deposited on the landfill. Seychelles is a sink for wooden pallets due to the large fraction of imported goods. Whereas some interviewed stakeholder from commercial businesses reuse some of the pallets including the plastic pallets, the large share of wooden pallets is still deposed at the Providence landfill. There are currently three operating charcoal producers in Seychelles, one of them on Mahé and three in Praslin (A. Berta, personal communication, July 6, 2018). The charcoal is manufactured using wood from both primary resources and construction wood.

Waste input and technological aspects

As wooden pallets are made from solid dry wood and are usually untreated, they are well suited to manufacture charcoal. Yet, some pallets are treated with the fumigant methyl bromide, marked with the initials MB (Aggregate Recycling, 2018). However, currently these pallets are not considered as hazardous waste in Seychelles (see Chapter 3, Hazardous waste: material flows). As there is no existing collection and sorting system in place that diverts treated from untreated pallets, the average score in the category waste input is 4.00 (Table 2.7). In the category technological aspects, charcoal from wooden pallets reached an average score of 4.67 due to the simplicity and low-tech process. The current industries need little manpower to maintain the production. The additional transportation costs to connect the location of waste generation on Mahé with the charcoal industry on Praslin had an impact on the categorical score.

National Market and Implementation

According to our assessment, the recycling potential of charcoal in the national market is 4.67 (Table 2.7). Local stakeholders could expand their business even more as charcoal is currently still a highly demanded product. Nevertheless, there are uncertainties concerning the social acceptance of charcoal produced from waste wooden pallets. Therefore, the average score in the implementation section was 3.86 (Table 2.7).

Overall Charcoal had a total average score of 4.33 (Table 2.7).

Recycling alternatives in the international market

From the assessed recycling alternatives, the already existing exportation of heavy scrap metal reached the highest average score (4.43). It is closely followed by egg trays with a recycling potential of 4.19 and beverage cans, mixed and sorted light scrap metal each with a total average score of 4.14. In our assessment the polymer products, PET flakes and shredded plastic, achieved the lowest potential with total average scores of 3.86 and 3.67 of the recycling alternatives in the international market (Table 2.8).

Waste input material beverage cans

Metal cans as aluminum and tin cans are valuable resources that are expected to increase their global market value in the next years (Mordor Intelligence, 2018). In the Seychelles, the levy system on beverage cans was introduced in 2006 in order to create an incentive to recycle. However, a collection scheme is not in place, which leads to a large informal sector being responsible for the collection of about half of the recycled cans (D'offay et al., 2016). In 2017, 450 tons of beverage cans were exported in the form of aluminum or tin blocks (Source confidential).

Waste input and technological aspects

The required quality including low anthropogenic contamination of the metal can be met with the current informal collection. Therefore, aluminum and tin blocks as commodities reached an aver-

Table 2.8
Average scores (1–5) of the potential of the recycling alternatives for the international market ([1]currently existing recycling products) in the four categories waste input, technological aspects, national market and implementation in the international market. A high score represents a high potential, the coloring in grayscale facilitates the visualization of the different average scores.

Waste input material	Beverage cans	Paper and cardboard	PET bottles	Plastic (not PET)	Scrap metal		
International market	Aluminium and tin blocks[1]	Egg trays	PET flakes[1]	Shredded plastic	Mixed light scrap[1]	Sorted light scrap[1]	Heavy scrap[1]
Waste input	4.50	4.50	3.50	4.5	4.00	3.00	3.50
Technological aspects	4.17	4.33	4.50	3.50	4.17	3.83	4.83
National market	3.75	3.75	3.38	3.13	4.38	4.75	4.38
Implementation in the international market	4.60	4.60	4.00	4.40	3.80	4.00	4.40
Total average	4.14	4.19	3.86	3.67	4.14	4.14	4.43

age score of 4.50 in the category waste input (Table 2.8). From a technical perspective, the stakeholders mentioned few concerns. Although the compression is a straightforward process the separation of aluminum and tin cans is currently done manually, which results in high costs. Additionally, there are negative impacts on the recycling process capacity due to input fluctuations and resulting irregular working hours. These reasons resulted in an average score 4.17 (Table 2.8).

International Market and Implementation

There is a relatively constant demand for aluminum and tin on the international market and according to a stakeholder, the current Indian buyers would accept a higher quantity. However, numerous issues were mentioned concerning the international market. Particularly, the fluctuation of market prices in the past and the shipping of the export commodity, which entails great administrational efforts and high costs. All that resulted in an average score of 3.75 in the category international market of our MCDA (Table 2.8). Generally, the recycling of beverage cans is perceived by the public as a well-functioning system in the Seychelles and is broadly accepted. Furthermore, the existing local recyclers have still capacity to expand, and therefore the implementation of further beverage can recycling exhibited an average score of 4.60 (Table 2.8).

Overall exporting beverage cans to the international market resulted in a total recycling potential of 4.14 (Table 2.8).

Paper and cardboard

As mentioned in the Section on *'PC recycling in the national market'*, a small share of the imported PC is recycled in the Seychelles for the domestic market. However, as most PC is deposed on the landfill, there might be further recycling potential also for the international market. In our assessment, we evaluated the recycling of PC to egg trays.

Waste input and technological aspects

In our assessment of egg trays for the international market the categories waste input and technological aspects reached average scores of 4.50 and 4.33, respectively (Table 2.8). These categories performed equally in our MCDA for the national and the international market. Further details on these average scores are elucidated in the section of the national market.

International Market and Implementation

According to predictions, there is an increasing global market demand for recycled egg trays. However, various aspects affect the recycling potential of this product alternative in the international market. According to Maersk Shipping and Cargo Services, the shipping of egg trays, for example, represents a financial limitation as a container costs between $ 1,500–2,500 depending on the destination. Therefore, egg trays made from PC reached an average score of 3.75 in the category international market (Table 2.8). So far, no comparable overseas transactions have been made, which is why experience in implementing global trades with recycling products are lacking. However, no substantial concerns were mentioned by our stakeholders, which led to an average score of 4.6 in that category (Table 2.8).

Overall, manufacturing egg trays for the international market achieved a high recycling potential with a total average score of 4.19 (Table 2.8).

Waste input material PET bottles

The current recycling system for PET bottles in the Seychelles is running since 2006 and is similar to the established beverage can recycling system. The collection is mainly driven by the large informal sector. According to calculations a yearly amount of 450 tons of PET bottles are diverted from the landfill (Agricole et al., 2016). They are sorted by color, shredded and exported as PET flakes.

Waste input and technological aspects

A larger quantity of PET bottles would be favorable to maintain the operation of the shredder at a constant level and to avoid irregular operation hours. Furthermore, some concerns on the collected PET quality arise. As a result, PET flakes reached an average score of 3.50 in the category waste input (Table 2.8). However, the preprocessing of the commodity is low-tech and requires little maintenance. Therefore, the PET flakes from PET bottles resulted in an average score of 4.50 in the category technological aspects (Table 2.8).

International Market and Implementation

Numerous countries, such as China and Vietnam, set recent import bans on plastic scrap. In addition to these import bans, the mineral oil price has caused demand and price fluctuations of PET flakes and other plastic polymers. Additionally, the destination country of the shredded PET changed various times in the recent years. Longer distances to the current export countries Russia and Ukraine, compared to Asia, led to a substantial increase in freight costs (approx. $ 1,000/ton more). Particularly, for the colored PET flakes, with a lower market price and demand than transparent flakes, the shipping costs represent a financial limitation. These aspects strongly affect our assessment of the international PET market and led to the lower average score of 3.38 in this category (Table 2.8). Nevertheless, the export of PET flakes has been in place for over ten years. It represents a recycling system that reduces the volume of waste on the landfill and reduces the pressure of primary resources. Good public perception and ecological benefits of exporting PET flakes led to an average score of 4.00 for the assessed category implementation in the international market (Table 2.8).

Overall, PET flakes as a recycling alternative exhibited a total average score of 3.86. From our assessed recycling products, PET flakes had the second lowest potential in the international market (Table 2.8).

Waste input material plastic (not PET)

According to the landfill data from 2016 and 2012 (Source confidential) there are shares of plastic product packaging of 4 % in waste class 1 (municipal and commercial waste), 4 % in waste class 2 (hotels, commercials and the industry) and 3 % in waste class 5 (mixed waste). Shares of general plastics are 7 % (waste class 1), 6 % (waste class 2) and 5 % (waste classe 5).

Waste input and technological aspects

The collection and sorting of plastic polymers presents a large challenge especially for municipal and mixed waste. The separation of packaging material from imported goods, however, could be sorted at the source to ensure the required input quality of the plastic flakes. This applies especially for the assessed commodity packaging foil and PP. This resulted in an average score of 4.50 in the category waste input (Table 2.8). The amount of collectable PP is low and fluctuations can therefore lead to long storage of the material. Subsequently, this reduced the potential of plastic scrap in the category technological aspects to an average score of 3.5 (Table 2.8).

International Market and Implementation

The challenges regarding plastic import bans and oil price fluctuations in the international market mentioned in the section on PET bottles also apply to other plastics. The high uncertainties regarding the demand and the market price as well as the high freight costs led to a recycling potential of 3.13 in the category market (Table 2.8). There is currently an initiative of exporting packaging foil (mostly Polyvinyl chloride (PVC)) and Polypropylene (PP)

cups jointly sourced from leading local exporting enterprises to close international markets (Source confidential). L. Globally, plastic is perceived as a growing issue in sustainable waste management and therefore the public perception of plastic recycling is positive. These factors led to a recycling potential of 4.50 in the category implementation in the international market (Table 2.8).

Overall, exporting shredded PVC and PP plastics resulted in a total average score of 3.67 which according to our study represented the lowest assessed recycling alternative in the international market (Table 2.8).

Scrap metal

Scrap metal has a relatively high monetary value and the global market is recovering from the crisis in 2008 (Chalmin, 2010). Scrap metal has been exported for many years by various businesses in the Seychelles (Interviews, Advisory Board). In 2017, a total amount of 1,177 t scrap metal was exported (Source confidential). In our analysis we distinguished between three scrap classes (heavy scrap, mixed light scrap and sorted light scrap) which, according to our knowledge, all exhibit different properties in their handling and therefore their recycling potential. Whereas heavy scrap consists of large metal parts, local exporters compact light scrap into blocks before shipping. The latter is either exported in a mixed form or separated into the metals aluminum, copper and brass.

Waste input and technological aspects

Currently, there is no collection system for scrap metal in the Seychelles. Disposer dump it either at Providence landfill, bring it to the local recycling business' or the recycling business themselves collecting it, depending on the agreement and value of the material. Even tough, the processing machinery is flexible, input fluctuations can have a negative influence on the recycling process. The waste input quality can be negatively affected by corrosion during long storage, which is particularly relevant for heavy scrap. In our assessment, heavy scrap metal reached an average score of 3.50 in the category waste input (Table 2.8). Anthropogenic contamination lowers the value of scrap metal, which is particularly relevant for light scrap metal. Additionally, the labor intense sorting process of light scrap metal affected the recycling potential of the waste input material. Sorted light scrap metal exhibited an average score of 3.00 compared to mixed light scrap, which reached an average score of 4.00 in the category waste input (Table 2.8). Concerning the technological aspects, the mentioned separation had the highest influence on the average score of the recycling alternatives. Particularly, the dismantling of sorted light scrap metal is complex and work intensive. Thus, sorted light scrap metal resulted in an average score of 3.83, while mixed light scrap metal resulted in an average score of 4.17 in the category technological aspects. Heavy scrap metal, on the other hand, reached a potential of 4.83 due to the simple handling (Table 2.8).

International Market and Implementation

For all three assessed commodities, heavy, sorted light, and mixed light scrap metal, there is an international market with a high demand. However, the market prices vary among the three commodities, with highest prices for sorted metals. Therefore, sorted light scrap metal reached the highest score from the assessed scrap metals in the category international market (4.75, Table 2.8). In the category implementation in the international market heavy scrap metal (4.40) reached the highest score, followed by sorted lights scrap metal (4.00) and mixed scrap metal (3.80, Table 2.8). There are uncertainties concerning social and environmental standards in the processing fa-

cilities of the destination country. The differences between the values of the three scrap metal alternatives are due to past experiences, the complexity of the necessary infrastructure, and uncertainties in potential contamination rates.

Overall, heavy scrap metal performed best among the three assessed scrap metal alternatives with a total potential of 4.43. Light scrap metal, both mixed and sorted showed a lower total potential of 4.14 (Table 2.8).

ELECTRE III: Analysis of recycling alternatives

As described in Section *'Mathematical analysis'* we analysed our MCDA using the method ELECTRE III. The sum of differences (see Figure 2.6 for the national and Figure 2.7 for the international market) indicates the average performance of a product against all other products from which the ranks were derived. In the national market, crushed glass had the highest rank. It was 0.62 higher than the average performance of the other compared products. Cardboard boxes, charcoal and the egg trays all exhibited a performance level over the average value. The alternative paper bags was 1.62 below the average value and therefore reached the fifth rank. In the international market, heavy scrap metal had a substantially better performance level than egg trays placed on the second rank. The four recycling alternatives, sorted light scrap metal, mixed light scrap metal and beverage cans also showed positive values. The two polymer alternatives, PET flakes and plastic scrap, received the lowest ranks. With a value of –1.62 plastic scrap performed substantially lower than all compared alternatives.

Comparison of Average Rank and ELECTRE III

The order of the products in Section *'Evaluation of recycling alternatives'* corresponds to the ranks obtained using the ELECTRE III method. However, the size of the difference between the average scores and the sum of differences is substantial. The comparison of an alternative pair, the subsequent calculation of the ELECTER-like marginal concordance index, and the sum of difference prevents the outranking of single criteria as described in Section *'Mathematical analysis'*. For instance, a high score of the criterion 'Availability of Market' cannot compensate for

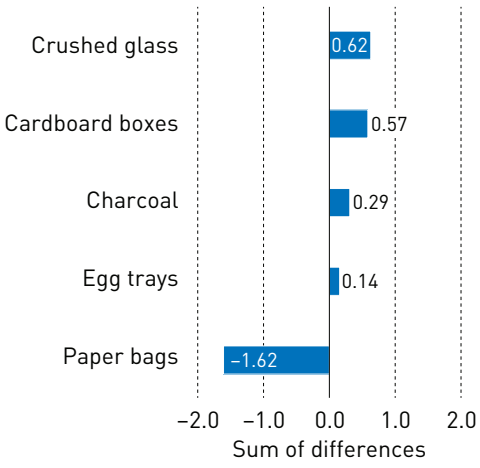

Figure 2.6
Sum of differences of the recycling alternatives in the national market (according to their rank).

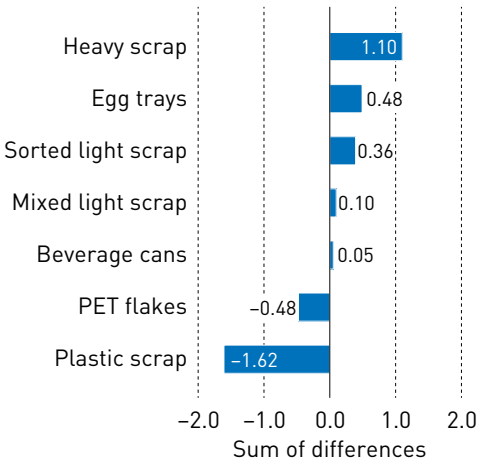

Figure 2.7
Sum of differences of the recycling alternatives in the international market (according to their rank).

a low score of, for instance, the criterion 'Stability of Market Demand'. When comparing the differences between the average scores (Section *'Evaluation of recycling alternatives'*) and the sum of differences in Figure 2.6 and Figure 2.7 this effect is visible. For example, in the international market, the difference between the values of the sum of differences (shown in Figure 2.7) of PET flakes (–0.48) and plastic scrap (–1.62) is larger relative to the score difference (0.19, Section *'Evaluation of recycling alternatives'*) using our first method explained in Section *'Mathematical analysis'*.

Further explanations on each of the recycling alternatives and the composition of the obtained results are elucidated in the Section *'Mathematical analysis'*.

2.4 Discussion

The goal of our study was twofold: First, we wanted to develop a tool which allows both policy makers and the private sector to easily assess the potential of new recycling options. Second, we demonstrated the principle practicability of our tool for the context of the Seychelles. We therefore assessed 28 recycling options and then analyzed the recycling potential of the twelve most favorable recycling alternatives.

2.4.1 Tool development

Our tool includes two parts, the Exclusion Process (EP) and the Multi-Criteria Decision Analysis (MCDA). For both parts, we developed criteria based on knowledge gained from stakeholder interviews, site visits and literature research. For the EP we identified 13 'killer' criteria in the categories waste input, national market, and international market, which allow a simple pre-assessment of new recycling options. They form a guideline for both policy makers and the private sector to identify (further) recycling options. The second step of our tool was the MCDA. At the beginning of the analysis, we identified 21 continuous criteria, using a 1–5 point Likert scale ranking. These criteria cover aspects on waste input, technology, national and international market, and the implementation in the national and international market. The MCDA allows a more detailed and elaborated assessment of the recycling potential of different recycling alternatives. All recycling options that passed the EP in our study also received a high overall score in the MCDA (> 3). Thus, the MCDA verifies the efficiency of the EP as a pre-selection tool. Our study shows that the results from both parts, the EP and the MCDA, are similar, which makes it obvious and feasible to merge the two into one.

2.4.2 Substantive results

In our assessment, cardboard boxes performed best among the evaluated national recycling alternatives, followed by crushed glass as landfill cover and egg trays. These recycling alternatives all require relatively low-tech manufacturing, and the input quality is sufficient using the current technology and human capacity. In addition, they all face few limitations in the implementation into the existing market in the Seychelles due to the favorable public perception of similar products that have already been introduced on the market. Cardboard boxes for the international market on the first rank gives an excellent example of how to create value from a waste class. Furthermore, the secondary product would leave the system of the Seychelles as packaging material for the exported goods and would not, for that reason, end up on the landfill.

According to our stakeholders, heavy scrap metal for the international market exhibited the highest potential for the Seychelles in the current context. Simple handling and good international market conditions are the main advantages that make

shipping profitable despite the high freight costs. Sorted light scrap metal showed a good potential in the current market. Already available processing technology and profitable recycling businesses are a good base for the further establishment of scrap metal recycling to reduce landfill waste.

Other recycling options were already excluded from our assessment process, because they would not substantially contribute to the reduction of waste landfill. This, per se, does not mean that some of these options should not be implemented, as in some cases (e.g., small-scale recycling art business) the conditions for a substantial reduction of solid waste are not given. Other reasons for exclusion varied greatly, ranging from quality issues to insufficient value of the commodity intended for export.

During our interviews, some criteria emerged that turned out to be key issues for recycling options, e.g., financial aspects. They play an important role in the recycling business. Exporters are strongly dependent on the global market prices. Low prices or high volatility can be harmful to the businesses. For instance, PET flake export currently suffers from a lack of international demand. Especially in the context of the Seychelles, the high freight costs represent a major financial limitation for the export of goods like less valuable polymers than PET (e.g. mixed plastic, PP, PS). A key inhibitor for the national market is competition from cheap, imported goods that may be of lower quality than locally produced goods. Related to the market, electricity prices seem to make up a substantial share of the costs for recycling. Current progression in the energy prices (a higher energy consumption increases the cost per unit) potentially prevents larger and more efficient recycling facilities. However, recycling options that require large-scale and costly facilities (as needed for glass melting or the production of PET bottles) were generally considered unfeasible by recyclers due to the small amounts of these products and/or their high-energy consumption. Therefore, the economy of scale can also be a limiting factor. Worth mentioning is also the fact that recyclers depend on land to store and process the waste. Land is scarce in the Seychelles and there seems to be some concerns among recyclers as to the efficiency and transparency of the leasing process. We did not investigate how the available land is allocated and how it influences the recycling sector. Yet, land access and allocation might be a decisive factor.

Market access and market stability are other key criteria for recycling businesses. Market entry barriers due to the competitive advantage of import products have hindered the market access of secondary products to the national market of the Seychelles. This has been noted for paper bags, paper plates and take away boxes. Market stability is a key issue for national trade and especially for the international trade of recycling goods, such as plastic polymers and other commodities. Political aspects, e.g., national import bans and fluctuating prices for commodities present substantial constraints for recycling businesses.

Furthermore, the reliability of a collection system and the existing recycling infrastructure regarding sorting and storing waste are crucial to ensuring the quality of the waste. High quality of sorted waste increases the recycling potential in the national and in the international market. For instance, stakeholders mentioned reductions in quality due to contamination of aluminum cans and PET bottles as well as corrosion on metals This could be avoided by improvements of the collection systems. Therefore, optimizations in collection systems could further enhance current recycling systems and increase the recycling potential of new recycling alternatives.

2.4.3 Limitation and further research

There are also some limitations of our tool and challenges we were facing during our investigation. The greatest challenge to our approach was receiving precise and reliable information. Contradictory information limited the selection of the criteria as well as their application. Crosschecking the information was not always possible due to the missing availability of sources or time constraints. Hence, some contradicting results had to be tolerated. For example, we expected the recycling potential of beverage cans to be similar to the recycling potential of sorted light scrap due to the comparable circumstances. However, according to our study, the beverage cans achieved a different potential. This hints at the subjective stakeholder perspectives of the different recycling system organizations. Despite this, we received robust and verified criteria that provide insights into the necessary preconditions, key drivers, and potential risk factors of recycling systems.

We identified further limitations during the application of our MCDA. The assessed criteria may vary in their relative importance, thus weighing coefficients could increase their effect on the aggregated score. However, we could not justify specific weighing of criteria using the current state of knowledge. Therefore, we could not prevent outweighing of certain criteria in the analysis using the average score of our first analysis. For instance, shipping costs represent a financial limitation for export businesses, especially in SIDS. In this case, a low rating of this criterion may be compensated by a high score of other criteria. However, the second analysis using ELECTRE III prevents this outweighing of a single criterion. In our case, the result of the ranks is analogous in both analyses. Yet, the dimension of the rank differences of the recycling alternatives varies.

Our tool turned out to be applicable to the context of the Seychelles and may have a value for local decision makers, entrepreneurs and consultants in the waste and recycling system of the Seychelles or other SIDS. The assessment of the potential of recycling alternatives in the national and international markets may help identify challenges and, at the same time, find new opportunities for local recycling and pre-processing for the international market.

Future research may focus on refining and improving the proposed tool and respective assessment criteria. Moreover, additional recycling options, such as fuel pellets, glass as construction material and e-waste, could be assessed using our tool, which would help gain a more holistic picture of the recycling system in the Seychelles.

2.5 Conclusion

We developed a tool to assess the potential of recycling in the Seychelles and investigated the feasibility of a number of recycling alternatives. The tool can be applied for local recycling as well as for export of processed waste. The tool facilitates assessments of different recycling options for turning waste into a commodity or a secondary product. The first part of our tool is an exclusion process (EP) that utilizes local expertise to identify preconditions for a successful recycling system. The second part is a multi-criteria decision analysis (MCDA) method which allows for a detailed analysis of recycling alternatives' potential. In applying our tool, we identified key criteria for recycling in the Seychelles which can be useful to policymakers. Furthermore, we applied the MCDA method to identify the most promising recycling options for the Seychelles. This included both national recycling and

waste pre-processing for further recycling abroad. Either one of them is well established activities in the Seychelles. Local recycling activities currently include paper and cardboard, while pre-processing for international markets include beverage cans, PET, and scrap metal. According to our study, there is still untapped potential for glass, paper and cardboard, wood, and probably for other waste fractions which we have not considered in our study, such as plastics, electronic waste, and construction material.

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3 Hazardous waste: Material flows

Ole Frenzel, Pauline Béziat*, Christy Kehdi*, Vanesia Dodin**, Emmanuel Ogale***

3.1 Introduction

'Hazardous Waste' (HW) encompasses all kinds of waste that pose direct or indirect threat to human or environmental health. It includes but is not limited to flammable, corrosive, toxic and radioactive materials, being often non-degradable or persistent in nature. If not disposed of properly, HW risks to negatively impact human health, ecosystem integrity and finally economic prosperity since costly remediation practices can become inevitable (Khan, Husain, & Hejazi, 2004; Aderemi & Falade, 2012).

In the Seychelles, substantial efforts have been spent by various stakeholders aiming at ensuring a safe HW handling. Beginning with the ratification of the 'Basel Convention On the Transboundary Movement of HW' in 1993, multiple individual mechanisms controlling different parts of the HW stream have been implemented (Basel Convention, 2018). As part of those, it is illegal to transport any kind of HW 'within or through Seychelles' or 'to any country' from Seychelles without explicit authorisation from the Agency (des-

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ignated under section 12 of the Act) and the prior informed consent of the receiving country (Environmental Protection Act – Chapter 71, Part III (12), 1995).

The instrument in place controlling the HW movements are the 'HW Basel Permits' which are being issued by the Ministry of Environment, Energy, and Climate Change (MEECC) to all generators of HW since 2011 (earliest permit accessed). The objective of this mechanism is to create a central node for all HW generated on the island. While the competent authority for signing Basel Permits is the MEECC, part of the handling is managed by the Landscape and Waste Management Agency (LWMA) who receives the applicants' forms and collects a HW fee before passing the file on to MEECC. After 4 years of spin-up time, the Basel permit mechanism appears to have reached the state of common practice in Seychelles. Nevertheless, a study is needed to assess the share of the total HW that is being covered by the permits.

3.1.1 Definition of hazardous waste

Having ratified the Basel convention, the Seychelle's definition of HW must refer to Annex I and III of the convention. Following this, HW is defined in the Seychelles Environmental Protection Act as waste that is "poisonous, corrosive, irritant, noxious, explosive, flammable, toxic or harmful to the environment" (Environmental Protection Act – Chapter 71, Part I (2), 1995). Additionally, Seychelles has slightly amended and extended this classification e.g. to certain phytosanitary wastes that are locally regarded as hazardous as well (Basel Convention Country Fact Sheet Seychelles, 1993). Given the islands' high amount of marine traffic, "wastes which derive from the normal operations of a ship, the discharge of which is covered by another international instrument" are explicitly excluded from the Basel Convention and are hence not officially defined as hazardous.

3.1.2 Further Regulations

While the Basel permits are the strongest regulatory instrument in place for HW in the Seychelles, the nation is signatory to additional relevant conventions. Notable are the chemical conventions of Rotterdam (ratified in 1998), Stockholm and Minamata addressing contamination/handling from pesticides, persistent organic pollutants (POP's), and mercury respectively.

3.1.3 Current disposal procedure

Once a material has been identified as hazardous by the person wanting to dispose of it, it is his/her (i.e. the contractors) obligation to suggest an adequate disposal mechanism while handing in a HW Basel permit application to the MEECC. If this is not the case, staff from the ministry itself or external consultants designate the material fate. They take into account the volume and chemical characteristics of the waste, and refer to the material safety data sheets (MSDS) before designating a disposal mechanism. Once an application is approved, the contractor delivers the material to the selected site and pays an additional fee depending on the final weight of the HW (MEEC – Services, 2017).

3.1.4 Amount of hazardous waste generated

In 2010, the Rodeco Consulting GmbH issued a technical assistance report on hazardous waste handling and treatment in Seychelles. According to this document, the amount of hazardous waste recorded in the country amounts to about 9 tons per year (referring to 2010). It is however estimated, that this covers only about 10% of the total amount being generated (Rodeco Consulting GmbH, 2010). Moreover, it is stated in the report that most HW stems from domestic sources, with industry only being responsible for 20–30% of the total generation. It remains unclear which considerations this estimation is based upon. This is especially critical given that the

relative share of HW from domestic and industrial entities strongly depends on the specific definition of HW used, that is specifically the inclusion of batteries and car tyres.

Fate of hazardous material in the Seychelles

Upon ratifying the Basel convention, Seychelles strictly restricted the import of HW (and other wastes) into the country meaning that no entity has the right to import any HW to the island. Export is permitted, both for final disposal and for recovery, however, any such transboundary movement is strictly dependent on the prior consent of the receiving country, with the MEECC being responsible for acquiring the consent (Basel Convention Country Fact Sheet Seychelles, 1993). Given the limited capacities for the oftentimes technologically demanding treatment of HW, export is one of the most important HW fates on SIDS. In the Seychelles, this opportunity is actively exploited for waste oils and batteries, it remains unclear to what extent other HW enters international markets (Talma & Martin, 2013).

Excluding the option of treatment and neutralization two possible fates remain, namely incineration and landfilling/other storage. Both options seem to be exploited to some degree, with several incinerators being present on the island.

Further, there has been a designated storage space for HW present in Seychelles in the past; it used to represent a disposal facility for waste that are not accepted at the landfill. This space is not accepting any further materials. It has been deposited together with its content at the Providence landfill due to its poor general state and the associated safety hazard.

Landfills, mainly Providence and Anse Royal, are the major terminal sinks for HW locally. The responsible agency, STAR, is recording the amount of hazardous waste being delivered to Providence under waste class 11 at the weighbridge.

Research objectives

Overall, the situation draws itself like a puzzle. Hazardous waste is being generated in Seychelles by different entities and deposited in different sinks. Several mechanisms (weighbridge, Basel permits etc.) are in place in order to record HW flows; they are however unable to cover the full picture. The objective of our study was hence to gather as many pieces of the puzzle as possible to trace the fate of HW on Seychelles from source to sink. For various reasons (e.g. high potential for centralised HW handling exercises, limited timeframe of study), we excluded households from this study and concentrate our efforts on the industrial sector.

3.2 Materials and Methods

3.2.1 Data Collection

The data analysed in this report were compiled from different sources including questionnaire response from various companies and organizations, Basel permit forms and export contracts from MEECC and LWMA, as well as HW import data from the National Bureau of Statistics (NBS). In addition, we conducted several interviews with different stakeholders (see Appendix 3.1) to gather additional data and extend our understanding of the HW flow on the island.

Hazardous Waste Questionnaire

To assess the amount of HW produced in Seychelles, we first created a classification of relevant HW categories based on

the Basel Convention. The identified categories include 'Left-over, excess and used chemicals', 'Waste oils and emulsions', 'Clinical wastes', 'Batteries', and 'Waste tires'. Please refer to Appendix 3.2 for details and a list of all sub-categories considered. Given that there is a representative in the MEECC working on the topic of electronic wastes specifically, we omitted this category from our classification.

Although being aware of the fact that waste tyres are not officially considered hazardous under the Basel convention (they instead belong to category B3140 – waste pneumatic tyres), we decided to include them in our study given the local context of Seychelles. While not being inherently hazardous, waste tyres may generate significant hazards if present in large volumes and under certain storage conditions. Apart from being an excellent rodent habitat, standing water inside warm, dark tyre piles is the ideal breeding ground for mosquitos and vermin, facilitating the spread of infectious diseases (Aderemi & Falade, 2012; EPA South Australia, 2010) Further, large tyre stockpiles are a fire hazard: although relatively hard to ignite in the first place, the inherent air spaces create the ideal environment for fires that are extremely hard to extinguish; tyre fires typically generate very large amounts of heat and smoke (EPA South Australia, 2010). The presence of large tyre volume adds an additional risk to landfill fires through the production of dioxins which are extremely toxic already at low concentrations (Aderemi & Falade, 2012).

Similar to waste tyres, batteries and waste oil are also not officially considered HW in Seychelles although a risk is being acknowledged "when present in bulk quantities." Note that according to the Basel convention, many types of batteries are characterized as hazardous, notably lead-acid batteries (A1160, Annex VIII List A) which constitute a large share of the batteries being imported to Seychelles. Waste oils are also classified as hazardous under the Basel Convention, belonging to waste stream Y8 of Annex I ('waste mineral oils unfit for their originally intended use') which is further being characterised in A3020 (Annex VIII List A). The hazardous character stems from waste oils commonly containing carcinogenic polycyclic aromatic hydrocarbons (PAHs) such as benzo(a)pyrene and benzo(a)anthracene (Secretariat of the Basel Convention, 2002).

On the basis of our HW categorization, we designed a questionnaire targeting the quality and quantity of industrial HW as well as the prevailing disposal mechanisms. This questionnaire consists of five major sections corresponding to the five aforementioned waste categories. All sections are divided into the respective sub-categories, proposing several ranges of volume, weight or quantity for the respondents to choose from. The third column suggests four disposal mechanisms (normal mixed waste, incineration at airport, incineration at port, incineration at power station). In all rows an entry 'other' is present with sufficient space for the respondent to add an individual reply.

To facilitate the filling of the questionnaire, the units were chosen on a basis that is easily accessible to the user (i.e. batteries in number rather than weight). In addition, we designed an information sheet for the survey participants containing a description of the case study, our research questions and a definition of the categories listed in the questionnaire including an extensive list of examples. The questionnaire of the HW survey and the information sheet can be found in Appendix 3.3 and 3.4.

Using the Seychellois business registry obtained from the NBS, we contacted about 170 companies via email that are active in sectors/industries suspected to produce HW. Those companies were invited to participate in the online version of the questionnaire prior to the beginning of the field phase. During the field phase, hard copies of the questionnaire and information sheets were distributed to 124 companies in Victoria, Providence, Eden Island, and Anse Royale. A mix of different company types was covered, including representatives from the retail, transport, automotive and medical sector.

Basel Permits and Export Contracts

Next to the questionnaire, the most important source of information to this study was the Basel permits received from the MEECC and LWMA. Overall, we obtained 131 permits (41 permits filled in 2018, 44 from 2017, 32 from 2016, none from 2015, 1 from 2014, 1 from 2013, 7 from 2012 and 5 from 2011). Furthermore, the MEECC provided us with the 2012 – 2017 contracts regulating battery and waste oil exports with the receiving countries, i.e. South Korea and India respectively. In total six waste oil and eleven battery export contracts were issued in the given timespan. Regarding the waste oil contracts, half of the permits were issued for STAR Seychelles and the other half for Wastea (successor institution of STAR). As for the battery export contracts, the permits were issued for Surya Enterprises, Samlo & Sons and Cut All.

Interviews

Several stakeholders were interviewed to provide further insight into the current system (for full list of all interviewed experts see Appendix 3.1).

While the meetings with Mr. Frederick Kinloch and Mrs. Michelle Azemia focused on the function of the Basel permits system as well as the current role of the MEECC in the handling of HW, the interview conducted with Mr. Lemmy Payet aimed at elucidating unclarities regarding the use of the Basel permits. Moreover, conducting an unstructured interview with Gerard Anacoura, the STAR manager in charge of Providence landfill, not only provided several valuable insights on the current HW management of STAR but also provided us with the landfill weighbridge data from 1999 until June 2018.

To expand our HW sinks database, we furthermore interviewed representatives from the Seychelles Port Authority (SPA) and the Seychelles Civil Aviation Authority (SCAA) to inquire about the port and airport incinerators respectively. In addition to this, semi-structured interviews were conducted with stakeholders involved in the export of batteries such as Mr. Gowessoo and Mr. Naidoo to approximate both the amount and origin of batteries they export annually as well as to gain additional insights into their HW treatment. The interviews with Mrs. Sarah Romain and Mr. Elvis Federick provided additional insights concerning the way the Seychelles Petroleum Company Ltd. (SEYPEC) and Public Utilities Corporation (PUC) respectively handle the waste oil they generate or receive from other generators. The interview with Mrs. Branda Rath and Mr. Weli yielded further information concerning the operation of the Victoria Hospital incinerator. Lastly, we also met with Mr. Robert Rose, who has been involved in consulting activities for the MEECC regarding the disposal of HW in the past, to receive his expertise and insights about the operation, strength as well as weaknesses of the current HW management system in the Seychelles.

3.2.2 Data Analysis

To obtain a realistic overview of the HW management system in Seychelles, all provided data including those from the distributed questionnaires, the import data, the Basel permits, the information provided by the hospital incinerator as well as the Providence landfill weighbridge, were first evaluated and subsequently combined into a single overall system picture. In a second step, the data received for each individual HW category were analysed in more detail. In the following, the evaluation of the questionnaire, import, Basel permit and incinerator data will be discussed in more detail since these required additional processing prior to being merged with the other data.

Questionnaire Data

The answers obtained from the questionnaire were first digitalized and subsequently grouped according to the defined waste classes. Moreover, to combine, analyse and interpret the data from the different sources, the amount of waste was converted to weight values for each category. To do so, the average weights for car batteries, car tires, household batteries, and special tyres were assumed to be 18kg, 7kg, 8g, 7kg respectively.

Import Data

The import data cover the period from 2013 to 2017. Throughout this period notable inter-annual fluctuations were encountered for most of the import streams with the data for 2013 deviating most significantly from all other years. To estimate the overall annual import rates of hazardous goods, we thus not only relied on the data from 2016 onwards (as for the other waste streams) but also included those of 2014 and 2015.

All data that did either not fall into our predefined categories (e.g. e-wastes) or had not been imported since 2014 were eliminated. The only exception to this was asbestos which has been eliminated from the data even though it was still imported in 2014. We decided to do so since no subsequent asbestos imports were registered indicating that the ban which was officially set up in 2009 was enforced.

The remaining imports were then regrouped according to our predefined categories and for each group of HW the average annual import, as well as its standard deviation, were calculated for the period of 2014 to 2017. To estimate reasonable annual import data, a range of one standard deviation around the average value was assumed. Since for both clinical waste and waste oils the lower boundary of the estimated range fell below the smallest annual import data for the respective timeframe, these values were replaced by the lowest import value. Finally, it should be noted, that no import data were given for car tyres since there are not considered hazardous goods when being imported.

Basel Permits

The permit data cover the period from 2011 until 2018. Given that a significant coverage of HW permits is only available since 2016 (117 permits out of 131), only permits obtained from 2016 to 2018 were considered in the analysis. The waste types covered in the obtained permits are liquid and solid HW, asbestos, expired foods and drinks, and glass. For each year, the permits data were clustered according to the previous categories.

Some of the permits were not clearly filled; either the type of waste or the amount was not reported. Those permits were neglected from our study. In addition, we encountered cases where the waste amount was not reported in weight but some characteristic volume. Requiring a consistent unit for flow stream calculations, we converted these data to weight units based on density, packaging dimensions etc. Lastly, for each company and for each predefined sub-category (e.g. pharmaceutical products, drugs and med-

icines), the amount of liquid and solid HW waste was averaged over our 2.5 years' study period.

Incinerator Data

The last data set serving as a material source input to our flow analysis was one obtained by the Health Care Agency at the Victoria Hospital. The hospital incinerator data comprised both the overall amount of waste being incinerated as well as detailed information concerning all external companies delivering material to be burnt at the incinerator between January 2016 until March 2018. Since the incinerator is used for burning HW as well as non-HW, we first eliminated all non-HW data. The remaining data were grouped according to the waste producer, and the data from the same sub-category and company type were averaged over the three years. This procedure allowed us to obtain HW data for six additional companies that we could not cover in the questionnaire, as well as to complement the questionnaire results from another enterprise which overall added another 281 kg of HW (mainly pharmaceutical products and contaminated materials) to the analysis.

Overall Hazardous Waste System

In order to obtain a holistic overview of the current HW system, all obtained data were combined into a single data set used to calculate material flows. To do so, the companies listed in the questionnaire, permits and hospital incinerator data were clustered by type as follows: 'Medical & Beauty', 'Management & Education', 'Automotive & Construction', 'Transport', 'Manufacture of Consumables' and 'Retail & Print'.

For the graphical presentation, all data were first summarised according to their source (the industry they originated from) and waste category (e.g. source '1' disposed 'X' quantities of HW category 'A', 'Y' quantities of HW category 'B', etc.). Subsequently, those waste categories were distinct according to their collection and final disposal (e.g. 'Z' quantities of HW category 'A' were collected by 'aa' and disposed of in way '*', 'W' quantities by 'ab' and disposed of in way '+', etc.). The general underlying structure of the Sankey diagrams (a specific type of flow diagram, in which the width of the arrows is shown proportionally to the flow quantity) is represented in Figure 3.1.

All data ranges were converted to means prior to calculating flows. Regarding the disposal, two prominent replies from our questionnaire were normal mixed waste or STAR. In all but one case we assumed both the normal mixed waste and the waste labelled with disposal 'STAR' to end up at the landfill. The exception to this is waste oil, in which we assumed the waste oil labelled with 'STAR' to be exported, and the oil labelled with 'normal mixed waste' to enter the landfill. Moreover, four questionnaire entries were grouped into the category battery collectors. Whenever 'stockpile' was given as an answer or simply no disposal information was provided, we opted for the classification 'other'.

Once all flows had been calculated, the data was fed into the online program 'Sankeymatic' to design Sankey diagrams both for the general overview (five main material classes) and subplots for the material sub-categories. Lastly, all other material flow data that did not form part of the questionnaire/permit dataset were added to the diagram.

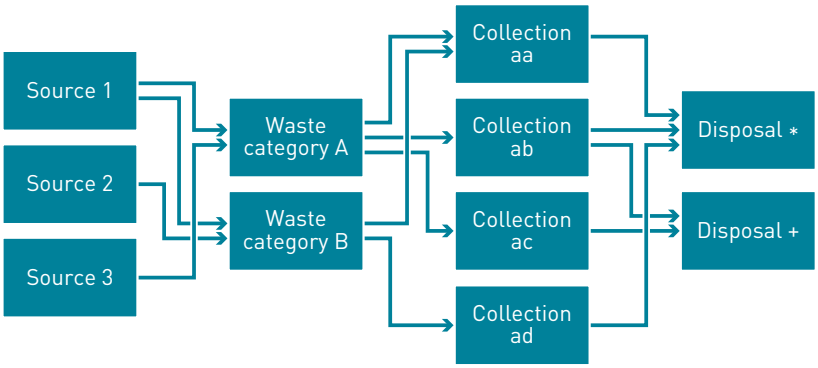

Figure 3.1
Diagram summarizing the underlying structure of the Sankey diagram.

3.3 Results

The overall objective of our study was to trace the fate of industrial HW on Seychelles by tapping various information sources and joining all acquired data sets to a bigger picture. While the final result of this effort will be introduced in Section 3.3.2 *'Sankey diagram – Tracing Hazardous Waste'*, we first wish to discuss the sub-results of our different investigations.

3.3.1 Individual Data Sources

Door to Door Survey

124 companies initially accepted to either fill our questionnaire on the spot (rare) or to take it to their office to fill it in the course of one week. Out of these 124 forms, we were able to recollect 96 (= response rate of 77%). Out of the 96 collected questionnaires, 75 were filled and could be used for the data analysis (= 60% of total sample).

As illustrated in Figure 3.2, the majority of enterprises having replied to our questionnaire belongs to the sector 'Automotive & Construction' (35%) as well as 'Medical & Beauty' (20%). The least amount of companies covered were part of the sector 'Manufacture of Consumables' (7%). The total amount of hazardous waste recorded in the respective questionnaires amounts to 382.5 – 530.3 tons per year[1].

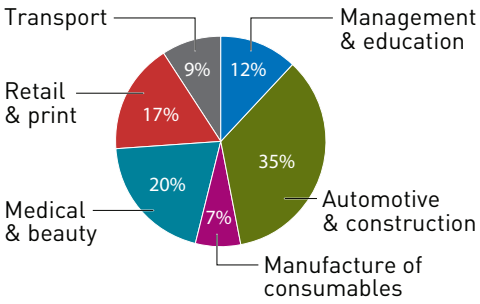

Figure 3.2
Door-to-door survey on industrial hazardous waste on Mahé, Seychelles. A total amount of 75 questionnaires has been filled by companies which we have grouped into 6 branches of industries 'Automotive & Construction', 'Transport', 'Retail & Print', 'Manufacture of Consumables', 'Management & Education' and 'Medical & Beauty' (see Appendix 3.5).

Basel Permits

In theory, all HW generated on the island should pass through the MEECC office to be recorded in a Basel permit file and directed to its final disposal site. Comparing the amount of HW that arrives at the landfill (as recorded by the weighbridge) with the amount registered in the permits allows a first rough assessment on how well this system has been implemented. Figure 3.3 presents the permits and weighbridge data for the years 2016–2018.

As mentioned, we decided to omit all data before 2016 since entries were extremely sparse indicating that the permit system was either not well in place or the respective files were not adequately archived /not made available to us. In total, the permit data represented in Figure 3.3 correspond to 101 permits from 2016

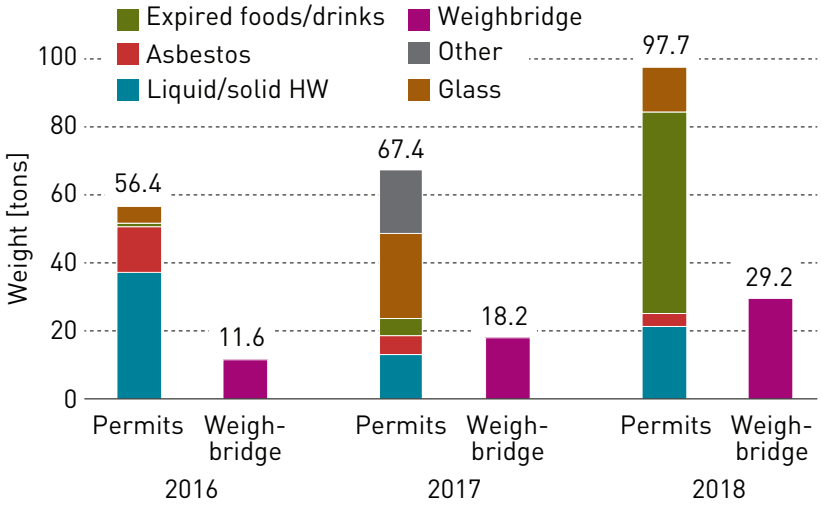

Figure 3.3
Hazardous Waste Basel permits and STAR hazardous waste recording on Mahé, 2016–2018. Left bar: data from the Basel permits obtained from LWMA and MEECC; right bar: weighbridge data of class 11: 'Hazardous Waste' obtained by STAR. All values are in tons per year. Permit data has been grouped into five categories: liquid/solid HW, asbestos, expired foods and drinks, glass and other waste.

1 The questionnaire was set up in a way that did not ask companies for exact material masses, but range averages (see Appendix 3.3). Although this approach introduces considerable uncertainty in the calculated mass flows, we expected it to ease the process of survey filling for our respondents and hence potentially increased the sampling size.

to 2018. As shown in this Figure, the total amount of material recorded increased from 2016 to 2018 from about 57 to 98 tons, coinciding with a continuous increase in the amount of HW material recorded at the landfill weighbridge.

We emphasize that in Seychelles, the Basel permit form is not exclusively used for HW as defined in the Basel Convention ('BC-HW'). The form is currently being used to record glass waste and expired foods and drinks next to BC-HW. Note that Figure 3.3 lists asbestos as a separate category distinct from HW since it is considered inert waste at the landfill by STAR. Considering only the BC-HW, we find that a total amount of 75.2 t has been recorded in the permits in the course of the past 2.5 years, suggesting an average yearly generation of 30.1 t. Note that this value exceeds the yearly amount of HW registered in the 2010 report (i.e. 9 t/y) implying that either the recording has improved or the actual HW generation increased dramatically.

For the sake of clarity, we will in the following only further investigate/ discuss the data obtained for BC-HW. Regarding these 'real' HW permits, it should be pointed out that not all of them were actually signed and completed with the Basel stamp. Figure 3.4 shows the share of permits that have been approved by the MEECC and their allocated disposal site.

Of the total amount of 38 permit applications of BC-HW between 2016 and 2018, 30 were approved covering a material flux of about 62 t. This implies that about 13.2 t of the HW that contractors reported off were not designated a disposal site; it remains unclear where this flow ended. In some cases, it was specified on the permit that the material should be stored at the contractors' site until an adequate disposal facility would be in place, meaning that it is interim stored at the producers' places.

Of the approved material, the largest share (49.7 t) was sent to Providence Landfill ('under close supervision of LWMA officers'), with about 4.6 t requiring neutralisation prior to disposal. This neutralisation is normally necessitated for acids (and bases). In these cases, the contractor is asked to pour the material onto coral sand (i.e. calcium carbonate) or sodium bicarbonate. In others, specific instructions are provided by MEECC on the permit as to how the disposal at the landfill shall be executed[2].

Other than the landfill, final destinations listed in the permits were the waste oil stream ('co-incineration with waste oil'), e.g. for chemicals such as xylene or formaline. It is unclear at which site/ whether waste oil incineration is currently taking place in the Seychelles. Lastly, about 5.8 t of the material is registered in permits that are signed and stamped, but without any specification of where the material would be sent to.

2 An example roughly reads "Excavate a trench of 2.5 x 2m with land fill manager. Rock dust and wood say should be used as layers in the process of pouring the chemical into the trench, with layers of 1.5m of aggregate dust as base in the trench covered with wooden saw dust. For every 20 gallons of chemicals repeated layers, finally the trench shall be covered in coral fill."

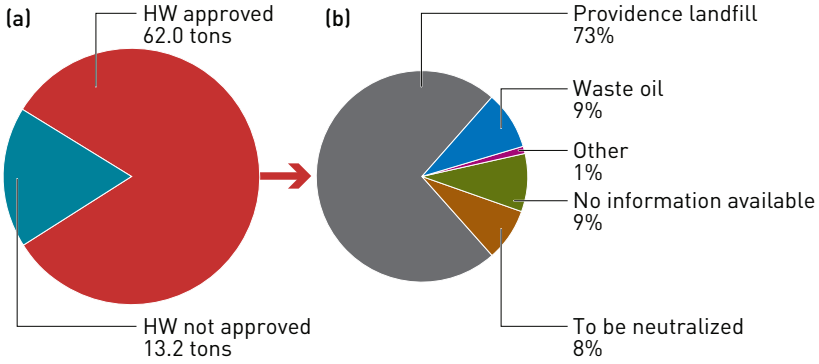

Figure 3.4
(a): Pie chart presenting the amount of HW from 2016 to 2018 permits that either have or have not received approval from MEECC for disposal. (b): The weight percentage of approved HW according to its disposal facility where 'other' includes both incineration and oil incineration.

Incinerators

Overall, we identified six incinerators on the island (see Table 3.1) of which three are currently in operation. In the following, the current status of each incinerator will be briefly discussed.

Victoria Hospital

The incinerator at the Victoria Hospital is an important sink for clinical waste on Mahé. It is located right at the hospital and run by the Health Care Agency. Any external entity wishing to dispose of material (including e.g. confidential documents to be burnt) at the incinerator has to pay a fee of 125 rupees per kg of waste. This policy has been introduced in 2015, before which a general fee of 1000 rupee was charged for any amount of material delivered. While small amounts are being accepted spontaneously directly upon registration, contractors for larger amounts (mostly pharmacies and private clinics) have to make an appointment for their waste to be introduced to the incinerator.

The machine burns about 150 kg waste per day (at 252 days a year), with the bottom ash being sent to the landfill every two operational days. Note that no Basel permit for hazardous waste has to be issued for hazardous pharmaceutical waste prior to incineration.

PUC

While it was often stated by companies that they had "heard of people sending their waste oil to PUC" we were not able to confirm such information. In an interview with PUC's electricity operations manager we learned, that the company indeed has a working incinerator which is however exclusively used to burn oil sludge from the public utilities themselves. It appears that PUC does not (anymore) accept any waste oil from external stakeholder.

The sludge from PUC itself is a by-product of the electricity generation; the generators are burning heavy fuel oil from which all sludge and particulate matter need to be removed with a centrifuge prior to being used. About 4,000L waste sludge are being produced for 12,000h of operation per plant. The incinerator does not yet have any appliance in place harvesting the thermal energy, it is, however, currently being considered to add a turbine to the system.

Port Victoria & Mahé International Airport

Two further, fully automatic, incinerators are located in the port Victoria and airport area. Both have been funded by the EU Development Fund under the 'Melon Fruit Fly Eradication Programme'; all activities were completed in 2007 (Coop-

Table 3.1
Overview incinerators on Mahé.

Incinerator	Currently operating	Additional notes
Victoria Hospital	Yes	Used for medical waste & confidential documents
PUC	Yes	Exclusively used to burn oil sludge from the public utilities company
Incinerator Port	No	High operational costs prevent economic feasibility
Incinerator Airport	No	High operational costs prevent economic feasibility
SM Plant Services	Yes	—
SEYPEC	No	Currently being constructed

eration European Union and Republic of Seychelles, 2008). The main intention was to fight melon fly (bactrocera curcurbitae) which had most likely been introduced to the country via aircraft food meals around 1999 and was deemed responsible for production losses of up to 60% of cucurbit crops on the island. Hence, together with a large suppression programme, two incinerators were to prevent the re-introduction of the fly and other invasive species to Seychelles (European Commission, n.d.). The company Incinco was responsible for commissioning and installation. Incinco states that both incinerators were specifically designed to dispose of general waste, including kitchen and wet waste from food preparation in the airport and dock area (Incinco, n.d.).

Both incinerators are however currently inactive and have been so for the past years. A joint report by the Republic of Seychelles and the European Union reads "due to financial constraints on the government side and rising operation costs (petrol dependency), their proper use is compromised" (Cooperation European Union and Republic of Seychelles, 2008). The CEO of the Seychelles Port Authority (SPA), Mr. Laporte confirmed this inactivity to be the result of operational costs being unfeasibly high. According to the SPA, the technology chosen for this installation does not fit its purpose. SPA further reported of an ongoing project that includes the import of a new incinerator for Port Victoria, involving the Seychelles Ministry of Agriculture and the National Biosecurity Agency.

SEYPEC

The Seychelles Petroleum Company is active in the recycling of waste oil on Mahé. In this process, as well as in the normal operations aside oil recycling, SEYPEC is producing oil sludge (lubricant oil/water emulsions) – the majority of which stems from cleaning the companies' storage tanks. Up to now, this sludge is being handled by SM Plant Services, an incinerator run by Mr. Serge Monthy, who comes to collects the sludge at SEYPEC directly. Between January and June 2018, SEYPEC has disposed of about 40,000 L sludge this way. The company is however currently in the process of installing its own incinerator in order to dispose of the sludge internally.

3.3.2 Sankey diagram – Tracing Hazardous Waste

Figure 3.5 merges all our data sets and provides a broad estimate of big hazardous waste flows on Mahé. It is not exhaustive, nor claims to represent full reality in all cases: the diagrams aim at showing flows in tons per year, averaging data over different time frames (see caption for details). Hazardous waste flows are however often one-time events, with companies stockpiling chemical waste over years and disposing of it all together at one specific moment in time.

The diagram illustrates that the biggest parts of the hazardous material being imported to Seychelles are oils and chemicals (~96,000 t and ~2,650 t respectively). Oils are mainly diesel oils (59.5%), fuel oils (furnace) (12.4%) and kerosene (8.6%). Chemicals are harder to generalise; the import consists of a large variety of different chemicals in equal amounts. 'Highest' shares are found in chlorine (4.4%), polishes and creams (3.5%) and rodenticides in aerosol containers (4%). In terms of batteries, lead-acid predominates, followed by lithium and manganese dioxide.

In total, our data shows the following HW waste generation (See column 'Materials' in Fig. 3.5):

- 42 tons of chemical waste
- 280.2 tons of waste oil
- 46.4 tons of clinical waste
- 56.6 tons of batteries
- 134.4 tons of tires

In the subsequent sections, the specific results obtained for the various HW categories will be discussed in detail.

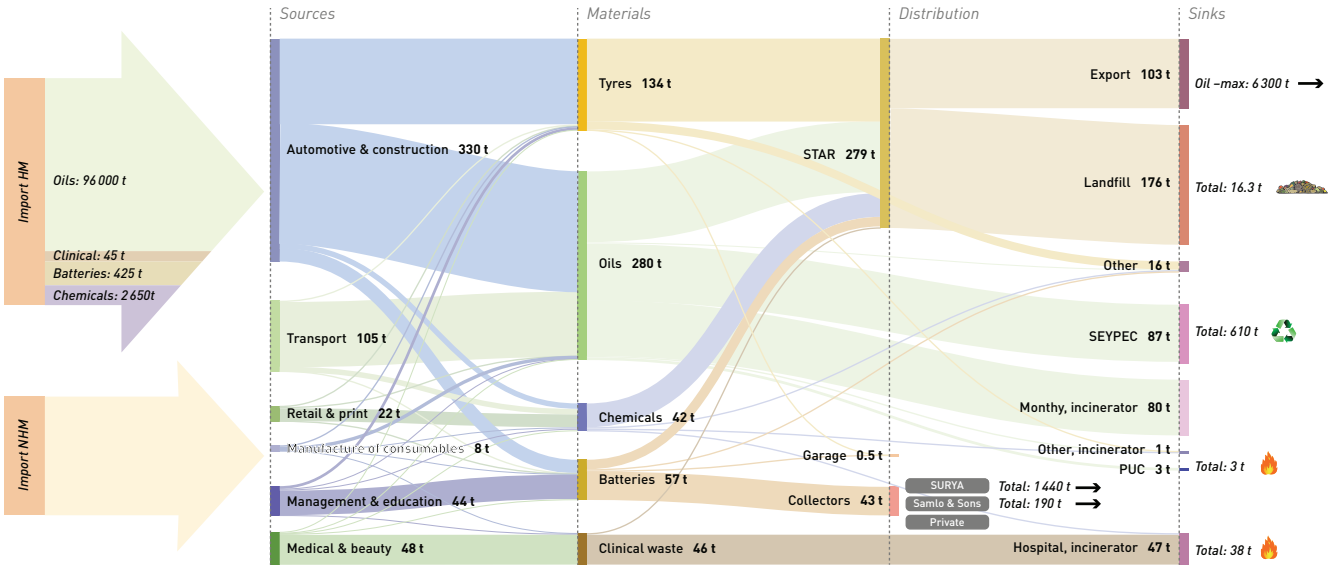

Figure 3.5
Hazardous waste streams on Mahé, Seychelles. Data written in italics (Imports and Sinks) represent the whole of Seychelles (see below for data source) while those written in bold (Sources, Materials and Distribution) represent data obtained from 119 companies on Mahé through questionnaires, hospital incineration data (from 2016 to 2018) as well as Basel permits (from 2016 to 2018). All flows are in tons per year. From left to right:

Import: The import of hazardous materials is controlled by customs; this dataset has been obtained by the Seychelles National Bureau of Statistics. Figures are yearly averages taking into account imports between 2014 and 2017. Both, the hazardous material and non-hazardous material are being processed by industry generating hazardous waste as a by-product.

Sources: All companies have been grouped into 6 categories namely 'Automotive & Construction', 'Transport', 'Retail & Print', 'Manufacture of Consumables', 'Management & Education' and 'Medical & Beauty' (see Appendix 3.5). Materials: Five types of HW are being considered: tyres, oils, chemicals, batteries and clinical waste.

Distribution: The recorded hazardous materials in our flow diagram have the following destinations: export, landfill, recycling (SEYPEC), incineration (Mr. Monthy; PUC; Hospital; other), collection and subsequent export (batteries) and other individual sinks that are not addressed in this diagram.

Sinks: These data are based on information derived from stakeholder interviews, HW export permits (2012–2017) as well as Providence weighbridge data (2016 to 2018). In the following the most important information will be given: STAR has a maximal allowance for waste oil export of 6,300 t. The company further records the amount of hazardous waste arriving at the providence landfill (waste class 11); the average yearly amount recorded from 2016–2018 is 16.3 t. SEYPEC receives waste oil from various companies on Mahé for oil recycling with the yearly average being 610 t (data provided by SEYPEC). Moreover, the following assumptions were made: PUC is burning waste oil/oil sludge in their own incinerator together with drainage, not accepting any oils from external companies but only the PUC-owned plants. On average, 4,000 L are generated for every 12,000 h of operation. Surya and Samlo & Sons export batteries from Mahé, on average a total amount of 1,440t and 190t respectively. The Incinerator at the Victoria Hospital burns clinical waste and confidential paperwork.

Chemical Waste

The main sources of chemical waste (Figure 3.6) include retail and printing (23.2 tons/year), automotive and construction (6.6 tons/year) as well as transport (7.02 tons/year). While the first mainly dispose of paints and inks as well as organic solvents, the latter two strongly contributed to other chemicals which include for instances expired chemicals such as sodium bicarbonate or calcium chloride, antiscalants, acids, and alkali-basis. Both paints and inks, as well as the other wastes, are finally disposed of by STAR. Aside from this about 1.7 tons of pharmaceuticals, 0.72 tons of wood preservatives and 0.265 tons of biocides which mainly originate from the medical and beauty as well as the management and education sector were found to be disposed annually.

Waste Oil

In our assessment, the predominant sources of waste oils include the automotive and construction as well as the transport sector with 177.8 and 95.6 tons per

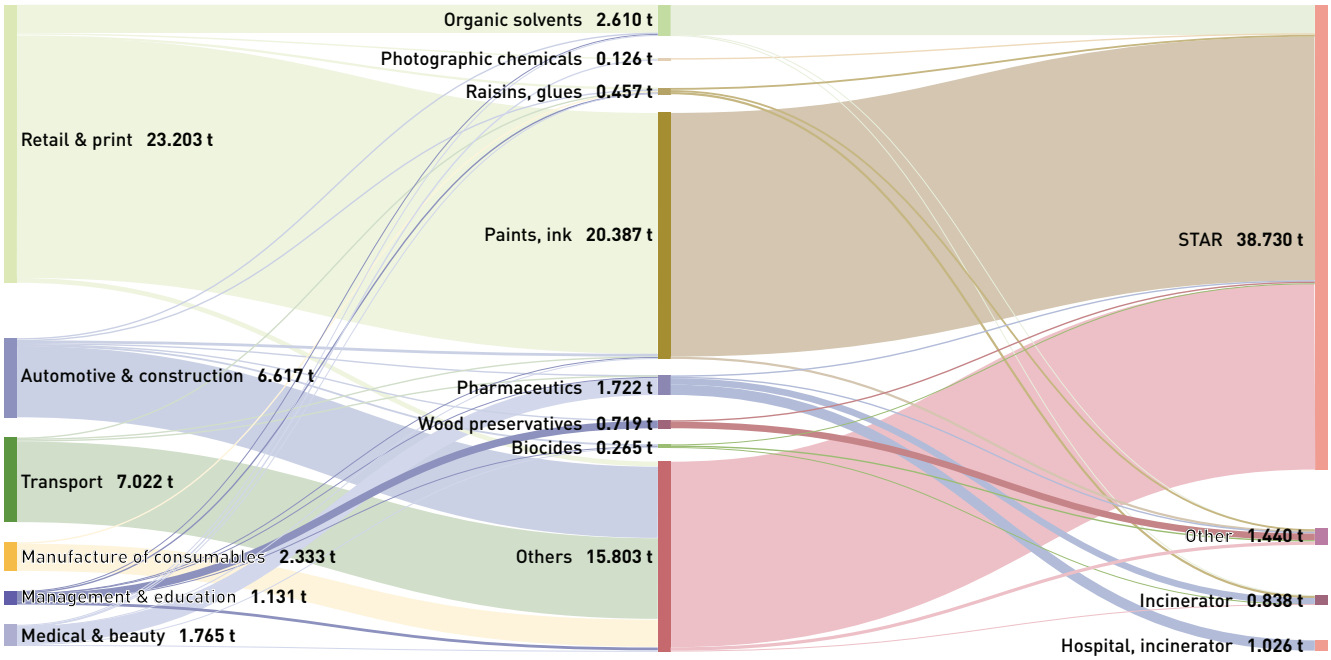

Figure 3.6
Sankey diagram displaying the HW streams for chemical wastes in the Seychelles based on data obtained from distributed questionnaires. Total amount of the chemical wastes per year: 42.034 tons.

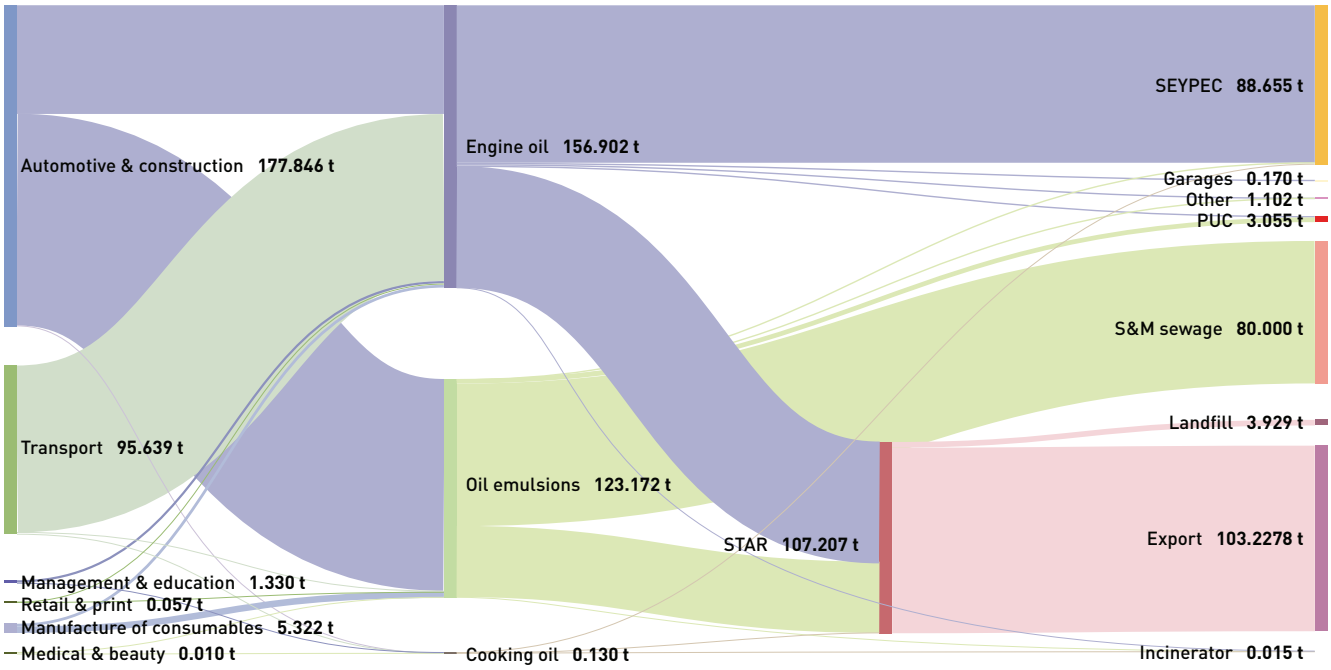

Figure 3.7
Sankey diagram displaying the HW streams for waste oils in the Seychelles based on data obtained from distributed questionnaires. Total amount of waste oil per year: 280.154 tons.

year respectively. While the transport sector disposes nearly exclusively engine oil, about two-thirds of the waste oils from the automotive and construction sector were other oil emulsions. About 60 percent of the engine oil is finally being treated by SEYPEC with the remaining share going to STAR. For oil emulsions, two-thirds are taken care of by S&M Sewage while the remaining third is once more dealt with by

STAR. Of the 107.2 tons of waste oils annually delivered to STAR, 103.3 tons are being finally exported while 3.9 tons are being landfilled.

Clinical Waste

According to the questionnaire data, the annual disposal of clinical wastes (Figure 3.8) amounts to about 46.3 tons per year which are composed of 36.7 tons of pathological waste and 9.6 tons of contaminated materials. For both categories the companies classified as 'Medical and Beauty' were the main source while their common sink is the medical incinerator at the Victoria hospital.

Batteries

The battery waste stream (Figure 3.9) is strongly dominated by vehicle batteries originating from the management and education (36.3 tons/year) as well as automotive and construction sector (18.1 tons/year) which amount to about 56.6 tons per year while household batteries only add up to about 19 kg/year. Naturally, we would expect to record much higher quantities of household batteries if our questionnaire was not confined to industry only. While household batteries are disposed of in the normal mixed waste and thus finally being deposited at the Providence landfill, the main share of the vehicle batteries (43.4 tons/year) is being collected and finally exported. Only about 12.6 tons of the latter are annually being landfilled of which a certain (however unquantified) share would additionally be collected, treated and exported.

Tyres

By far the largest source of waste tyres (Figure 3.10) is the automotive and construction sector with about 127.1 tons per year of which all but about 9 tons are car tyres. A second major source of special tyres is the management and education sector (4.9 tons/year). The main share of

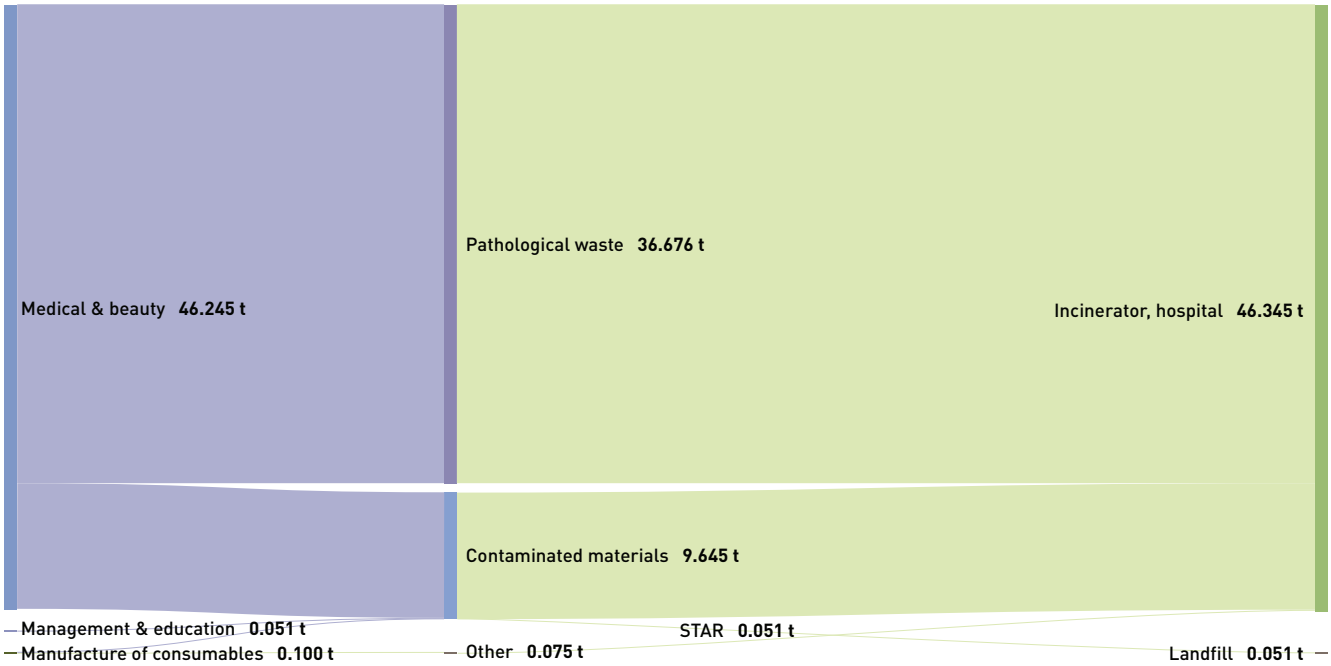

Figure 3.8
Sankey diagram displaying the HW streams for clinical wastes in the Seychelles based on data obtained from distributed questionnaires. Total amount of clinical waste per year: 46.396 tons.

both car tyres and special tyres is being landfilled. It should be emphasized, that a notable share of the tyre waste stream being disposed of as 'other' is likely being landfilled. The reason for this is that landfilling was not explicitly displayed as a disposal method but only 'Normal mixed waste'.

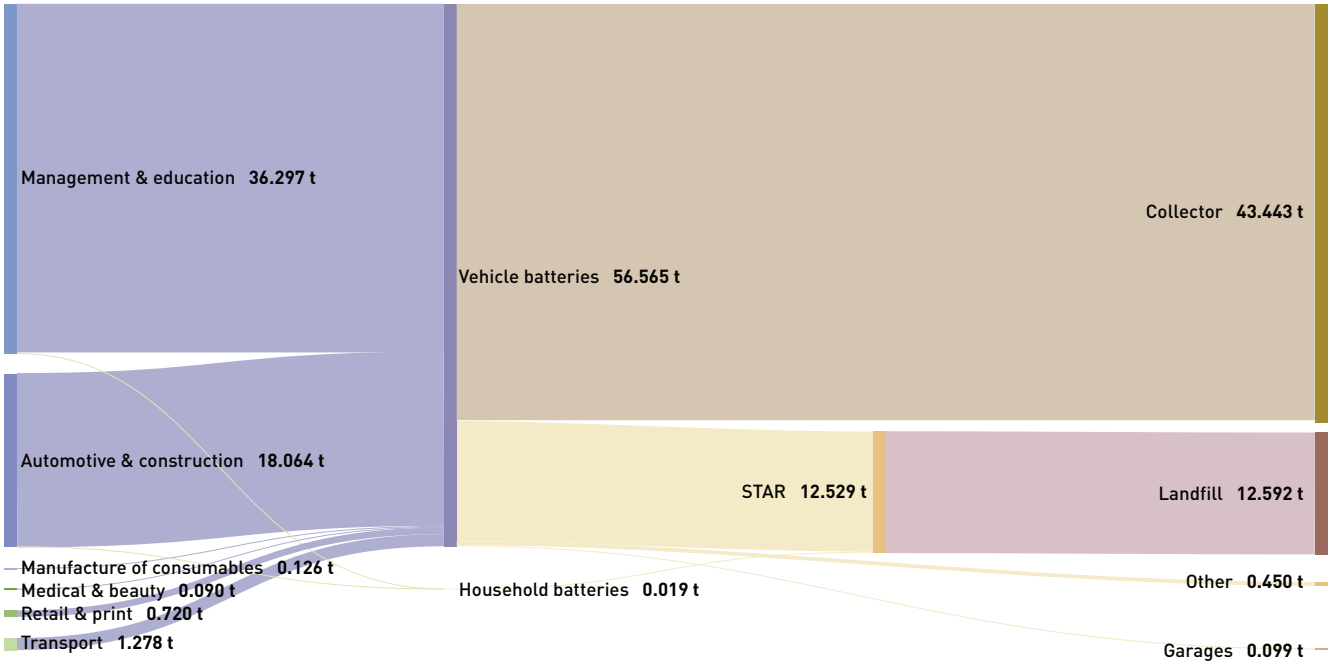

Figure 3.9
Sankey diagram displaying the HW streams for batteries in the Seychelles based on data obtained from distributed surveys. Total amount of battery waste per year: 56.584 tons.

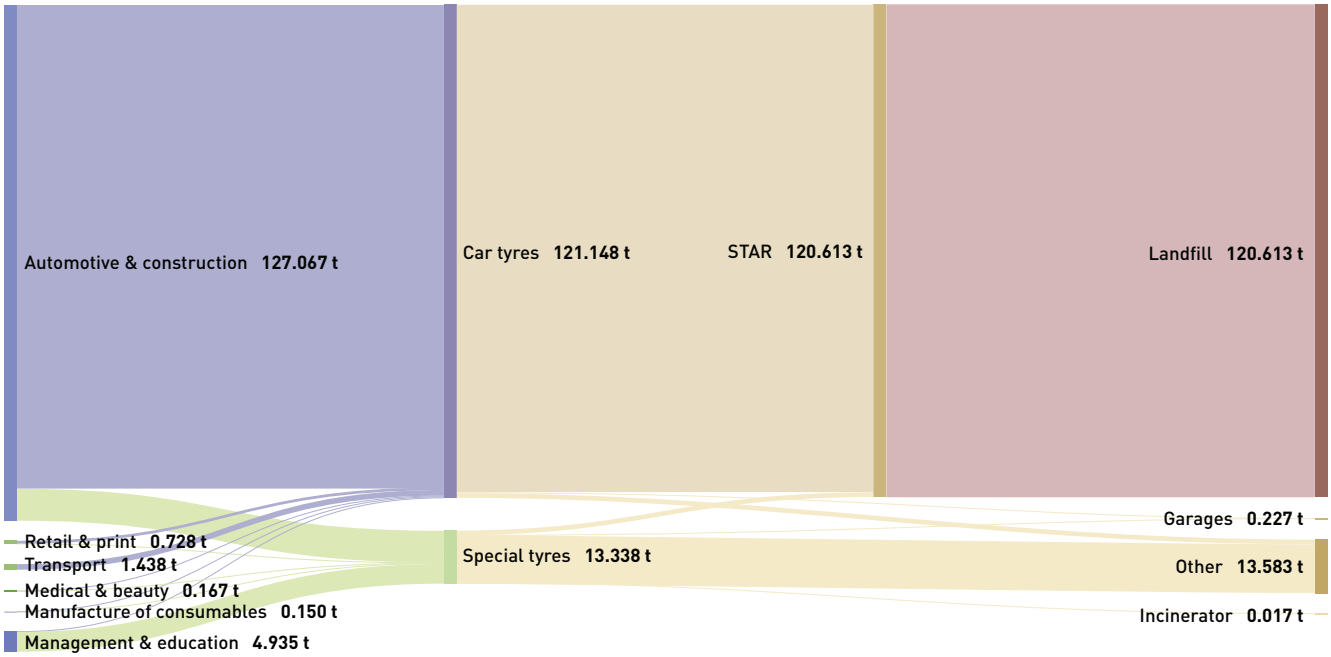

Figure 3.10
Sankey diagram displaying the HW streams for waste tyres in the Seychelles based on data obtained from distributed surveys. Total amount of waste tires per year: 280.154 tons.

3.4 Discussion

In this section we will first evaluate the quality of the data obtained. Subsequently, the encountered strength and weaknesses of the current HW management system on the Seychelles will be discussed based on both observations made during the field study and information provided in the stakeholder interviews.

3.4.1 Data Quality

Questionnaire data

The obtained data are based on the responses of 96 companies. It must be pointed out, that the responses given were often not based on well-documented data but rather on personal estimations. Moreover, it must be taken into consideration that HW is a sensitive topic (since subjective to fees) and that the data provided might thus be subject to whitewashing.

To the best of our knowledge about 1,800 companies as well as additional 100 governmental bodies are currently registered in the Seychelles' business registry, implying that we overall covered about 5% of all enterprises. Given that we specifically focused on those types of industries that are potential HW generators plus that we not only covered companies from multiple different sectors but also of various sizes to get a more holistic overview and that we especially aimed to cover as many of the most important stakeholders (i.e. IOT, SEYPEC, Penlac, SPTC) in our data set as possible, we are nonetheless confident that our data provide a first reasonable overview of the most important HW streams on Mahé.

HW permit data

In terms of the obtained permit data, we would like to stress that there were only few data available for the period prior to 2016. Especially striking is the fact, that for both 2014 and 2015 not a single permit was available implying that either no permit was issued or the provided data were incomplete. Although no data prior to 2016 were deployed in this study, this aspect raises the question about overall data consistency independent of the timespan.

Export data

One drawback with respect to the export data is that they only report the maximum allowance for waste oil or battery scrap metal respectively. For this reason, the data given in the permits were replaced by more precise data, reporting the actual export volume instead of the allowance level, obtained during personal interviews whenever possible. A second aspect that requires attention is the fact that the export data for batteries are solely based on the quantities provided by the contacted collectors. To the best of our knowledge, there are however other exporters which are not covered in these data and that the estimated quantities might, therefore, be underestimated.

3.4.2 HW Handling in Seychelles – Strength and weaknesses

Throughout the study, we found that relatively neat systems for the handling of waste oil, clinical waste, and batteries in Seychelles are in place. Several indicators (e.g. the increased number of HW permits issued which most likely stems from better enforcement) are pointing towards a continuous improvement of the HW management. It was pleasing to find that the Health Care Agency incinerator is working well, and that its service is being used by many of the private clinics and pharmacies on Mahé.

Despite these positive aspects, the overall HW management system remains 'messy' and requires fundamental improvements in the nearby future. In the following some main obstacles or shortcomings of the current HW system in Seychelles (which were either observed directly or emphasized during stakeholder interviews) will be briefly discussed.

First, a clear, widely acknowledged definition of HW is missing. Currently different stakeholders regard different kinds of waste as hazardous or not (e.g. tyres, asbestos). The amount of waste classified as 'hazardous' arriving at the landfill STAR weighbridge likely falls far behind the true amount of HW disposed of here. Although only covering about 124 companies, our analysis recorded an average yearly amount of about 42 t chemical waste of which about 39 t are directed to STAR – this value alone clearly exceeds the 16 t HW recorded at the STAR weighbridge. Several stakeholders have suggested the waste identification and classification at the landfill being an important problem that could, at least partially, explain this observation.

Second, clear guidelines for handling hazardous wastes especially regarding their final disposal are lacking. For instance, to date no appropriate procedure for disposing off lithium-ion batteries or radioactive parts of medical equipment has been established.

Third, Seychelles has to face specific HW materials that arise due to its peculiar position of a SIDS with a very large industrial fish industry. In the operation of refrigerating systems for example, large amounts of ammonia tainted oils are produced. To date there is no adequate disposal solution / procedure / facility. The oils cannot be exported and are not accepted for recycling by SEYPEC – they pose a particular problem to industries dealing with the manufacturing of consumables (e.g. in the fish processing industry). Several companies indicated on our survey that the material is being stockpiled in drums until a solution is found.

Fourth, a major challenge is the disposal of chemical laboratory waste, for which there is currently no handling system in place. According to our survey, the major fate of chemical waste is the landfill which is clearly not suited for such disposal. There is a strong need for a central storage facility for chemical waste in Seychelles, accepting material from industry as well as the major laboratories (Seychelles Bureau of Standards, IOT, Seychelles Fishing Authority, Seybrew etc.). There are various options for the treatment (and partially recycling) of hazardous waste, whose feasibility is however questionable in Seychelles given the SIDS nature. Hence, a safe and leak-proof central stockpile preparing chemical waste for export is desirable. Such a storage facility would also greatly increase the sustainability of the already in place vehicle lead battery export system: since batteries are required to be empty prior to export, their acid has to remain on the islands. It is currently neutralized with coral sand and disposed at the landfill, hence constitutes a significant risk for heavy metal contamination.

Fifth, the operators of the Victoria Hospital incinerator indicated that some of the private clinics and pharmacies are reluctant to have their material be burnt since the new system (a fee per kg instead of a general fee for the whole delivery) is in place. It does occur that stakeholders are unwilling to pay and hence dispose of their clinical and pharmaceutical waste in a different way (i.e. the landfill). To prevent such hazardous waste dumping, a new system (e.g. a mandatory waste incineration fee for all stakeholders engaged in medical activities independent of the final waste volume) could be considered.

Sixth, the currently used permit form either requires to be updated or there needs to be proper instructions on when to use it (e.g. there is a strong need to introduce additional forms for instance regarding expired food waste). Directly linked to this aspect, one must point out that the HW system is subject to a significant amount of miscommunication as is

strikingly highlighted by the following examples: the MEECC was not informed that the LWMA was using the Basel forms to fill out permits for the disposal of expired food and drinks, as well as glass. Additionally, the MEECC claimed that the incinerator at the hospital is overrun hence no further permit material was going to be sent there for destruction. This statement was however denied by the Health Care Agency according to whom the incinerator is working properly. A third example in this respect is that the Seychelles Bureau of Standards mentioned that their waste oil goes to PUC, although PUC informed us that they do not receive any waste oil from outside the company. It should be noted, that this latter issue might be easily overcome by fostering the communication between the involved stakeholders e.g. through bringing them together at a roundtable.

Finally, it was noted in several interviews that people are not properly trained to work with hazardous wastes. They, for instance, do not wear proper clothing and are generally unaware of safe handling (e.g. not sufficiently labelled) and storage of the HW. The HW management lacks both strong enforcement as well as sufficient monitoring schemes. An illustrative example is that asbestos was still being imported in 2012 although officially banned in 2009. Disposal controls are lax and do not ensure adequate protection of Seychellois environmental health.

3.5 Conclusion

HW covers only a minor share of the overall waste stream in Seychelles. It however requires a disproportionally higher amount of attention, given the risks it holds for human health, ecosystem integrity and finally economic prosperity.

This study compiled data from a variety of sources, from official governmental agencies over private backyard workshops to multinational companies, aiming at producing an overview of HW flows on Mahé. It yielded a first good overview of how the situation of HW in the Seychelles presents itself and how it is currently managed. The obtained data reveal some weaknesses (e.g. uncertainty in survey results, gaps between data from various sources), however, we are confident that the given results are a first approach to improve the understanding and the management of the current HW system especially regarding the sources and sinks of this waste stream. This analysis has revealed considerable inconsistencies of information and a clear lack of complete records in the HW streams. The Basel permits were introduced with the objective to form a central node for all hazardous materials in Seychelles, with the MEECC being capable to trace and direct every volume of waste that holds the risk to harm environmental or human health. This system is not working perfectly; the Basel permits are to date not a central node for the Seychellois HW streams.

Further, we identified a lack of clear HW disposal guidelines and an overall absence of monitoring as well as enforcement mechanisms. Lastly, there is a need for hands-on education and training and for a clear assignment of responsibilities in hazardous waste handling.

Our study provides a baseline which should be expanded with more in-depth work. In particular, we think that further companies are to be targeted to complete the picture. In addition, also households should be targeted by the waste managers since multiple small amounts of HW such as batteries, expired cleaning detergents etc. can pose a major hazard when regarded collectively.

Small Island Developing States such as Seychelles are, by nature, facing a very particular challenge when it comes to the management of hazardous substances. Such substances require an elaborate, well-managed system of transport and disposal facilities including sophisticated treatments and most importantly clear monitoring. In the Seychelles, very substantial efforts have been made by various stakeholders trying to ensure a safe HW handling. Multiple mechanisms and structures are in place already, nevertheless, it is evident that this system is one still in the making. It is essential that this system is brought further in the near future meaning that HW should become an integral part of the Seychelles overall waste management strategy.

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4
Waste treatment I: Anaerobic digestion

Giulia Manzolini, Cédric Furrer*, Fiona Hornung*, Brian Souyana**, Annie Vidot***

4.1 Introduction

An essential part of all waste is organic, which means that the material can be broken down into basic molecules (e.g. carbon dioxide, water) by organic processes carried out by bacteria, fungi and other microorganisms (Vögeli, 2014). In the Seychelles, organic waste currently ends up untreated in the landfills, leading to a polluting leachate and bad odours by methane emissions, which pose a risk to both the environment and human health (Alcindor et al., 2016). On the other hand, organic waste contains valuable nutrients and potential energy which can be extracted in the form of various outputs, depending on the waste fractions and the chosen process. However, characteristics of the local economy as well as social and environmental properties determine and eventually limit the choice of treatment options. Often the most feasible option is not a single treatment process but a combination of treatment processes (Schleiss, 2018). In the following, we present three options to treat organic waste: (1) composting, (2) insect larvae driven waste transformation, and (3) anaerobic digestion. All three processes require an ambient temperature above the freezing point with an optimum at 15–35°C. The feedstock option can consist of fruit and vegetable waste, fish and meat waste, and/or animal manure (Mertenat, 2018).

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(1) Composting is a well-known and often utilized process to treat organic waste. During this aerobic microbiological process (i.e., under oxygen consumption), organic material is degraded into compost. During this process, the input is reduced to roughly 60% of its initial mass. Compost is a stable soil like material, which improves the soil structure and increases its nutrient availability (Schleiss, 2018).

(2) A lesser known option is to feed the organic waste to Black Soldier Fly (BSF) larvae. These insect larvae grow and hence degrade organic material aerobically. The products are the larvae themselves which are rich in proteins and fat, and a compost-like residue which can be used as soil enrichment. The larvae can be sold in various forms, for example, as animal meal or pellets (Dortmans B.M.A., 2017). More information about the process and further studies can be found in Appendix 4.4.

(3) Anaerobic Digestion (AD) is the microbiological degradation of organic waste under the absence of oxygen. The volume of the initial input material is reduced up to 20%. The outputs of the process are heat, biogas and digestate. The biogas mainly consists of carbon dioxide (CO_2) and methane (CH_4) in a rough ratio of 40:60. The methane fraction can be used as cooking gas or converted into electricity. In general, the digestate, which is the solid and/or liquid material remaining after undergoing anaerobic digestion, is often still rich in nutrient content and therefore is used as fertilizer (Vögeli, 2014). According to experts from the University of Applied Science of Zürich (ZHAW), the digestate could alternatively be post-composted and used as landfill cover (Alcindor et al., 2016).

We focus our work on anaerobic digestion. A study by our colleagues of the transdisciplinary case study (tdCS) 2016 showed that as composting is a very well-known and widely applied technology in the Seychelles, it does not need further attention (Alcindor et al., 2016). Moreover, this study revealed that feedstock is available that could feed into the AD stream. The goal of this study is to provide an analysis of capital investment and operational costs (CAPEX and OPEX) as well as the revenues from a hypothetical AD plant. We expand the findings of tdCS 2016 by adding to the conventional revenues of an AD plant, which mainly consist of revenues from sales of the fertilizer, BSF larvae (fed on the digestate from the AD), and post-composted digestate as landfill cover.

The following research questions guided us through our work:

- Which organic waste streams could be used as input for an AD plant and what output can be expected?
- Which AD plant size would be suitable for the existing inputs? Which are its related capital investment (CAPEX) and operational costs (OPEX)?
- The revenues of which products lead to favourable conditions for an economically feasible AD plant in the context of Seychelles?

4.2 Material and Methods

As a first step, we conducted an extensive literature research to identify possible organic waste treatment technologies and to understand the principle foundations of the underlying processes (for details see Appendix 4.2 and 4.3). Interviews with experts in the field of organic waste management (lecturers at ETH Zürich, from ZHAW and Sandec (EAWAG); for a full list of interviews see Appendix 4.1) gave insights about which AD configuration to choose. In a next step, we constructed different scenarios and evaluated their profitability. Main procedures and assumptions of the study as well as underlying detailed values and used formula are summarized in Appendix 4.6 – 4.9 or are available on request.

Figure 4.1 shows schematically the five-phase procedure followed in our study (light blue boxes): sources, inputs, process, outputs and products. First, we identified the possible sources of organic waste and their different amounts as well as combinations of different classes that could represent the inputs for the AD plant (4.2.1–4.2.3). This facilitated a prediction of the possible future development of organic waste sources as well as the construction of the different scenarios. The following phases consisted of calculations of process (4.2.4), outputs (4.2.5) and products (4.2.6) for the different scenarios constructed in the initial phases. Finally, possible major costs and benefits were assessed in order to give an estimate of the economic feasibility of an AD plant (4.2.7).

4.2.1 Analysis of landfill data

Data from the landfill regarding the composition of the waste formed the backbone of our study and was indispensable for estimating the potential of AD on the Seychelles. STAR provided us with information of load and origin of trucks on Providence landfill during 2012–2017. Contents of incoming truck load at the weighbridge by STAR staff is classified according to the classification system of the Landscape and Waste Management Agency (LWMA) (Table 4.1).

Table 4.1
LWMA Waste Classes (2018).

1.	Municipal solid waste (MSW)
2.	Commercial waste
3.	Green Waste
4.	Liquid Waste
5.	Mixed Waste
6.	Metal waste
7.	Putrescent Waste
8.	Waste oil
9.	Construction waste
10.	Inert waste
11.	Hazardous Waste
12.	Others

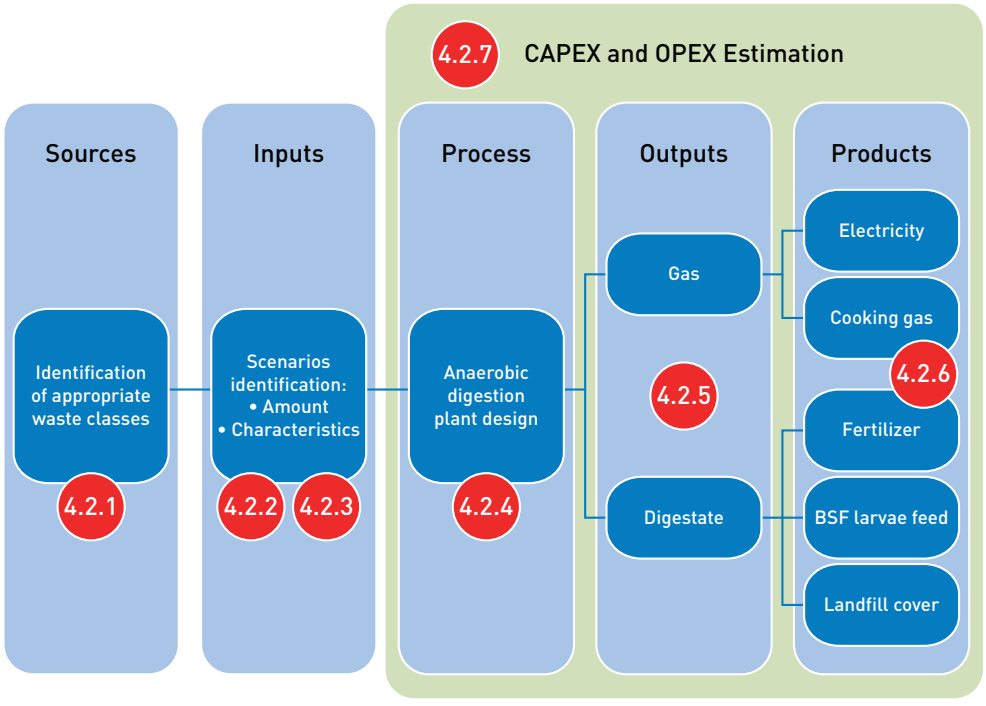

Figure 4.1
Procedure overview: the red numbers refer to the specific section in which we discuss the topic of corresponding blue boxes. The box in light green refers to the phases for which costs and benefits were evaluated.

Based on this classification and interviews with the respective responsible persons, we assessed which waste classes are most suitable as potential inputs for the AD plant. Crucial criteria in this regard are the presence of organic fractions, its separability from the rest, and its value for the AD process. Our calculations are further based on the characteristics of the organic fraction as determined by Alcindor et al. (2016) and a recent study from 2012 (Source confidential).

4.2.2 Scenario construction

To consider different future developments of organic waste, we evaluated four different combinations of organic waste sources to use as a feedstock for the AD plant. We then combined the different combinations in four different scenarios of future organic waste treatment system. Each scenario includes a set of the following variables:

- Waste collection system (e.g. households organic waste recycling)
- Co-existence with other technologies (e.g. composting of green waste)
- Extension of the sewage system (i.e. increased sludge production)
- New future sources of organic waste (i.e. aquaculture project)

Each scenario comprehends a variable percentage (0–100%) of each waste class considered and may include additional classes over time if expected.

We developed the scenarios based on insights we gained from interviews with local stakeholders. In total, we conducted more than 20 interviews with representatives from the government and the private sector (for a full list of all interviewed experts see Appendix 4.1). Interviews were semi-structured using individual questions for all interviewees. Further aspects such as the fluctuation and discontinuity of economic and population growth are not considered in this study.

4.2.3 Calculation and modelling inputs

Subsequent to the construction of the scenarios, we specified and modelled the amounts and characteristics of organic streams in the different scenarios.

As a first step, we calculated the total input as the sum of all the waste classes for each scenario at the beginning and at the end of the operating period of a possible AD plant. These calculations are based on the initial amount (tons/day) of each stream (e.g. hotel food waste from class 2) that goes to the landfill.

Total Solids (TS)

"When a water or sludge sample is filtered and dried at 105°C, the residue that remains is referred to as Total Solids. It is measured in mg/L (mass per volume) or as a percentage of wet weight. Moisture content plus TS (both expressed as percentage of wet weight) equal 100 per cent" (Vögeli, Lohri, Galalrdo, et al., 2014).

Volatile Solids (VS)

Volatile solids is "[...] the organic matter in a sample, usually expressed as a percentage of the Total Solids" (Vögeli, Lohri, Gallardo, et al., 2014).

Biochemical Methane Potential (BMP)

This parameter expresses the quantity of biogas/biomethane potentially available from the degradation of a biomass and is expressed as Nm^3/kgVS, that is, normal cubic metres of biogas or methane per kg of volatile solids. (Soldano et al. 2012).

In a next step, we calculated the main parameters, which describe the input characteristics for the different scenarios (total solids (TS), volatile solids (VS), and theoretical bio-methane production (BMP)). These calculations are based on the amounts (tons/year) expected per each waste category. Based on literature references (Deublein and Steinhauser, 2011) we used three different possible values of

each parameter (maximum, average, and minimum). This enabled us to analyse the whole value range. Subsequently, we calculated for each waste input mix of each scenario the weighted average value[1]. For details see Appendix 4.6 and 4.7.

It is important to emphasize that the presented procedure also includes assumptions. Foremost, we assumed a 20 year operational time of the AD plant, starting 2022 at the earliest. Furthermore, we assumed a planning and construction period of 5 years (C. Zurbrügg, personal communication, June 1, 2018; M. Benoiton, personal communication, July 09, 2018). Moreover, only the initial expected load (2022 – start of operating time) and the final expected load (2042 – end of operating time) and its corresponding parameters were calculated. This was done in order to have an estimation of the increase in volume required for the treatments and in outputs. The increase in volume implies different strategies for the investments. This means, we either dimension the plant for capacity at the beginning and plan a future extension or we plan to promptly build a plant capable of treating the expected amount of waste until the end of its life span. In our study, we did not assess the latter approach

4.2.4 AD Plant design

We used the results from the previous step as a base for the calculation of the AD plant dimension. The most important assumptions we made in this regard are explained in the following.

For the hypothetical AD plant, we assume a centralized one-stage system. This means that the whole AD process happens in one container. Further on, it is a mesophilic (25–40°C), wet (TS, total solids, content <16%) system. 10–12% TS is defined as the optimum for a wet system (Schleiss, 2018; C. Zurbrügg, personal communication, June 1, 2018). Based on the initial waste load TS content, dilution with water (Q_{H2O} m^3/day) was applied if necessary. A pH of 6–7.5 needs to be maintained throughout the whole process (Mertenat, 2018). The total flow (Q_{in-tot} in tons/day) was then defined as sum of Q_{H2O} and Q_{in}. For all the calculations the density of the input was considered as 1 t/m^3.

Following, and based on, the process of defining inputs (Sections 4.2.1–4.2.3), we identified the most feasible and appropriate design for an AD plant. In particular, we calculated the following design parameters: volume[2], height, diameter and number of the reactor(s), the organic load rate (OLR)[3], and the theoretical volume reduction of the input. See Appendix 4.8 and 4.9 for the parameters and formulas, respectively.

4.2.5 Modelling of outputs

As a next step, we calculated the outputs (gas and digestate) for each scenario, based on the following assumptions (for the formulae see Appendix 4.10 and Tables in Appendix 4.11):

- Both the AD plant and the Combined Heat to Power (CHP) (see Appendix 4.3 for the technology description) will be operating throughout the year 24/7. Stops for maintenance or other reasons were not considered.
- The degradation factor for the volatile solids (VS) is 0.7 (Deublein and Steinhauser, 2011).

1 The characteristics of the final mix is defined according to the average resulting from different classes. E.g.: 1 kg of class 1 with total solids (TS) 80% and 2 kg of class 2 with TS 90%. Mix = 3kg (class 1+2 mixed to the AD). Mix TS = (0.80*1 + 0.90*2)/3 = 87%

2 Active volume of the reactor which is needed to have the necessary capacity for treating the input. V= Q(m^3/d) of input * Retention Time (required for the plant = 30 days)

3 The organic load rate (OLR) is the load of organics that the reactor receives per unit of volume. It is a parameter which has to be within a specific range in order to reach an optimum process performance. OLR = kg oTR/ m^3 * d = kg VS (organic) / (d * Volume)

4.2.6 Modelling of products and connected technologies

AD is a process that converts organic waste into digestate, gas and heat. The final market products, however, are fertilizers (liquid and solids), BSF larvae feed, landfill cover, electricity, and heat. Therefore, the next step, after the calculation of the raw output produced, was the estimation of the possible final products of the plant. We analysed the amounts produced with the following treatment technologies:

- CHP generator, to convert the biogas into electricity (more information can be found in the appendix 4.3)
- Biogas-upgrading, to purify the biogas to a methane-rich gas, which can then be used as cooking gas
- Post-processing of digestate to profitable solid and/ or liquid fertilizer
- BSF, to feed the AD digestate to BSF larvae which can further on be processed into different products, such as pellets or animal meal (see Appendix 4.4 for the process description)
- De-watering and post-composting, to use the digestate as landfill cover

Again, we had to make some assumptions in order to be able to carry out the calculations (see Table 4.2 for the assumptions and Appendix 4.11 for the underlying formulas).

The biogas output of the AD process is composed of CH_4 and CO_2 in a methane/ carbon dioxide ratio of 55–70/30–45%. The calculation was based on the theoretical bio-methane production (BMP) values of the respective waste input fractions (see Appendix 4.6).

Moreover, the above mentioned 10% losses for the CHP technology refer to the initial biogas energy potential losses, since we assume that 40% goes to electricity and approximately 50% to heat – although, the electricity conversion rate depends to a very great extent on the quality or type of technology used (Deublein and Steinhauser, 2011).

Table 4.2
Assumptions for products amount.

Parameter	Unit	Value	Source
Biogas quality	% of total gas	55 – 70	Deublein & Steinhauser, 2011
Calorific value of biogas	kWh/m^3	6.0 – 6.5	Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014
Electricity demand AD plant per treated biowaste	kWh/t	2.135	Zschokke & Schleiss, 2016
Electricity demand Seychelles	GWh/year	424	Seychelles Energy Commission
Electricity conversion rate	%	40	Deublein & Steinhauser, 2011
Final conversion rate per m^3 biogas	kWh/m^3	2.4	Deublein & Steinhauser, 2011
Efficiency in heat conversion (CHP technology; 10% losses)	%	50	Deublein & Steinhauser, 2011

4.2.7 Capital costs, operational costs and revenues estimation

The final stage consisted of the estimation of the investments (CAPEX), operation and maintenance costs of the plant (O&M for AD plant), and operational costs for final products processing (OPEX) as well as the possible revenues from sales of the outputs and final market products. They were analysed separately for simplification. Thus, we did not perform a complete cost/benefit analysis. The net revenues (max, average, and min) were calculated for the different scenarios at the beginning and end of life of the AD plant.

For the economic analysis, we assumed a balloon or flat top configuration and a plant's life span of 20 years, as suggested by experts (interviewed ZWHA lecturers, 2018). Feedstock transport to the plant was not accounted for in our feasibility study. No price increases over the operational time were calculated. Price base is 2018.

For details of CAPEX and OPEX and REVENUES calculations see Appendix 4.13–4.15.

First, we present results concerning the usefulness of the present organic waste classes as feedstock for an AD plant. We then present our market analysis for the final products of an AD plant and the landfill data analysis. The chapter is rounded off by a comparison of the different scenarios.

4.3 Results

3.1 Waste classes

Potential organic waste streams come from different classes. Those shown in Table 4.3 were initially considered as potential organic waste streams. The last two columns give an overview of which part of the waste classes should be in-/excluded and why.

Table 4.3
Waste classes with organic waste. Cells highlighted in green, in column 3, refer to organic components used in the calculations.

Waste Class	Organic waste in the form of	Considered share for AD feedstock	Reason for exclusion
1: Organic fraction of MSW (OFMSW)	Kitchen residues, garden trimmings, cellulose packaging	Kitchen residues	Cellulose packaging is excluded; it reduces the biogas yield of the system
2: Industrial and commercial waste	Kitchen, green, cellulose packaging	Hotels kitchen residues	Cellulose packaging is excluded; it reduces the biogas yield of the system
3: Green waste	Tree trunks, garden trimming	Not considered	More suitable for composting
4: Liquid waste	Fish waste, PUC sewage sludge	All	If engine oil or other inorganics were present these must be excluded
5: Mixed waste	Wood, Cellulose, Kitchen	Not considered	Small amount and mainly construction waste (inorganic materials) and wood and cellulose based materials/packaging (organic suitable for composting)
7: Putrescent waste	Animal carcasses from fish processing companies	All (assuming a significant fraction of fat, blood etc.)	If mainly bony a lower yield should be considered
8: Waste oil	Kitchen oil	Not considered	Considered a very little stream; although, kitchen oil has a great potential in AD processes

Waste classes 1, 2, 4, and 7 include appropriate organic feedstock for AD. Waste class 3, green waste, is principally possible feedstock for AD, however, the expected amount is rather small and more appropriate for composting. Waste class 5 (mixed waste) contains of 5% kitchen waste, which does serve as AD substrate (Source confidential). However, separating that fraction from the rest of the waste necessitate a significant amount of labour and is therefore potentially very costly. Due to this fact, we excluded waste class 5 from our further assessment.

The current handling of kitchen oil (if there is any) is unclear. Therefore, and due to simplicity, we also excluded waste class 8 from our assessment. However, if kitchen oils were available, it would be a very valuable feedstock for AD, because of its high BMP. Further investigations are warranted, especially to understand the feasibility of pre-sorting and collection of it from large scale producers (e.g. restaurants, hotels, etc.).

Class 9, 10, 11 and 12 are construction and demolition, inert, hazardous, and special waste. As their organic content is negligible, we excluded these waste classes from our assessment.

4.3.2 Potential demand for products

Electricity

Electricity demand is increasing 4% per year but cannot be covered by further installation of renewables such as wind and solar (T. Imaduwa, C. Alexander & Guilly Moustache, personal communication, July 06, 2018). Hence, an additional renewable energy production is of interest.

Cooking Gas

More than 70% of consumers use liquefied petroleum gas (LPG) as energy carrier (LWMA, 2018). However, the demand is already fully satisfied by Seypec, which currently is selling 13 tons of LPG per day (Seychelles Petroleum Company (S. Romain. personal communication, July 09, 2018). Although biogas from AD could potentially compete with or replace LPG, this option was not considered further.

Fertilizer

Demand for liquid fertilizer is low in the Seychelles. Production would far exceed the demand which is why most of the liquid fertilizer produced would have to be exported. Solid fertilizer demand (more specifically, the demand for urea) exists but it is too low for a potential supply from an AD plant. However, most of solid fertilizer would have to be exported due to low domestic demand.

BSF larvae

BSF larvae have multiple local markets, of which the perhaps most promising one is chicken breeders. According to interviewed farmers, production of chicken is on the rise. In Seychelles, they buy their feed in 50 kg bags for 333 SCR (approx. $25). 10,000 chickens consume 20 bags per day, which gives 100 g of feed per chicken per day. Hence, the demand is high, and BSF larvae production could contribute to a local market. However, quality of the meal from BSF larvae can vary significantly. The higher the protein content of the waste input, the better the product (larvae) is. Besides chickens, BSF larvae could also be used to feed fish. Our research has shown, that the demand in this market has similar potential as that of the chicken breeders. In addition to the national market there is also a demand for BSF larvae as fish food on the international market. For example, Indian Ocean Tuna (IOT) is currently selling

their produced fish meal at $1,000/t and roughly 95% is exported to international markets (M. Benoito, personal communication, July 09, 2018).

Landfill cover

Solid digestate has the potential to substitute coral sand, which is currently used to stabilize the landfill while deposing waste. Moreover, it could act as multi-layers' bio-filter and help to reduce the landfill environmental impact. However, solid digestate as a landfill top cover layer will most probably not be possible, as solid digestate as such will not present a good substrate for re-cultivation (U. Baier, personal communication, May 2018).

3.3 Analysis of landfill data

As landfill data of 2017 were not available, we did our calculations on the LWMA data base from 2016 (Table 4.4). The following analysis only represents those waste classes that are, in our opinion, potential feedstock for AD (see Table 4.3).

Waste classes 1 and 2 only consist of the waste fraction defined as 'Kitchen'. We excluded the other fractions in our analysis on the grounds explained in Section 3.1.

The organic waste by IOT is neglected for this study, as IOT recently opened its own waste water treatment plant (WWTP) and AD plant to process all its organic waste. Accordingly, we included sewage sludge from PUC only (LWMA, 2018).

According to local wastewater treatment plant experts, landfilled sewage sludge at Providence has a cow dung-like structure, with a total solid (TS) content above 11% in the AD process (even >16% which is the limit for a wet system). After dewatering, the sludge becomes gelatinous and since, in the present context, we assume a wet system, this texture needs to be avoided. Therefore, the sludge needs to be diluted. The PUC belt press, which dewaters the sludge, has an efficiency of 80 % and we assume an average of 13% TS content in the sludge (average of the literature values considered). We therefore assume a dilution factor of 3.3 to represent the total volume of sludge. These calculations should be an object of further investigations, since the TS content of the raw sludge is very unstable and the data not very transparent. We suggest detailed analysis on its TS and VS content.

Table 4.4
Calculation of potential feedstock quantities.

Description	Unit	Class 1 MSW + commercial	Class 2 Commercial /hotels	Class 4 Liquid	Class 7 Putrescent	Total
LWMA waste 2016 Source: LWMA (2018)	t/y	26,867	10,040	10,890	1,083	71,841
Considered fraction Source: LWMA		18%	25%	52%	100%	
Dilution				330%		
Potential AD feedstock	t/y	4,836	2,510	28,314	1,083	36,743
	t/d	13	7	78	3	101

4.3.4 The scenarios

Based on the analysis of landfill data, we created four different scenarios. Scenarios describe possible future development paths for organic waste production, collection, and treatment systems. The four scenarios in this report differ in their assumptions about the development of organic waste volumes and the collection approach (Table 4.5).

In Scenario 1, organic waste from class 1 is not collected due to the lack of a pre-sorting and collection system. All other classes feed into AD. In Scenario 2, class 1 is collected and a population growth is accounted for while classes 2, 4 and 7 remain constant overtime (considering no increase in the production or collection). Scenario 3 accounts an extension of the sewage system and a subsequent raise in sludge production on top of the inputs of Scenario 2. Lastly, Scenario 4 adds to Scenario 3 the putrescent organic waste coming from the implementation of aquaculture plan, which is expected to produce an enormous amount of fish waste per year. The other classes are considered stable compared to scenario 3.

Table 4.5
Scenario overview. MSW: municipal solid waste; ✖ = not included; ✓ = included; ✓(=) = included but no change compared to reference data 2016; ✓(↑) = included and increase compared to reference data 2016; ✓(↑↑) = included and substantial increase compared to reference data 2016.

Storyline	Class 1 MSW + commercial	Class 2 Commercial /hotels	Class 4 Liquid	Class 7 Putrescent
1	✖	✓	✓	✓
2	✓(↑)	✓(=)	✓(=)	✓(=)
3	✓(↑)	✓(=)	✓(↑)	✓(=)
4	✓(↑)	✓(=)	✓(↑)	✓(↑↑)

Table 4.6
Organic waste streams of scenario 1.

Unit	Class 1 MSW + commercial	Class 2 Commercial / hotels	Class 4 Liquid	Class 7 Putrescent	Total
2022					
t/d (%)	0.0 (0)	6.9 (11)	51.2 (84)	3.0 (5)	61.1 (100)
2042					
t/d (%)	0.0 (0)	6.9 (11)	51.2 (84)	3.0 (5)	61.1 (100)

Scenario 1 – Commercial food waste and sewage sludge

Waste input

This scenario is based on the possibility that the organic fraction of Class 1 will not be separated in the future. This is considered as a possible option, as the willingness to separate and the implementation of a suitable collection system are uncertain factors.

The specific input streams of each waste class for scenario 1 and their amount of change in comparison to the present situation are presented in table 4.6. See Appendix 4.5 for the technical details concerning the characteristics of the stream.

Dimensioning

The design of AD plants, especially regarding volume, depends on the characteristics of the aforementioned input stream which are presented in Table 4.7 (see Appendix 4.8 for the procedure and the calculation).

Costs and revenues

We expect investments (CAPEX) for the full package in the approximate range of 14 to 31 million SCR (Table 4.8). This range is given by characteristics of the waste streams (max, mean, min). The costs are allocated as follows: AD plant (66%), CHP generator (33%), and centrifuge for digestate processing (up to 1%).

Operational and maintenance costs for the AD plant amount to 3.8 to 5.3 million SCR per year in the first two years. This includes foreign experts and training of local staff. From year 3 we expect that the

Table 4.7
AD dimensioning for Scenario 1. *Q_{out} = Q_{in} – volume reduction from the solid degradation. The reduction is low because the system is liquid. This means 10–12% of the Qin is TS content, of which only a part is or-ganic, and the rest is water. Hence the reduction is relatively low with only 6–8%.

		2022			2042		
Design parameters	Unit	Maximum	Average	Minimum	Maximum	Average	Minimum
Total volume of the plant	m^3	4,122	3,522	2,622	4,122	3,522	2,622
Number of reactors	—	3	3	2	3	3	2
Height of reactor	m	8	8	8	8	8	8
Radius of reactor	m	7	7	6	7	7	6
Total flow $Q_{out\ tot}$*	m^3/d	104	86	58	104	86	58
Volume reduction	%	6.5	5.4	4.9	6.5	5.4	4.9
Organic load rate	kg VS/m^3*d	3.1	2.6	2.3	3.1	2.6	2.3

Table 4.8
CAPEX, OPEX, REVENUES (in million SCR) of Scenario 1 (Constant input).

Year (of life)	Start (2022)			End (2042)		
Range (based on waste characteristics)	Maximum	Average	Minimum	Maximum	Average	Minimum
Capital expenditure (CAPEX)						
	31.0	19.0	14.0	31.0	19.0	14.0
Operational expense (OPEX) & Maintenance costs of AD plant						
Year 1 & 2	5.3	4.6	3.8	5.3	4.6	3.8
From year 3	1.9	1.4	1.1	1.9	1.4	1.1
OPEX (–) and REVENUES of products **with** export of fertilizers						
OPEX	–10	–13	–14	–10	–13	–14
REVENUES	25	19	19	25	19	19
Net benefit	15	6	5	15	6	5
OPEX (–) and REVENUES of products **without** export of fertilizers						
OPEX	–3	–2	–2	–3	–2	–2
REVENUES	17	6	5	17	6	5
Net benefit	14	5	3	14	5	3
Electricity production						
GWh/a	7.40	2.06	1.13	7.40	2.06	1.13
% of the electricity demand	1.74	0.49	0.27	1.74	0.49	0.27

Note: These numbers are only estimates and do not include any price changes (deflation, depreciation, etc.).

plant will be run by local experts resulting in much lower annual operational cost of 1.1–1.9 million SCR (Table 4.8).

As a last step, we calculated operational costs (OPEX) and REVENUES of products such as electricity, fertilizer (solid & liquid), Black Soldier Fly Larvae, and landfill cover. This results in net benefit of 5 to 15 million SCR for the situation which includes export of fertilizer. The export of fertilizer is a decisive factor in terms of net costs/benefits. Accordingly, in scenario 1 revenues decrease substantially under this condition as Table 4.8 indicates.

Table 4.9
Organic waste streams of Scenario 2. The growth rate in class 1 is based on population growth. The growth in population, however, does not affect the other waste classes.

Unit	Class 1 MSW + commercial	Class 2 Commercial / hotels	Class 4 Liquid	Class 7 Putrescent	Total
2022					
t/d (%)	14.6 (19)	6.9 (9)	51.2 (68)	3.0 (4)	75.6 (100)
2042					
t/d (%)	19.90 (25)	6.9 (8)	51.2 (63)	3.0 (4)	80.9 (100)

Scenario 2 – Including organic waste from households

The second scenario represents the case in which the organic fraction (food/kitchen waste) of Class 1 (municipal solid waste (MSW) & commercial waste) is separately collected (Table 4.9). This is an option under the condition that a respective collection system is implemented and accepted by the local population. This scenario would reduce the volume of landfilled organics significantly. Moreover, this scenario includes the assumption of a high population growth (Mangroo and Wälchli, 2016),which would imply a linear increase of 0.27 t/d of the organic fraction of Class 1[4].

Dimensioning

Table 4.10 provides information of the AD plant design for Scenario 2.

Costs and revenues

For scenario 2 we expect investments (CAPEX) for the full package in the approximate range of 18.7 to 53.4 million (Table 4.1).

Operational and maintenance costs for the AD plant of scenario 2 amount to 4.3 to 7.5 million SCR per year (2022) in the first two years and 1.3–2.4 million SCR from year 3 (2022) (Table 4.11).

(OPEX) and REVENUES of products results in net benefit of 15 to 28 million SCR (2022) for the situation which includes export of fertilizer and 4–22 million SCR (2022) without export of fertilizer (Table 4.11). For details see Scenario 1.

Scenario 3 – Extension of the sewage system

Waste input

The third scenario describes a situation in which the organic fraction of Class 1 (municipal solid waste (MSW) + Commercial waste) is separated and the extension of the sewage system will be implemented as planned (Table 4.12). The latter means the extension of the currently running waste water treatment plant (WWTP) at Providence (it will treat approximately additional 2000 m^3/day) and the further installation of a WWTP in Ile Aurore. The assumptions of Scenario 3 imply a linear increase of 1% per year (approximately 1 t/d) of the organic fractions. This increase in input material is based on the assumption that an increasing amount of houses are connected to the sewage system. Although this development is very likely, we cannot support the statement with data because there are none.

4 Based on the scenario presented by Mangroo and Wälchli (2016), we assumed for this scenario a high population growth from 92,000 in 2016 to 103,000 in 2040, which corresponds to a growth of approximately 480 people per year. Furthermore we assume that the production of waste per person will remain 2kg/d and that the content of organics as well will not change (27.7%) Yearly increase= 480 people *2kg/(day *person) * 0,001 (tons/kg) * 0.277 kgOrgan/kgMSW = 0.27 tons/day

Table 4.10
AAD dimensioning for Scenario 2. For details see Table 4.7.

		2022			2042		
Design parameters	Unit	Maximum	Average	Minimum	Maximum	Average	Minimum
Total volume of the plant	m^3	4,669	3,469	2,269	5,128	3,628	2,428
Number of reactors	—	3	3	3	3	3	3
Height of reactor	m	8	8	8	8	8	8
Radius of reactor	m	8	7	7	8	7	7
Total flow $Q_{out\ tot}$	m^3/d	145	109	72	159	113	77
Volume reduction	%	7	6	4.9	7.2	6.4	4.9
Organic load rate	kg VS/m^3*d	3.3	2.9	2.3	3.4	3.0	2.3

Table 4.11
CAPEX, OPEX, REVENUES (in million SCR) of Scenario 2.

Year (of life)	Start (2022)			End (2042)		
Range (based on waste characteristics)	Maximum	Average	Minimum	Maximum	Average	Minimum
Capital expenditure (CAPEX)						
	48.0	27.0	17.0	53.0	28.0	19.0
Operational expense (OPEX) & Maintenance costs of AD plant						
Year 1 & 2	7.5	5.9	4.3	8.1	6.1	4.6
From year 3	2.4	1.8	1.3	2.6	1.9	1.4
OPEX (–) and REVENUES of products **with** export of fertilizers						
OPEX	–13	–16	–22	–13	–17	–23
REVENUES	41	31	37	45	32	40
Net benefit	28	14	15	32	15	17
OPEX (–) and REVENUES of products **without** export of fertilizers						
OPEX	–4	–2	–2	–4	–3	–3
REVENUES	26	8	6	30	9	7
Net benefit	22	6	4	26	6	4
Electricity production						
GWh/a	12.03	2.66	1.48	13.72	2.88	1.60
% of the electricity demand	2.84%	0.63%	0.35%	3.24%	0.68%	0.38%

Note: These numbers are only estimates and do not include any price changes (deflation, depreciation, etc.).

Table 4.12
Organic waste streams of Scenario 3.

Unit	Class 1	Class 2	Class 4	Class 7	Total
	MSW + commercial	Commercial / hotels	Liquid	Putrescent	
2022					
t/d (%)	14.6 (19)	6.9 (9)	53.8 (69)	3.0 (3)	78.2 (100)
2042					
t/d (%)	20 (21)	6.9 (7)	64.0 (68)	3.0 (3)	93.7 (100)

Table 4.13
AD dimensioning for Scenario 3. For details see Table 4.7.

		2022			2042		
Design parameters	Unit	Maximum	Average	Minimum	Maximum	Average	Minimum
Total volume of the plant	m^3	4,745	3,545	2,345	5,812	4,312	2,812
Number of reactors	—	3	3	2	3	3	2
Height of reactor	m	8	8	8	8	8	8
Radius of reactor	m	8	7	7	9	8	7
Total flow $Q_{out\ tot}$	m^3/d	147	111	74	180	135	89
Volume reduction	%	7.0	6.0	4.9	6.9	5.9	4.8
Organic load rate	kg VS/m^3*d	3.4	2.9	2.3	3.3	2.8	2.3

Table 4.14
CAPEX, OPEX, REVENUES (in million SCR) of Scenario 3.

Year (of life)	Start (2022)			End (2042)		
Range (based on waste characteristics)	Maximum	Average	Minimum	Maximum	Average	Minimum
Capital expenditure (CAPEX)						
	49.0	27.7	18	59.5	33.4	21.4
Operational expense (OPEX) & Maintenance costs of AD plant						
Year 1 & 2	7.6	6.0	4.4	8.9	7.0	5.0
From year 3	2.4	1.9	1.4	2.9	2.2	1.6
OPEX (–) and REVENUES of products **with** export of fertilizers						
OPEX	–17	–20	–25	–15	–20	–27
REVENUES	47	36	42	50	37	45
Net benefit	30	16	17	34	17	18
OPEX (–) and REVENUES of products **without** export of fertilizers						
OPEX	–4	–3	–3	–4	–3	–3
REVENUES	28	9	7	33	10	7
Net benefit	24	6	4	28	7	5
Electricity production						
GWh/a	12.25	2.72	1.50	14.83	3.20	1.73
% of the electricity demand	2.89%	0.64%	0.35%	3.50%	0.75%	0.41%

Note: These numbers are only estimates and do not include any price changes (deflation, depreciation, etc.).

Table 4.15
Organic waste streams of Scenario 4.

Unit	Class 1	Class 2	Class 4	Class 7	Total
	MSW + commercial	Commercial / hotels	Liquid	Putrescent	
2022					
t/d (%)	14.6 (14)	6.9 (6)	53.8 (50)	32.7 (30)	107.9 (100)
2042					
t/d (%)	20.0 (10)	6.9 (3)	64.5 (32)	111.8 (55)	203.1 (100)

The AD plant design for Scenario 3 resulting from the aforementioned input streams are presented in Table 4.13.

Costs and revenues

For scenario 3 we expect investments (CAPEX) for the full package in the approximate range of 18 to 49 million SCR (2022) (Table 4.14).

Operational and maintenance costs for the AD plant of scenario 3 amount to 4.4 to 7.6 million SCR (2022) per year in the first two years and 1.4–2.4 million SCR (2022) from year 3 (Table 4.14).

(OPEX) and REVENUES of products results in net benefit of 16 to 30 million SCR (2022) for the situation which includes export of fertilizer and 4–24 million SCR (2022) without export of fertilizer (Table 4.14). For details see Scenario 1.

Table 4.16
AD dimensioning for Scenario 4. For details see Table 4.7.

		2022			2042		
Design parameters	Unit	Maximum	Average	Minimum	Maximum	Average	Minimum
Total volume of the plant	m^3	7,736	6,236	4,736	16,594	15,094	12,094
Number of reactors	—	3	3	3	>3	>3	>3
Height of reactor	m	8	8	8	10	10	10
Radius of reactor	m	10	9	8	9	9	8
Total flow $Q_{out\ tot}$	m^3/d	239	194	148	512	471	378
Volume reduction	%	7.2	6.6	6.0	7.4	6.4	6.2
Organic load rate	kg VS/m^3*d	3.5	3.1	2.8	3.5	3.1	3.0

Table 4.17
CAPEX, OPEX, REVENUES (in million SCR) of Scenario 4.

Year (of life)	Start (2022)			End (2042)		
Range (based on waste characteristics)	Maximum	Average	Minimum	Maximum	Average	Minimum
Capital expenditure (CAPEX)						
	79.7	52.8	40.1	171.2	131.8	105.9
Operational expense (OPEX) & Maintenance costs of AD plant						
Year 1 & 2	12.8	10.9	8.9	24.3	22.4	18.5
From year 3	3.9	3.3	2.6	8.0	7.1	5.8
OPEX (–) and REVENUES of products **with** export of fertilizers						
OPEX	–25	–29	–36	–62	–72	–85
REVENUES	71	56	62	163	139	150
Net benefit	46	27	26	101	67	65
OPEX (–) and REVENUES of products **without** export of fertilizers						
OPEX	–6	–5	–5	–14	–12	–11
REVENUES	44	21	17	94	52	44
Net benefit	38	16	13	80	41	33
Electricity production						
GWh/a	20.00	7.89	5.89	43.28	22.16	17.83
% of the electricity demand	4.72%	1.86%	1.39%	10.21%	5.23%	4.21%

Note: These numbers are only estimates and do not include any price changes (deflation, depreciation, etc.).

Scenario 4 – Implementation of Mariculture Masterplan

Waste input

The last scenario shows the case in which the effects of the implementation of the Mariculture Masterplan is considered (Table 4.15). The organic stream of this scenario consists of the streams from Scenario 3 (class 1, 2, 4 and 7) and an additional increase of class 7, from 2020 until 2030 when, according to the masterplan, a production maximum of 100,000 tons of fish per year is achieved. The assumptions of Scenario 4 imply a linear increase of 1% per year (approximately 1 t/d) of the organic fractions until 2019. From 2020 until 2030 this increase amplifies up to approximately 11% (10–11 t/d).

Dimensioning

The AD plant design for Scenario 4 resulting from the aforementioned input streams are presented in Table 4.16.

Costs and revenues

For scenario 4 we expect investments (CAPEX) for the full package in the approximate range of 40.1 to 79.7 million SCR (2022) (Table 4.17).

Operational and maintenance costs for the AD plant of scenario 4 amount to 8.9 to 12.8 million SCR per year (2022) in the first two years and 2.6–3.9 million SCR (2022) from year 3 (Table 4.17).

(OPEX) and REVENUES of products results in an overall net benefit of 26 to 46 million SCR (2022) for the situation which includes export of fertilizer and 13–38 million SCR (2022) without export of fertilizer (Table 4.17). For details see Scenario 1.

4.3.5 Comparison of scenarios

In this section we provide an overview and a comparison of the four scenarios previously presented. As mentioned earlier, waste input data, costs, and revenues reflect the year 2018. No growth rates regarding economy and no projection of any future price changes are considered (e.g. depreciation, deflation, etc.).

Waste input

The amount and the share of waste input varies substantially between the four different scenarios (Figure 4.2). Most significant is the change in Scenario 4, on the assumption that the Mariculture Masterplan is going to be implemented. In this

Table 4.18
Summary of costs and revenues for all scenarios (in bold where years to a return of the investment are more than 10 years).

Scenario	1			2					
	2022			2022			2042		
	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min
CAPEX	31	19	14	48	27	17.4	53.4	28.4	18.7
OPEX & Maintenance AD	5.3	4.6	3.8	7.5	5.9	4.3	8.1	6.1	4.6
Net Revenues from Products	15	6	5	28	14	15	32	15	17
Net Revenues from Products with export (fertilizer)	14	5	3	23	6	4	26	6	4
Years to return of investment with export (fertilizer)	3.1	**10.7**	**12.0**	2.3	3.2	1.6	2.3	3.2	1.5
Years to return of investment without export	3.5	**NEG**	**NEG**	3.1	**1,389.2**	**NEG**	3.0	**100.4**	**NEG**
% of electricity demand	1.74%	0.49%	0.27%	2.84%	0.63%	0.35%	3.24%	0.68%	0.38%

case, the amount of suitable AD waste input at the end of life of the AD plant would be more than twice (215%) the amount of AD waste input of Scenario 4. Furthermore, the extension of the sewage system in Scenario 3 leads to an increase of 16% of the amount of sewage sludge as compared to scenario 2. Finally, if organic waste from households can be diverted from landfilling, we expect about 14 t/d of waste input in 2022 and 2042 for Scenarios 2, 3, and 4, respectively.

Liquid output will be substantially higher than the solid output for all scenarios due to the AD configuration (wet system). For all scenarios, a waste volume reduction of about 5–7% is expected compared to the initial input. However, this proportion should be higher because of dilution of input.

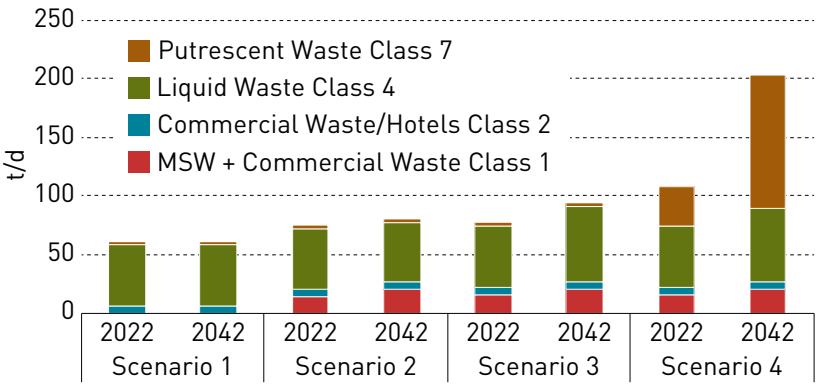

Figure 4.2
Comparison of waste input for the different scenarios. While 2022 reflects potential start of operation of AD plants, 2042 stand for the expected end of life of the facilities. Changes between 2022 and 2042 refer to ex-pected increase due to implementation of plans such as increase of capacity of sewerage plants or mariculture production.

Costs and revenues

CAPEX is directly linked to the size of an AD plant. Accordingly, scenario 1 refers to the lowest investment costs while for scenario 4 CAPEX is highest (Table 4.18). Also, operational costs increase with higher waste input. Time required for full return of the investment is shown ranges from 3 to >10 years (the latter are highlighted in bold), at which point in time a return on investment is not feasible at all, as running costs will exceed the revenues. The biggest share of revenues for all scenarios derives from the sales of liquid fertilizer on national and international markets. Smaller amounts of revenue are expected from the production of electricity, the retail of BSF larvae as substitutes for animal feed ingredients, and from post-composted digestate as landfill cover.

Additionally, it is important to keep in mind that labor costs differ significantly between the first two and the following years.

3						4					
2022			2042			2022			2042		
Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min
49	27.7	18	59.5	33.4	21.4	79.7	52.8	40.1	171.2	131.8	105.9
7.6	6.0	4.4	8.9	7.0	5.0	12.8	10.9	8.9	24.3	22.4	18.5
30	16	17	34	17	18	46	27	26	101	67	65
24	6	4	28	7	5	38	16	13	80	41	33
2.1	2.7	1.4	2.3	3.4	1.6	2.4	3.3	2.3	2.2	3.0	2.3
3.1	**78.7**	**NEG**	3.1	**324.9**	**NEG**	3.2	9.9	**10.7**	3.1	7.2	7.4
2.89%	0.64%	0.35%	3.50%	0.75%	0.41%	4.72%	1.86%	1.39%	10.21%	5.23%	4.21%

4.4 Discussion

4.4.1 Main scenario outcomes

An AD plant with a balloon- or flat-top configuration can be a feasible and profitable treatment choice for organic waste. Food waste from households, hotels and restaurants, liquid waste, such as sewage sludge from water treatment, and putrescent waste from fish and other lifestock production, are suitable feedstock for an AD plant. However, there are substantial differences and consequences in the outcome of the net revenues between the different scenarios.

All scenarios show net revenues. This means that, under the given circumstances and assumptions made in this connection, the operation of an AD plant is profitable. Revenues increase with both an increasing amount of organic waste that is treated and with the quality of the input. These two factors greatly influence the profitability of the AD plant. The quality of waste input, for example, is directly affected by the collection methods (e.g. lower quality if the organic fraction of MSW (class 1) is mixed with plastic residues). Therefore, it is essential to integrate and coordinate the development of an appropriate and effective collection system with the development of an AD project.

The results show a clear correlation between turnover losses, the biochemical methane potential (BMP) of the input, and the market of fertilizers. In the cases where the BMP is at a minimum value (minimum waste quality) and the fertilizer is not exported, for example, the return of the investment is too low to run an AD plant economically. Furthermore, in this low quality input scenario, the liquid part of the digestate would have to be disposed or treated separately. This would lead to additional (disposal) costs and may also entail an adverse impact on the environment. In the case of an average input quality, the profitability of the plant is significantly reduced. In case fertilizer cannot be exported, the number of years, which are needed, for a complete return of the investment would increase significantly as compared to a scenario where an export is possible. However, the economic feasibility also depends on the size of the AD plant and, connected to that, the amount of products produced with the AD plant and hence the income from their sale.

The study revealed some interesting insights for each product. First, electricity produced by the AD plant is a great source of revenues, even though we assumed a conservative and therefore a rather low sales price of 2 SCR/kWh (Frequently, companies pay up to 4SCR/kWh). Furthermore, the electricity produced by the AD process can theoretically cover up to 10 % of the local electricity demand (scenario 4, for details see Appendix 4.11). This would be of substantial support in reaching the goal of Seychelles for 15% renewable by 2030 (Seychelles Investment Bureau (SIB), 2010). However, in most scenarios the coverage of the local electricity demand is significantly lower. The underlying mechanisms are once more dependent on the quality and the amount of organic waste. Second, the heat cannot be used in the AD process directly, since the Seychelles climate allows the AD plant to already operate at the desired temperature. Still, the heat (which is produced in great amount during the conversion of methane to electricity) could potentially be used in the desalination plant, in other cooling processes, or for fertilizer production. However, we did investigate the waste heat only parenthetically. Therefore, we exclude the heat as a valuable source for additional revenue. Third, there is local demand for liquid and solid fertilizer in the Seychelles, albeit very low. In the case of the fertilizer (urea), for example, the production far exceeds the demand as 20% of the output of the AD process goes for solid digestate

(i.e. the little TS content in the output with a small percentage of water content) while 80% goes for liquid fertilizer. Only a small share of currently used fertilizers is with urea, which is the most similar to the one produced with AD, because its demand is low. Therefore, 99 percent of the liquid fertilizer has to be exported in all the scenarios due to the lack of local demand, and for the solid fertilizer its composition does not match very well the nutrient contents currently used in the Seychelles.

Unlike for fertilizers, the local demand for Black Soldier Fly (BSF) larvae feedstock and landfill cover is much higher. Because BSF has the potential to largely substitute imported food for animals (e.g. soybean meal), BSF helps to decrease Seychelles' dependency on international markets and thereby from unpredictable price fluctuations up to 30% too (Ferox Feed, 2018). However, the cost of production of local BSF larvae and landfill cover are most probably higher than the prices of imported products. Additionally, according to our research, producing BSF larvae is still at an early stage and lacks experience especially in connection with the production based on digestate from AD plants. According to experts from the University of Applied Science Zürich (ZHAW), the high ammonia and Volatile Fatty Acids (VFA) content might be of concern. To circumvent this problem, it could be an option to feed the larvae directly with food waste.

Although one of the main advantages of having an AD plant is to reduce the volume of organic waste, our research has shown that volume reduction is approximately 6% or lower only. This is because we suggest a wet rather than dry system. The latter is more complicated to handle, it needs costly high-tech components, and the amount of waste fed to the plant must be constant over time. However, in addition to the reduction of volume, the treatment of waste with AD also has other advantages, such as the reduction of odors and emissions at the landfill or the creation of a valuable output (fertilizer, electricity, etc.).

Furthermore, our study shows the importance of considering different development scenarios of organic waste for a proper design of an AD plant. For example, in Scenario 4, the amount of organic waste input doubles during the operational lifetime of an AD plan. Therefore, it would economically not be wise to build the plant at full scale at the very beginning. Rather, to safe investment and maintenance cost an additional unit can be built at a later stage when capacity is needed. Note, that our cost/revenues calculations reflect rough estimates. Further investigation is needed to evaluate the exact costs for all four scenarios elaborated in this report.

As a last point to be mentioned here, the operational costs differ significantly between the first two years of operation and the rest of an AD plant's lifespan. This is mainly because of high costs associated with international labor force which is required during the first two years until enough local expertise has been built up for operating the AD plant. Moreover, operational costs differ between the scenarios due to different sizes of the AD plants. In general, larger AD plants are causing higher operation and maintenance costs.

4.4.2 General limitations and assumptions

In the previous section, we emphasized the potential of anaerobic digestion as a treatment for organic waste. However, we also need to emphasize that the results must be read and interpreted with due caution due to necessary simplifications, scarce information, and uncertainties in the data.

The composition and the extent of the waste input stream are decisive for the planning and operation of an AD plant. There are uncertainties in the data (e.g., lack of organic waste production monitoring; incomplete data concerning the composition of different types of organic waste in each waste class). Due to these uncertainties, we were using parameter values from similar contexts and projects presented in the literature. Furthermore, some estimations about currently produced amounts and future trends are only based on personal communications since no clear plans or statistics are available. To calculate the increase in food waste produced in private households, we revert to appropriate growth rates. Economic growth estimations, however, were not considered.

The proposed dimensioning of AD plants is solely based on expert opinions. The scenario that considered the Mariculture as source for organic waste, and for which we suggested two plants instead of a large one, is based on the assumptions that the single stream coming from the Mariculture industry is treated separately. This might even be necessary since such a big amount of fish might completely change the BMP and the efficiency of the system. Moreover, in this scenario a much larger amount of water is needed and this leads to higher pumping and shredding costs for the solid parts (e.g., bones).

With regard to the implementation costs, it is important to note that the CAPEX for the construction of an AD plant are based on average prices (6,700 SCR/m^3) of comparable plants in Western Europe. However, these prices can vary significantly and do not necessary reflect costs for constructing an AD plant in the Seychelles. Despite extensive investigations, we have not found substantive data about local planning and construction costs for such a project.

Furthermore, we did not consider complete shutdowns of the plant which would be necessary for maintenance. However, this would affect the total annual production as well as the efficiency of the transformation processes.

4.5 Conclusions and outlook

AD as a treatment solution for organic waste has great potential to help Seychelles meet its goals of increasing the share of renewable energy by 5% until 2020 and 15% until 2030 (Seychelles Investment Bureau (SIB), 2010). Moreover, the products of AD potentially substitute imported fertilizers and fodder. However, its economic feasibility depends on the local demand and the possibility to sell the products that emerge from the process.

Incomplete or missing data regarding waste characterizations and market demands, as well as the feasibility of new presorting-collection system of the organic waste, weakens the robustness of the results.

Being aware of that, and the fact that some details are missing for a well-founded decision-making process, we are convinced that the results of our study provides a good basis for decision makers to understand the potential of AD as waste treatment option – in addition to incineration or as a sole solution.

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5 Waste treatment II: Incineration

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5.1 Introduction

Incineration is a waste treatment technology which efficiently reduces the waste volume and demand for landfill space. Combustion simultaneously offers high disinfection of waste, and energy can be recovered for heat or power production. Energy gained from combustion provides a substitute for fossil fuel combustion, thereby reducing greenhouse gas emissions. However, if the volume of waste is insufficient to contribute significantly to Seychelles energy production, incineration plants may not be economically viable (Bunce, 2010). The technology is well established and common practise in many countries in the global North, where state-of-the-art incineration plants work without adding fossil fuels as the calorific value, i.e. the energy of waste is usually sufficient to enable the burning process of municipal, industrial and commercial waste. However, incineration is not yet established in Africa (except the newly built waste-to-energy facility in Addis Ababa, Ethiopia, the first of its kind in Africa, started operating in 2018) and especially not in Small Island Developing States (SIDS). Incineration plants involve high investments and operating costs, skilled staff and requires both local and foreign currency throughout its operation, as there are only few experienced manufacturers worldwide. Moreover, composition of waste in developing countries is often questionable in terms

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of its suitability for combustion, as organic fractions and humidity are increased (Mohee and Mudhoo, 2012). If residues from the flue gas cleaning are not appropriately handled, they may contaminate the environment. Even if a volume reduction of around 80% is achieved, a certain fraction always ends up in bottom and fly ash and consequently on the landfill.

Incineration plants can be evaluated according to economic, environmental, societal and technological aspects, analogous to the model of the 'Four Spheres Framework for Sustainability' (Passet, 1979) on which we base our analysis. Economic examinations deal with the financing of capital (CAPEX) and operational expenditures (OPEX). Societal investigations treat aspects like the general public rating of the waste management system, possible improvement methods, as well as the understanding and acceptance of incineration technology. The study of ecological consequences is disregarded in this analysis although incineration plants have environmental effects particularly if not properly maintained. However, compared to landfilling incineration performs much better (e.g., Sharma & Chandel, 2017). Instead, we focus on technological issues such as waste composition, energy release from combustion, and plant dimensioning, but also consider economic and social perspectives in our analysis.

Waste incineration technology offers many advantages without heavily depending on enhanced sorting of waste fractions. Currently, there is no large-scale incineration technology for waste management in the Seychelles, however incinerators are used by the Ministry of Health (MH) for medical waste and some hotels or businesses may operate small incinerators (Bunce, 2010). A small incinerator is operating at the airport, however sporadic feeding, frequent interruptions, and additional fuelling prevent an efficient operation (Ministry of Environment Energy and Climate Change Seychelles (MEECC), 2008). A feasibility assessment for waste disposal on Praslin and La Digue concluded that greatest benefits would result from incineration technology only when accepting lower emission standards and successful site selection (Bro, 2008). However, the small-scale type of plant investigated there cannot be compared with the large-scale incineration plant analysed in the present report. A preliminary study of incineration in the Seychelles came to the conclusion that recycling would provide better economic and environmental returns, and that incineration would be inappropriate because of too high investment and operation costs, the lack of specific technical expertise, and insufficient level of infrastructure and planning (Bunce, 2010).

The goal of the present study is to demonstrate whether incineration is an option for waste management in the Seychelles as a major technology to substantially reduce the amount of waste going to the landfill. Incineration would for sure involve high investment costs in a short-term perspective. However, on a long-term base additional benefits could be created by preserving precious land resources, intact ecosystems and energy production. Waste management must be set into a bigger context where costs and benefits are balanced in order to find the best trade-off. Based on these considerations we focus on the following research question:

- Would an incineration plant be a feasible solution for the waste treatment in the Seychelles from a technological, economic and social perspective?

5.2 Methodology

5.2.1 General procedure

As mentioned, we base our analysis of waste incineration on the three following spheres: technological, economic and societal. Although incineration can have environmental impacts which, however, are less serious compared to landfilling (Sharma & Chandel, 2017), ecological analysis is neglected in this study. The feasibility of an incineration plant on the Seychelles is assessed for each sphere individually (see Figure 5.1). The applied methods for the three spheres are described precisely in Section 5.2.2. The know-how was obtained by consultation of literature and waste experts. A final overall assessment summarizes the obtained results for each separate sphere.

5.2.2 Methods

Literature review

We consulted a variety of documents about the waste management system with focus on incineration technology in the Seychelles and other countries. These include expert and government reports, studies by non-governmental organisations (NGOs), presentations by stakeholders, facility brochures and technical guidelines.

Expert interviews

In order to acquire knowledge about the planning principles and operation of an incineration plant several semi-structured interviews were conducted both in Switzerland and the Seychelles (for a full list of all interviewed experts see Appendix 5.1).

Technical analysis

The technical analysis is based on the properties of a modern incineration plant with moving grate combustion, wet bottom ash discharge, flue gas treatment by means of particulate filter, wet scrubbing, and dry absorption in order to reach European air quality standards.

Landfill data

Based on the annual waste data from the weighbridge at Providence Landfill from 1999 to 2016 received from the LWMA, we analysed the waste composition and selected the classes which are suitable for incineration. These classes are: 1 municipal; 2 commercial and industrial waste; 5 mixed waste delivered by private trucks (see red highlighted boxes in Figure 5.2). A disturbance fraction of 5% in the classes of mixed, industrial and commercial waste needs to be removed before incineration because these materials are supposed to disturb other processes or negatively influence the equipment (Source confidential).

An average annual growth factor based on data from 1999 to 2016 from LWMA was assessed for each of the three combus-

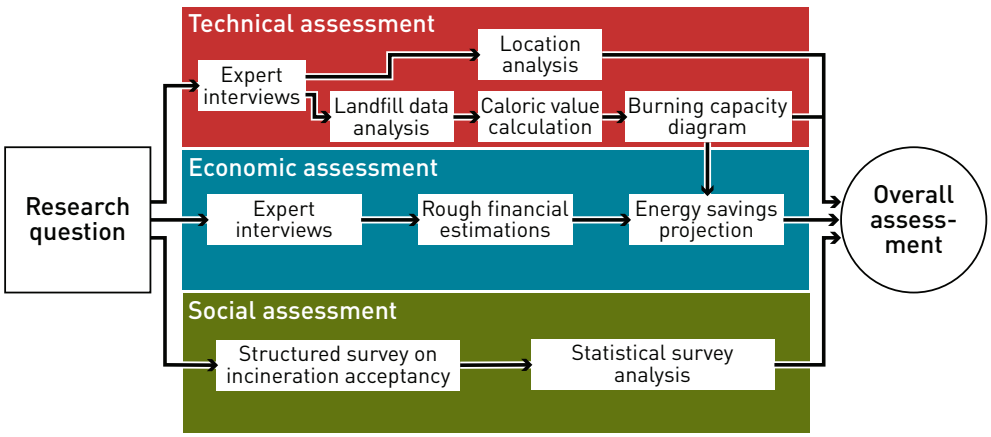

Figure 5.1
Overview of applied assessment methods. The arrows depict the information transfer from one process to another.

tible classes in order to extrapolate to corresponding waste amounts in 2018. The same procedure was applied to all other waste categories in order to have a projection of the total waste production and derive weight percentages. The combustible waste amounts in 2018 are the fundament for assessing the calorific potential, eventually resulting in an overall evaluation of the technological feasibility.

The classes of hazardous waste, inert and construction waste, liquid waste, and green waste are excluded since they are not suitable for incineration. Reasons for the exclusion are as follows:

- Hazardous waste and special waste should not be incinerated, but collected and treated separately, as risks of pollution would be too high (see Chapter 3, Hazardous waste: material flows)
- Inert or construction waste are almost incombustible and would decrease temperature on grate due to their low calorific values. Only separated, combustible material, which contribute a minor fraction to the construction waste, should be added.
- With regard to liquid waste (mostly sewage sludge), waste oil, and putrescent waste, grate incineration is not suitable, as liquids would just seep through. Other treatment options, like anaerobic digestion, should be considered for liquid and putrescent waste (see Chapter 4, Waste treatment I: anaerobic digestion).
- Concerning waste oil, separate collection and treatment could allow for reuse or recycling as preferential utilization options.
- For green waste, composting would be more beneficial than combustion. The major benefit of recycling green waste, apart from obtaining a useable commodity (compost), is that it improves the quality of the residual waste for combustion by raising the net calorific value and reducing moisture content (Mohee et al., 2015).

Scenarios

Two scenarios were developed based on the preliminary evaluation of combustible classes:

1. Incineration of all combustible waste classes
2. Incineration of all combustible waste classes except organic waste fractions.

The first scenario assumes that basically all waste from the previously selected combustible classes end up in the incineration plant in order to check whether there is sufficient waste for an incineration plant to be viable (see brown highlighted boxes in Figure 5.2). Even if classified as combustible, a certain fraction always ends up in the bottom and fly ash, as a complete volume reduction is not practicable. The waste classes arriving at the landfill represent real compositions of waste, and sorting them is in reality not efficient or possible. As long as the total waste amount is combustible, single fractions with low calorific values or recycling potential are of no concern for incineration plants (M. Waldner, personal communication, May 14, 2018).

The second scenario assumes the implementation of an anaerobic digestion plant, where suitable organic material is digested (see green highlighted boxes in Figure 5.2). The calorific value of organics is usually quite low and thus not favourable for incineration. Organic treatment methods offer more efficient processing for these waste fractions (M. Haupt, personal communication, May 09, 2018). Therefore, we subtracted kitchen waste from combustible waste and considered it for anaerobic digestion instead. We therefore removed 18% kitchen waste from the municipal waste class for the second scenario. For the industrial and commercial waste, we removed 25% kitchen waste and for mixed waste class 4% were subtracted (Source confidential).

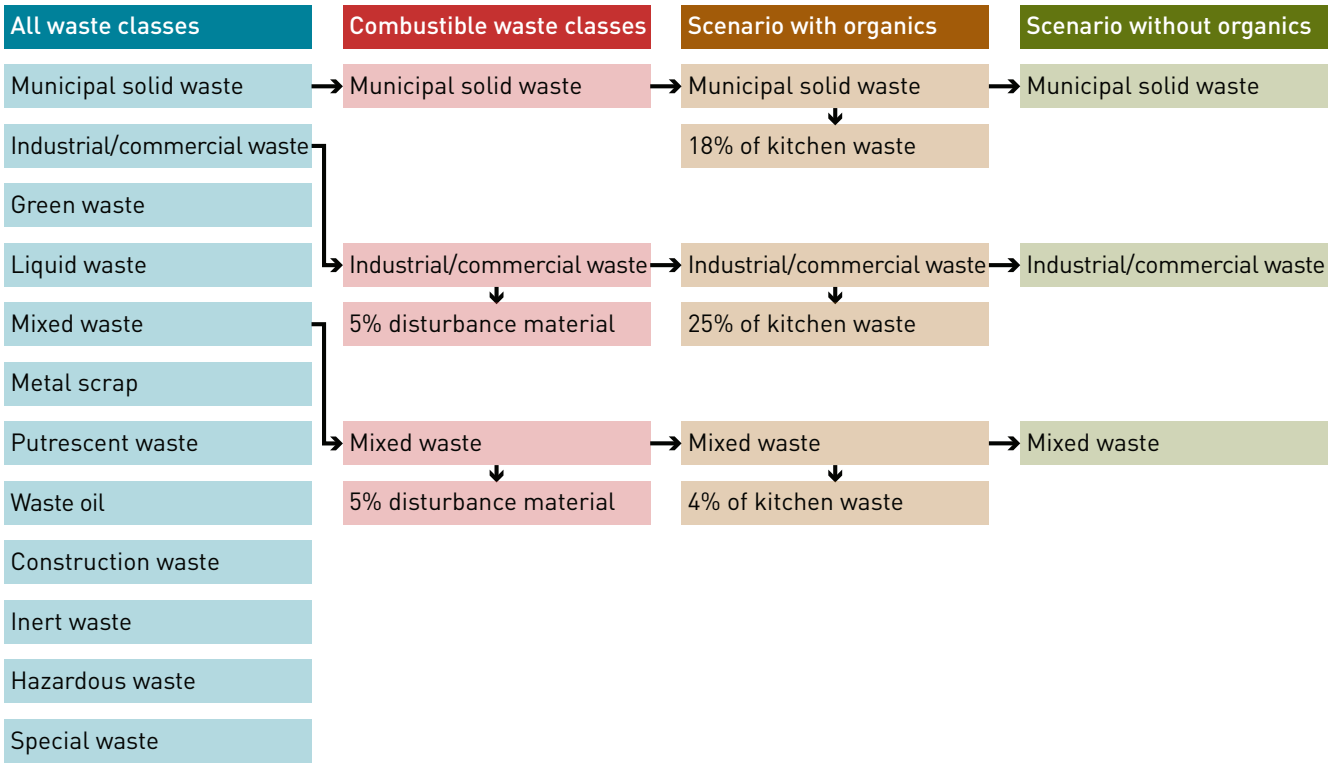

Figure 5.2
Assessment procedure for development of scenario 1 with all combustible material from municipal, industrial / commercial and mixed waste foreseen for incineration and scenario 2 where kitchen waste is subtracted assuming implementation of separate organic treatment methods.

Estimation of calorific values

Calorific value is a measure of the energy contained in a specific material that is released as heat during complete combustion. It varies greatly for different materials and is one of the most important waste characteristics when assessing the feasibility of an incineration plant. In order to assess the calorific value of the combustible waste, the respective composition has to be known. Using detailed information from report by a confidential source regarding the composition of the combustible waste classes 1 (municipal), 2 (industrial and commercial) and 5 (mixed waste), the contained waste types (e.g., plastic, kitchen waste, construction wood) were weighted inside their class according to their relative share of the total weight. In a next step the calorific value of each class was determined using the respective relative share of each waste type. Finally, the three considered classes were weighted again according to their contribution to the total amount of combustible waste. This resulted in the lower heating values for the two aforementioned scenarios (see Figure 5.2).

Burning capacity diagram

The burning capacity diagram is a crucial component (when assessing the technical feasibility of an incineration plant) depicting the hourly waste throughput versus the released thermal energy which, in turn, depends on the calorific value of the waste (Clericetti, 2004; Böhmer et al, 2008). This is important for plant design, since it reveals the range and relationship of throughput and calorific values at which the operation of a plant is mechanically and energetically efficient. On the basis of this information the zone of economic viability can be defined.

As a first step, a range of hourly throughputs needs to be defined in order to construct the burning capacity diagram. The minimal throughput is determined by subtracting all possible recyclable waste

types from the current waste amount (see Chapter 2, Feasibility of recycling: an appraisal methodology and 4, Waste treatment I: anaerobic digestion). The maximal throughput was set based on a scenario with high economic and population growth and no recycling at all, according to research from the Case Study 2016 (Mangroo & Wälchli, 2016). The hourly throughput can be calculated by dividing the annual waste amount by an assumed 8,000 annual operating hours of an incineration plant (A. Sigg, personal communication, May 16, 2018). The obtained hourly throughput results for the Seychelles are listed in Table 5.2 (Section *'Burning capacity'*).

For the calorific values a minimum and maximum need to be determined as well. The lower bound is set at 7 GJ/t, which equals the minimum required for combustion without additional fuelling (A. Sigg, personal communication, May 16, 2018). The upper bound was set at 16 GJ/t as based on values of different realized incineration plants (Hitachi Zosen Inova, 2017).

Multiplying the hourly throughput with the calorific value and the conversion efficiency leads to the thermal power production, which is the main output of the burning capacity diagram. The conversion efficiency is the combined efficiency of the boiler and the turbine as calculated by multiplying the individual efficiencies. It quantifies which part of the initially produced steam can be transformed to power and what is lost during transformation. Table 5.3 (Section *'Burning capacity'*) shows the efficiencies applied for this study, whereof the individual efficiencies were taken from a study by Lemann & Neumann (2012, p. 100 ff.).

Once the aforementioned values have been obtained, the point of nominal functioning, representing the current situation, can be determined using the hourly throughput and calorific values for Scenario 1, where all combustible material is incinerated. The numerical values are shown in Table 5.2 (further down). Since the characteristics and amount of waste are very variable, the minimal and maximal limits where operation of an incineration plant is still feasible need to be defined in terms of amount, calorific value and power production. According to the state of the art, the minimum baseline is set at 60% and the maximum top line at 100% of the nominal power production (Figure 5.6). Operational conditions are further restricted by certain calorific value requirements and maximal capacity of 150% of the nominal throughput (Figure 5.6). Once all these limits are specified, a feasibility zone Figure 5.6) is obtained, in which the operation of an incineration plant is viable (Clericetti, 2014; Böhmer et al., 2008). The resulting diagram for the Seychelles is shown in Figure 6 (Secion *'Burning Capacity'*). This feasibility zone was assessed using the values of Scenario 1. The reason behind that choice is that Scenario 1 considers the waste amount, composition and recycling efforts as they are at the moment in the Seychelles. Scenario 2 was chosen, since the organic fraction seems the most probable to be sorted out. Since an incineration plant is built for a lifespan of several decades, it is important to assess the impacts of decisions like for example increased recycling. The point of nominal functioning that results for Scenario 2 is represented by the orange dot in Figure 5.6. Its location in the feasibility zone will be discussed further in Section *'Burning capacity'*.

Location analysis

In order to recommend a location for an incineration power plant, a spatial analysis was conducted. According to the Environmental Systems Research Institute (ESRI), a spatial analysis is defined as "the process of examining the locations, attributes, and relationships of features in spatial data through overlay and other

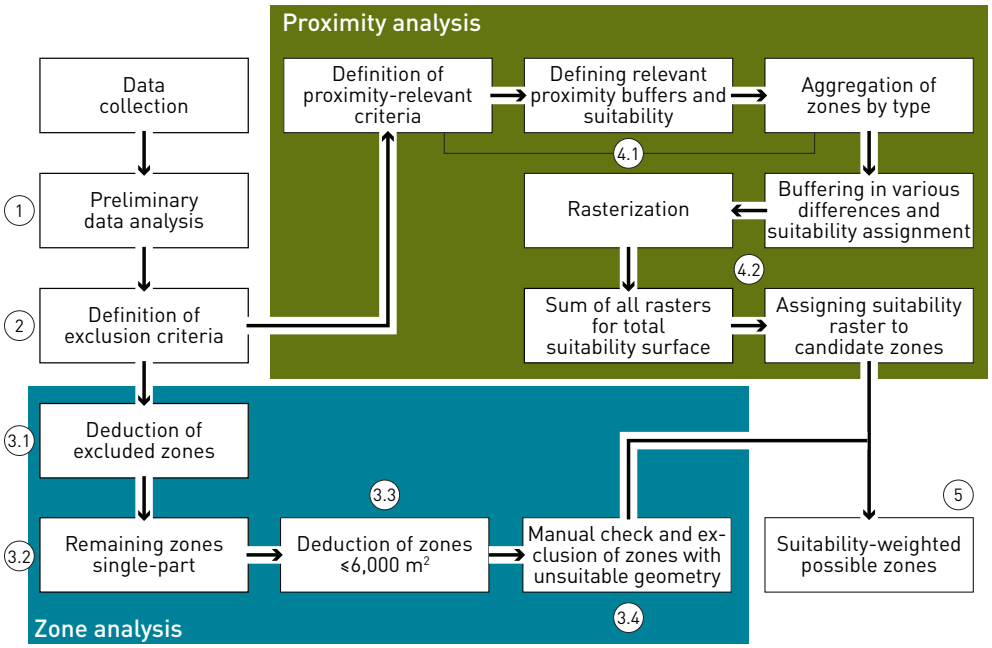

Figure 5.3
Overview of the spatial data processing procedure. The data is analysed in two separate procedures, zone analysis (blue) and proximity analysis (green), whereof the results are combined for interpretation. The numbers refer to the steps explained in Appendix 5.2.

analytical techniques in order to address a question or gain useful knowledge. (...)" (ESRI, 2018).

To analyse the data spatially, we used two different approaches (see Figure 5.3). On the one hand, we used the geodata to determine where a potential incineration plant could be constructed. We have done this by analysing the land use plan and identifying which areas are suited for a plant and which are not. This will be referred to as the zone analysis. On the other hand, we used the geodata to establish regions next to which zones a plant could be feasible. This step is important, because one of the most prominently mentioned concerns in the acceptance study (see Section 5.3.3) is "Yes, but not in my backyard", whereby the idea of building an incineration plant generally is well accepted. Additionally, we considered ecological factors such as buffer and transitional areas between settlement areas and natural reserves. This will be referred to as the proximity analysis.

The purpose of combining the two kinds of analyses is to get an overview of possible locations for an incineration plant considering the suitability of the neighbouring areas (for details see Appendix 5.2).

Economic assessment

For the economic assessment rough estimations on investment and treatment costs are elaborated based on interviews with Swiss incineration plant experts with experiences from realization of other projects. A qualitative assessment about expected costs is conducted for the Seychelles. The possible annual savings through energy production are assessed in a quantitative analysis based on production and consumption data supplied by the Seychelles Energy Commission (SEC). The expected electrical plant power output was transformed into crude oil equivalents, which is an energy unit from average calorific values of crude oil. The determined quantities roughly equal the quantity of oil being replaced by incineration energy. Furthermore, the oil equiva-

lents were transferred into financial units. Due to the fluctuations of crude oil prices, the annual savings were calculated for average oil prices in 2017 and in a 5-year span (2012–2017) in order to deal with a more robust value. The annual savings are then extrapolated to expected lifetime of an incineration plant, supposed to be 25 years, in order to have an estimation of net potential savings balancing the high investment costs of an incineration plant. All these calculations are estimations that do not consider important economic factors, such as discounting rates or currency fluctuations. They should be adopted as rough guiding spans.

Societal acceptance

We assessed the societal acceptance of an incineration plant descriptively using a structured questionnaire. Different aspects, like public opinion regarding the local waste management system and its effectiveness, understanding and acceptance of incineration technology, preferable solutions and willingness to pay for waste disposal, were part of the investigation. We conducted a total number of 75 surveys in different districts of Mahé allowing for a balanced sample in terms of gender, age, educational background and welfare levels (for a complete questionnaire see Appendix 5.3).

Overall feasibility assessment

In a concluding step, our findings from the individual technological, economic and societal assessments are gathered in an overall feasibility assessment based upon research from Rand, Haukohl & Marxen (2000) from the World Bank. Their decision maker's guide for municipal waste incineration plant assesses the feasibility of large-scale incineration plants in developing countries, thus, demonstrating great similarities to the Seychelles, where a possible incineration plant would also be considered as large-scale but at the very lower bound. We applied and evaluated their recommended criteria specifically for the Seychelles and compared our gained knowledge and insights with their suggestions. The entire decision guide (Rand, Haukohl & Marxen, 2000) can be found in Appendix 5.4.

5.3 Results

This Section present results of the technical, economic and social assessments. First, we present an introduction to incineration technology, followed by an analysis of waste classes arriving at the landfill, a scenario assessment, and the determination of calorific capacities. The results of the technical assessment are concluded with the location outputs of the GIS analysis. The economic assessment is based on estimations of investment and treatment costs of an incineration plant as well as saving possibilities. The social assessment presents results of conducted surveys with focus on the future of the waste management system, concerns regarding incineration technology and willingness of financing.

5.3.1 Technical assessment

Figure 5.4 depicts schematically the waste lifecycle from collection, combustion, treatment to final products (e.g., electricity and heat) and remaining waste (e.g., bottom ash and fly-ashes). The colours in the figure summarize processes which are described chronologically in the following:

1. Waste collection (red): Waste is collected and transported to an incineration plant. Recyclables and incombustible waste should be separated as other treatment options offer better recovery or as combustion processes could be disturbed.
2. Waste combustion (yellow): Appropriate waste for incineration is transported to the facility where it gets weighted

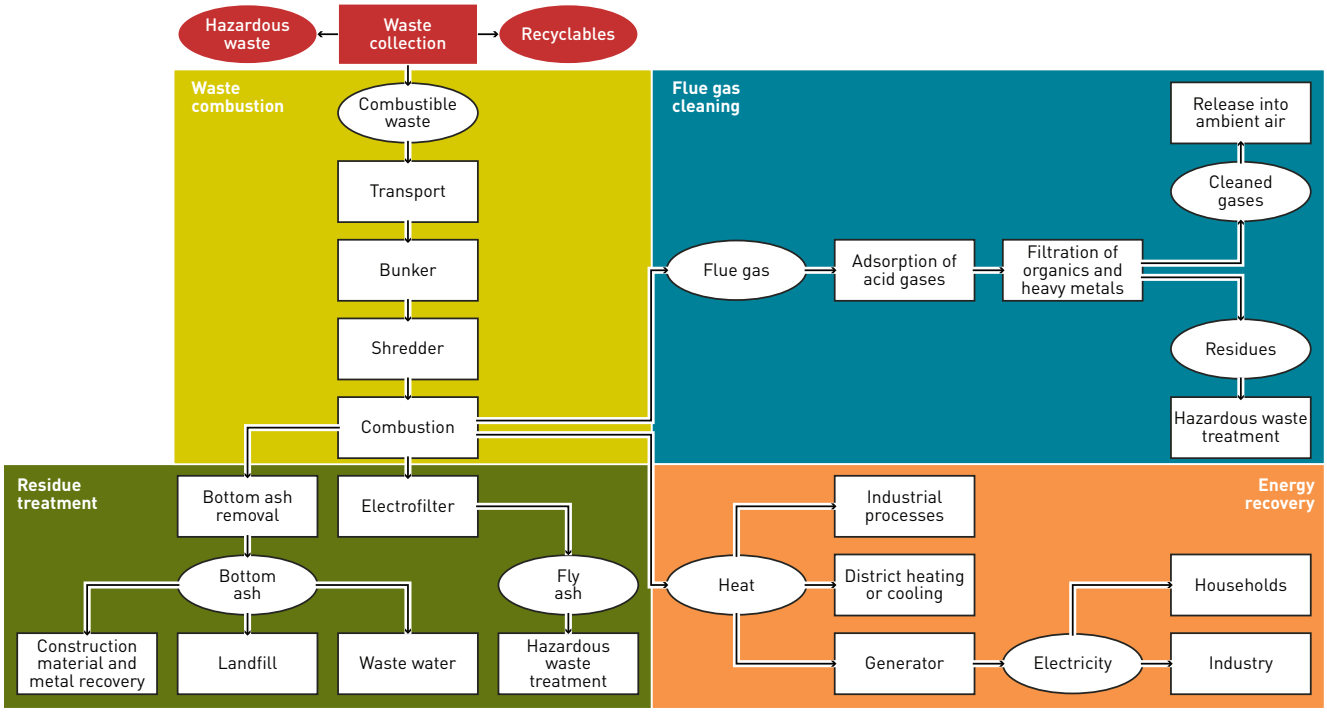

Figure 5.4
Waste lifecycle in an incineration plant. The processes are summarized to five main groups as indicated by different colours: waste collection and separation of incombustible waste (highlighted in red), waste combustion (highlighted in yellow), residue treatment (highlighted in green), flue gas cleaning (highlighted in blue) and energy recovery (highlighted in orange).

and stored in a bunker. Automatic or manual mixing is conducted with a grab in order to achieve homogenous burning temperatures. The shredder is fed by the grab and reduces particle size to attain complete burning. Shredded waste is dried with heated primary air and transferred to the combustion grate where it is burned (Lemann and Neumann, 2012)

3. Residue treatment (green): After combustion, the solid leftovers, called fly ash and bottom ash, are extracted. They amount to approximately 20 % of the original waste volume. This means that incineration does not completely replace landfills but reduces the volume for disposal significantly. Fly ashes must be treated as hazardous waste. Bottom ash is cooled with water, stored in a bunker and can be safely put into landfills or recycled as construction aggregate after proper combustion. Valuable metals can be recovered from bottom ash; the extraction, however, is costly. The waste water from bottom ash cooling must subsequently pass through the nearest water treatment plant which is probably situated at Providence.
4. Flue gas treatment (blue): Another product after combustion are flue gases that must be further treated in order to minimize environmental impacts and conform with European air quality standards. Dust particles are collected by particle filtration, followed by wet scrubbing or dry absorption in order to remove contaminants like hydrochloric acid, sulphur dioxide, fugitive heavy metals or organic compounds like dioxins and furans. This results in a substance that must be disposed of as hazardous waste. After treatment the cleaned flue gases are released to ambient air.
5. Energy recovery (orange): Incineration plants generate heat that can be trans-

formed to electricity and like this substitute fossil fuelled power plants and steam supply for industrial customers. In the area close to the landfill there is no direct heat demand. It may be used for district cooling systems, as district heating is not needed in the Seychelles.

Landfill classes

Different types of waste are disposed on the landfill, of which municipal waste contributes most by means of weight percentage with 37.0% (see Figure 5.5), followed by mixed waste coming from private trucks with 27.7% and industrial and commercial waste amounting to 14.9%. These three classes together sum up to 77.6% weight of total projected waste in 2018. As they are categorized as combustible according to Figure 5.2, this implies that the three largest waste classes are suitable for incineration.

The residual 22.4% are not intended for incineration due to various exclusion criteria mentioned in Section *'Technical analysis'*. The incombustible waste classes are based on approximately two thirds of liquid waste, followed by putrescent and vegetation waste contributing 2% to 3% respectively. Some small shares of scrap metal, waste oil and construction waste end up in the landfill as well. Hazardous, special, and inert waste only contribute negligibly to waste amounts in the year 2018.

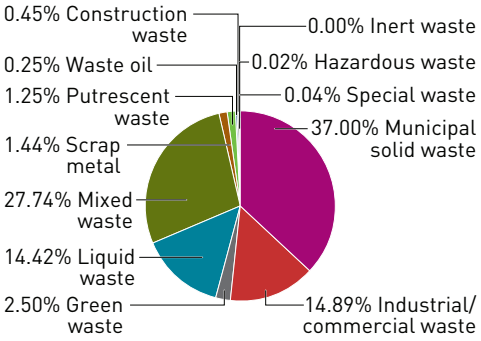

Figure 5.5
Projection of waste composition in 2018. The diagram shows the weight percentages of waste classes arriving at the landfill Providence II. Projections for 2018 are based on waste registered at the weighbridge by LWMA between 1999 and 2016.

Scenarios

As mentioned the three remaining waste classes suitable for incineration are municipal, industrial and commercial waste and mixed waste (Scenario 1). They comprise 77.6% of Seychelles' waste after having subtracted disturbance material, which equals 65,475 tons per year (see Table 5.1). Considering the scenario 2, where parts of the organic fraction are excluded from combustion, the amount for incineration would decrease to 55,766 tons per year, respectively 66% of total waste amounts.

The average growth factors between 2000 and 2016 for the combustible classes vary from 1.05 to 1.10 depending on combustible waste class assessed. All waste classes display positive growth factors, signifying good availability for future waste combustion projections.

Estimation of calorific values

The calorific value largely depends on the composition of the waste. Materials like plastic or construction wood have high calorific values, while materials with higher water content, like green cut or kitchen waste, tend to have lower calorific values. Since for Scenario 2 the kitchen waste is removed, the calorific value is higher than for Scenario 1. Generally, the concern in countries where organic fractions contribute significantly to total waste amount, is that the calorific value is too low and additional fuel oil is needed to continuously reach the minimal required temperature of about 850°C (EUR-lex, 2011). The lower limit for calorific values for continuous burning is at 7 GJ/t (A. Sigg, personal communication, May 16, 2018). As shown in Table 5.2, the determined values for the two scenarios are well above this limit in the Seychelles. Therefore, no additional fuel oil is needed for the complete combustion of waste.

Table 5.1
Annual waste amounts, percentages of weight, and growth factors for combustible, combustible without organic and total waste fractions in 2018. Absolute waste values are given in tons per year, the growth factors are based on average of annual waste growth factors from 2000 to 2016 assessed individually per class.

Waste description	Annual total (t)	Weight percentage (%)	Growth factor (–)
Municipal solid waste	31,262	37.0	1.05
Industrial and commercial waste	12,576	14.9	1.08
mMixed waste (private)	23,437	27.7	1.10
Scenario 1: combustible without disturbing material	65,475	77.5	–
Scenario 2: combustible classes without organics	55,766	66.0	–
All waste classes	84,488	100.0	1.05

Burning capacity

Table 5.2 shows the most important values used for the construction of the burning capacity diagram. They were calculated according to the methodology in Section *'Technical Analysis'*. For the definition of minimum waste amount, maximum recycling efforts were assumed, leading to the subtraction of the following recyclable categories (Source confidential):

- Class 1 (municipal waste): Cellulose distribution packing, glass, metal product packing, aluminium product packing, metals, construction wood and electronic waste.
- Class 2 (industrial and commercial waste): Cellulose distribution packing, plastics, glass, aluminium product packing, metals, construction wood and electronic waste.
- Class 5 (mixed waste): Cellulose distribution packing, glass and metals.

After subtraction of these recyclables, a minimum waste amount of 33,533 tons was left (see Table 5.2). Divided by 8,000 annual operation hours, an hourly throughput of 4.2 t/h resulted. The maximum waste amount bases on a scenario with high economic and population growth and no recycling efforts according to research from the Case Study 2016 (TdLab, chapt. 7, 2016), ending up with 143,367 tons of waste per year and an hourly throughput of 17.9 t/h. The total combustible amounts for scenarios 1 (65,475t) and 2 (55,766t) were determined according to the description in Section *'Scenarios'*. After division by the 8,000 annual operation hours, hourly throughputs of 8.2 t/h and 7.0 t/h resulted. The calorific values for Scenario 1 and 2 were calculated according to the methodology presented in Section *'Technical Analysis'*, and the weighted results are shown in Table 5.2. The upper and lower limits for the calorific values were taken from literature and experience reports as explained in Section *'Technical Analysis'*.

As elaborated in Section *'Technical Analysis'*, in addition to the calorific values and hourly throughputs, the conversion efficiency is necessary to determine the final power production, since some energy is lost during transformation from heat to power. Table 5.3 shows the respective efficiencies for the boiler and the turbine as well as the

Table 5.2
Design parameters used for the construction of the burning capacity diagram.

	Minimum	Maximum	Scenario 1	Scenario2
Total combustible amount [t]	33,533	143,367	65,475	55,766
Hourly throughput [t/h]	4.2	17.9	8.2	7.0
Calorific value [GJ/t]	7.0	16.0	11.7	13.4

Table 5.3
Overview of boiler and turbine efficiency applied for the construction of the burning capacity diagram according to Lemann & Neumann (2012), p. 100f.

Efficiency	Minimum	Mean	Maximum
Boiler	0.7	0.725	0.75
Turbine	0.25	0.3	0.35
Combination	0.175	0.218	0.263

combined one, which resulted from multiplying the individual ones. This combined efficiency was used to determine the power production of a plant as shown in Table 5.4 in Section 5.3.2.

Figure 5.6 shows the resulting burning capacity diagram. The diagonal lines in turquoise for Scenario 1, green for Scenario 2 as well as brown and black for max and min calorific values. They were obtained by multiplying the hourly throughput with the respective calorific value from Table 2 and the mean efficiency from Table 5.3, yielding the power production in megawatt (MW). The red dot is the point of nominal functioning for scenario 1, describing the current situation for 2018. Based on this point, a feasibility zone was defined in blue, where an incineration plant works properly according to the methodology in Section *'Technical Analysis'*. The dotted blue line indicates a thermal overload of 10%, which is not ideal but should not be problematic for a short time period either. Such an overload might occur if waste characteristics and amounts increase for a short period. If a plant is operated in this zone for an expanded time period, it can lead to increased pollution emissions as well as a reduction of the lifespan of different components.

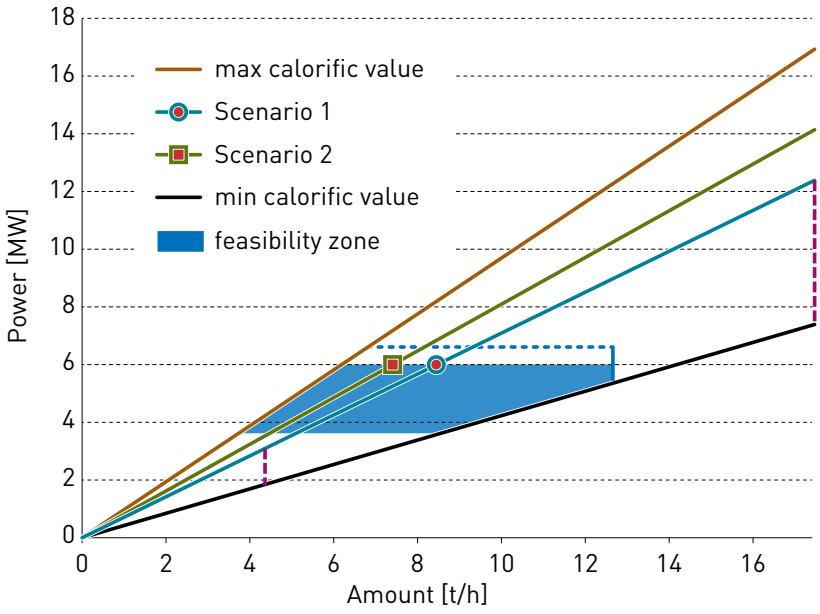

Figure 5.6
Burning capacity diagram displaying the blue framed feasibility zone for a plant built around the point of nominal functioning for Scenario 1, marked by the big red dot. The base and top line illustrate 60% and 100% of the nominal power production. The dotted blue line shows a thermal overload of 10%, which is acceptable for a short while. The maximum throughput limit of 12.9t/h (vertical blue line on the right of the feasibility zone) lays 50% above the nominal throughput. The violet dashed lines indicate the minimal throughput (maximal recycling efforts for waste amounts in 2018) and maximal throughput (worst case 2040, assuming highest population and economic growth rates without recycling) The diagonal lines indicate the respective calorific values for Scenario 1 (turquoise), Scenario 2 (green), upper limit (brown) and lower limit (black). The orange dot shows the point of nominal functioning for Scenario 2.

The nominal functioning point for scenario 2 is situated close to the nominal functioning point of scenario 1 and lies within the blue feasibility zone. This is an important observation, meaning that even if the kitchen waste is sorted out and treated separately, the incineration plant still works efficiently. The reduced hourly throughput is nearly compensated by the higher calorific value for scenario 2, revealing only a slightly reduced power output (see Table 5.4 in Section 5.3.2).

Further it can be seen that even for the minimum waste scenario (violet dashed line), where recycling efforts are maximized and waste production remains constant, the point of nominal functioning might still lie within the viable range depending on the calorific value. However, this cannot be guaranteed with certainty, since further analysis would be required to assess the new calorific values that likely would be higher. Even if the point of nominal functioning of this scenario would lie within the blue zone, it is not recommendable to run a plant at the lower limit as not being economic.

The upper throughput limit (vertical blue line on the right) of the functioning zone equals 12.3t/h. The maximum waste throughput amounts to 17.9 t/h (violet dashed line, see Figure 5.6). This amount is located outside the feasibility zone and could not be managed by the incineration plant. This extreme, however, is based on highest population and economic growth assumptions without any recycling.

If recycling would be maximized as presumed for the minimum waste assumptions, the hourly throughput would equal 9.2 t/h, which would lie within the feasibility zone even for increased waste production.

Location analysis

In order to reduce transportation costs and minimize unnecessary trips, the incineration plant should be located as close as possible to the main areas of waste generation (e.g., large, dense settlement areas) and should be easily accessible from all over the island. A previous study already found the area around the current landfill in Providence to be a cost effective and efficient location (Bunce, 2010). Interviews with representative from MEECC and LMWA also revealed that the Providence area is the government's preferred location for such a facility.

The MEECC currently prefers the positioning of the incinerator to be as close as possible to the current landfill, as this would enable the existing waste management system (transport) to continue functioning in the same way as it does today.

The spatial analysis found that the Providence area would indeed be a suitable location for an incineration plant (see Figure 5.7). Five of the six most suitable areas are found in this area. This shows that Providence is not only a good location based on its centrality, but also based on its dis-

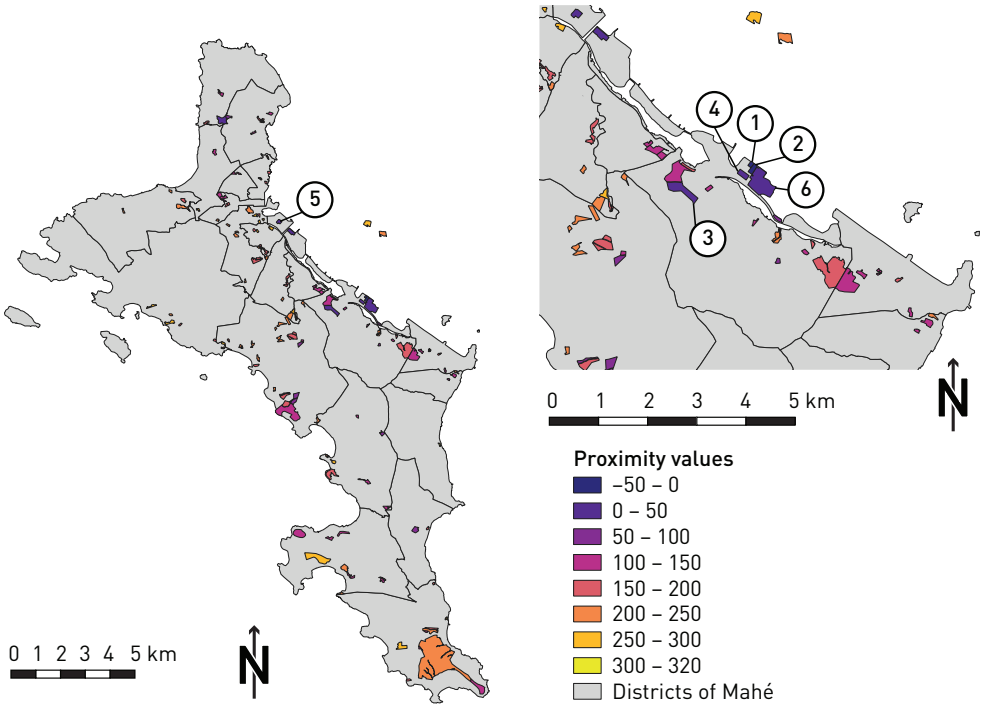

Figure 5.7
Results of the GIS analysis. The results of the zone analysis are fitted with the suitability values from the proximity analysis. The higher the suitability values, the less suited they are. The most promising candidates are found in the area around Providence (enlarged Section), the top 6 are labelled. For more details including the buffer distances and suitability values for GIS layers see Appendix 5.6.

tance to settlement areas and ecologically important areas. The urban characteristic of Providence, with its industrial typology would well fit to an incineration plant, and the generated noise emissions would not pose additional noise to the closest residential areas. Additionally, synergies with existing utility facilities, such as power sub-stations, could be used to access the energy grid more easily and efficiently. A negative factor of the Providence sites would be their proximity to the airport. This would impose restrictions on the height stack of the plant. However, there are incineration plants already operating in proximity to the airport (e.g. in Istanbul, under construction). Exhaust fumes should pose no threat to aviation (A. Sigg, personal communication, May 16, 2018). The suitable location outside Providence (candidate 5, see Figure 5.7) is located near the Victoria port area. The proximity to the city may not be well accepted and would require a complete re-design of Mahé's collection system (for detailed proximity analysis see Appendix 5.5). Additionally, synergies with existing waste facilities at Providence could not be used as efficiently. We therefore conclude that this location is unreasonable.

5.3.2 Economic assessment

Investment costs are relatively higher for small plant capacities in comparison to large ones (Rand et al., 2000). The Seychelles' current annual waste production refers to a small plant capacity, signifying that investment costs could be relatively high. According to the 'Municipal Solid Waste Incineration – A decision maker's guide' by Rand et al. (2000), investment costs would be approximately 40 to 50 million US dollars stated in 2000. Another rough investment estimation from a managing director at an incineration plant in Switzerland for an incineration plant packed in steel construction with complete process engineering on an already developed property adds up to approximately 50 million (M. Wild, personal communication, May 11, 2018). This rough estimation was supported by an experienced director of operations for incineration plants (A. Sigg, personal communication, May 16, 2018). These two estimations, however are not meant to be precise or definite but aim to give an idea of order of magnitude.

When looking at operational costs the net costs per treated metric ton decrease with increasing plant size, meaning that we have again relatively high bearings for a possible rather small incineration plant in the Seychelles. A rule of thumb from two Swiss incineration plant experts (A. Sigg, personal communication, May 16, 2018, M. Waldner, personal communication, May 14, 2018) suggests that investment costs equal operational costs after about 15 to 20 years. If considering investment costs of 40 million US dollars, this would then amount to 50 to 66 million US dollar operation costs for an expected lifetime of 25 years for such an incineration plant.

Incineration is significantly more expensive in operation than controlled landfilling, which currently amounts to 18 million SCR per year that the government pays to STAR. For a plant to be economically feasible, costs must be minimized through sale of energy recovered. Sale of energy to large-scale industrial consumers nearby can minimize plant construction costs and recover a high percentage of energy. Incineration plants produce heat which can be converted to electricity through thermoelectric generators. This makes sense, as demand for electricity is usually higher than heat demand, although the conversion involves energy losses. Plants producing a combination of electricity and heat involve higher complexity of mechanical and civil works, resulting in higher construction costs. As not many heat consumers exist in the area of Providence landfill, a combined approach of heat and power is inevitable from our point of view.

On the other hand, the electricity produced from an incineration plant acts as a renewable source of energy, thus diminishing the Seychelles' fossil fuel import quantity and dependency. Our calculations (see Table 5.4) suggest that our plant from scenario 1 (producing 4.7–7 MW) and those from scenario 2 (producing 4.5–6.8 MW) will have an annual production of 39.4–59.6 GWh of electricity (scenario 2). This will roughly translate to savings of 3,390–5,122 tonnes of oil equivalent per year (scenario 2). Considering the market prices of the last 5 years, this results in annual oil import savings of 1.58–2.4 million dollars per year (scenario 2). Should the plant be built, it will be responsible for 9.3–14.1% (scenario 2) of Seychelles energy production and is able to boost the share of renewables from the total energy mix to the range of 18.9–23.7% of the total production (scenario 2).

The extrapolated annual oil savings for an expected plant lifetime of 25 years (see Figure 5.8) show that a significant part of the investment costs could be covered by the resulting reduction of fossil fuel imports. Based on the estimation of two Swiss incineration experts, the minimum investment costs were set to 40 million US dollars and the maximum investment costs to 50 million US dollars (see beginning of this section). Applying their rule of thumb that investment costs equal 15 to 20 years of operation, the operation costs were calculated for an expected lifetime of 25 years, amounting to 67 million US dollar and 83 million US dollar, respectively. Savings of fossil fuels were adopted from Table 5.4, whereof minimum and maximum annual savings are based upon the 5-year average for an expected lifetime of 25 years, thus resulting in minimal savings of 39.5 million US dollars and maximal

Table 5.4
Overview of electricity production and energy savings a technically feasible incineration plant in the Seychelles. These are rough projections and are often based on 2017 data, without considering currency fluctuations or discount factors.

	Scenario 1			Scenario 2		
	Low Efficiency	Average Efficiency	High Efficiency	Low Efficiency	Average Efficiency	High Efficiency
New Plant Input [MW]:	4.7	5.8	7	4.5	5.6	6.8
Annual production [GWh]:	41.2	50.8	61.3	39.4	49.1	59.6
Resulting annual oil savings:						
TOE[a]	3,540.2	4,368.7	5,272.6	3,389.5	4,218.1	5,121.9
BBOE[b]	24,218.8	29,887.1	36,070.6	23,188.2	28,856.5	35,040.0
USD, 5 year average, 2012–2017[c]	1,650k	2,036k	2,457k	1,580k	1,966k	2,387k
USD, 1 year average 2017	1,164k	1,436k	1,733k	1,114k	1,387k	1,684k
Resulting oil savings: (Plant lifetime 25 years)						
USD, 5 year average, 2012–2017[c]	41,245k	50,899k	61,423k	39,491k	49,144k	59,675k
USD, 1 year average 2017	29,093k	35,902k	43,330k	27,855k	34,664k	42,092k
Share of overall energy production (2017)[d]	9.7%	12.0%	14.5%	9.3%	11.6%	14.1%
Share of renewable energy production (2017)[e]	19.3%	21.6%	24.1%	18.9%	21.2%	23.7%

[a]Tonnes of (crude) oil equivalent
[b]Barrels of Brent Oil equivalent
[c]Average 5 year US Dollar prices of 1 gallon of US crude oil (U.S. Energy Information Administration, 2018).
[d]Read: An incineration plant would contribute to X% of the overall Seychelles energy production in 2017.
[e]Read: The share of renewable energy production (including incineration) would contribute to X% of the overall energy production.

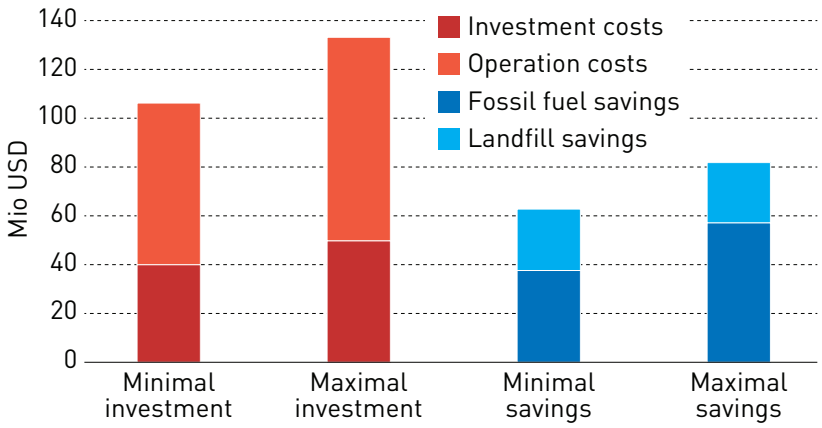

Figure 5.8
Economic comparison of costs and savings of an incineration plant, assuming minimal and maximal investment and operation costs and minimal and maximal savings through fossil fuel savings. Minimal investment costs were set to 40 million USD and 50 million USD for maximal investment costs which corresponds to 67 million USD and 83 million USD according to 15 years OPEX = CAPEX. Minimal savings for fossil fuels base on 5-year average from 2012 to 2017 and amount to 39.5 million USD for a lifetime of 25 years and maximal savings equal 61.4 million USD. Landfill savings are based on a fixed amount of 18 million SCR paid annually in 2018, equally to 31.2 million US dollar for the total of 25 years. All costs are calculated for an expected lifetime of an incineration plant of 25 years, assuming linear increase.

Table 5.5
Overview of factors that can influence the suggested investment and operation costs and how we assess the situation qualitatively for Seychelles. Plus signs represent additional costs, while minus signs indicate saving possibilities. A zero means no influence on project costs.

	Relative cost impact for Seychelles
Marine climate (corrosion)	+
lLabour costs	– –
Transport of material and spare parts	+ + +
Geographic location (experts)	+
Land costs (government property)	0
Proximity to utilities (e.g. power stations)	–

savings amounting to 59.7 million US dollars (scenario 2). Additional savings can be earned through omission of landfill operation costs, summing up to 18 million SCR annually in 2018. Multiplied with the expected lifetime, savings of 450 million SCR equally to 31.2 million US dollars can be achieved. Savings on land reclaiming are not considered for this rough comparison which would offer further savings potential. Additionally, leachate treatment could be omitted, which would create further saving potential. This aspect is not covered either.

Table 5.5 gives a qualitative estimation of investment and operation costs trying to assess where costs for the Seychelles are expected to be higher, lower or equal to a regular European incineration plant. Due to the marine climate, we expect somewhat higher costs arising from additional protection against salt and corrosion. However, salinity should not be a problem, if vulnerable equipment is properly isolated (M. Wild, personal communication, May 14, 2018). Since wage levels are lower in the Seychelles, the labour costs should be smaller as well. For transport of material and spare parts we predict high additional costs. The remote location of the island will increase transport costs, and the scarce land availability implies higher land costs for storage areas of spare parts. Another effect of the isolated location is low access to waste experts and plant engineers. As current expertise in the Seychelles is limited, trained personnel needs to visit which would incur high travel costs. If the incineration plant is to be built on land owned by the government, no additional costs should arise due to accordance of ownership. The development of an incineration plant location further affects expected costs. Providence would offer an already developed area in proximity to landfills or power stations for instance.

5.3.3 Social acceptance

The survey (N=75) – given its small sample size – provides some indication about the willingness to accept an incineration plant and the concerns regarding an incineration plant. About 84% of the respondents are aware that waste is landfilled at Providence (for more details see Appendix 5.7). Some of the respondents also know that STAR collects and transports the waste. Concerning the effectiveness of the system no clear answer emerged for about one third of the respondents classifying it as not effective, fair or efficient.

Figure 5.9 shows the participants' preferred solutions to the waste problem. The most frequently mentioned suggestion was recycling followed by sorting and incineration. This is an important outcome since sorting is a prerequisite for most recycling processes like composting, for example. Incineration could be a solution for the non-recyclable waste. Other arguments that were mentioned repeatedly were based upon societal changes including implementation, control or education of the people.

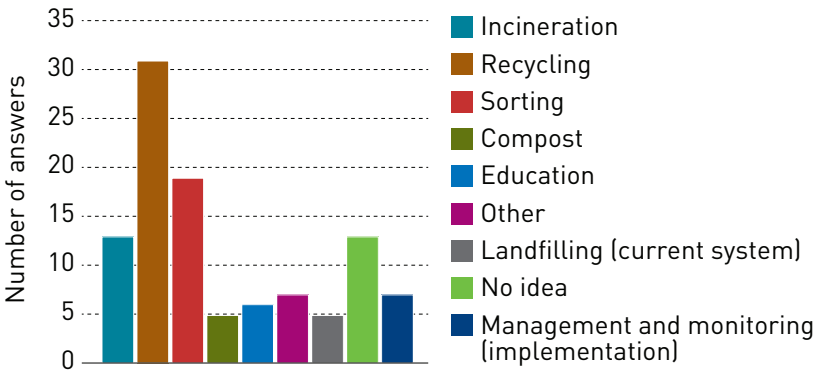

Figure 5.9
Possible or preferred solutions for waste management in the Seychelles. Open question, multiple answers possible (N=75).

Without introducing the topic, approximately 60% of the surveyed people had no knowledge about incineration technology. However, after a short introduction, about 90% thought it would be a good investment solving the Seychelles' waste problem, at least partially (not shown here; see Appendix 5.7). When asked about their main concerns regarding incineration technology, different reasons emerged, the most prominent being bad odour, location (not residential area), and noise emissions (Figure 5.10). About a fifth of the participants did not have any concern at all. Interestingly, most of these concerns are perceptions that do not reflect the technology's promises, which could be resolved by raising public awareness, since a properly handled incineration plant should not produce odour and noise emissions or reduce air quality.

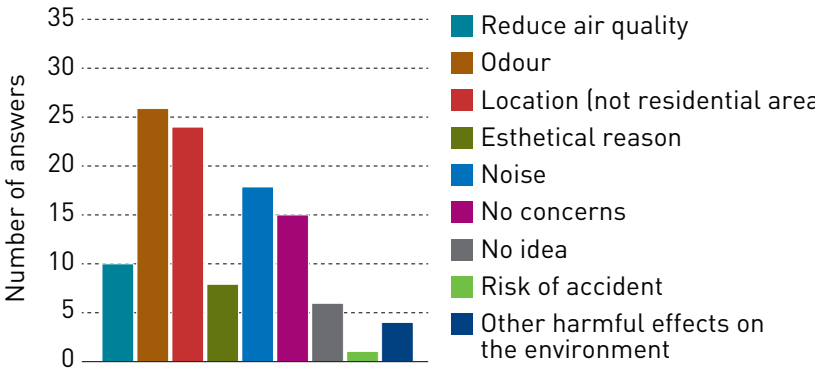

Figure 5.10
Main concerns about incineration technology in residential areas. Multiple answers possible (N=75).

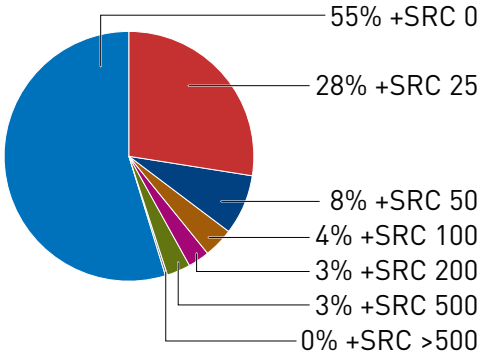

Figure 5.11
Opinions regarding household payments for waste disposal and corresponding amount of disposal fees (N=75).

When asked, whether households should pay for waste disposal, about 55% of the respondent said no (Figure 5.11). The amount which the other 45% would be willing to pay is shown in the same figure. 28% was willing to pay 25 SRC per month, 8% would accept to pay 50 SRC, and only very few would accept higher fees. When asked whether people producing more waste should also pay more, almost 90% agreed on this. It might therefore be an option to think about a polluter-pays principle fee. When asked why fees should be paid, most answered that people should assume responsibility of the waste produced by themselves, reflecting motivation for a

sustainable waste management. However, two other frequent responses were rather pessimistic, i.e., that fees are not effective, and that they should be covered by the government. These opinions may perhaps indicate a lack of willingness to pay waste disposal fees.

5.3.4 Overall feasibility assessment

In the following, we reflect our findings with the criteria from the Decision Makers' Guide to Incineration of Municipal Solid Waste (Table 5.6). This guide is a tool for the preliminary assessment of the feasi-

Table 5.6
Evaluation criteria for feasibility of an incineration plant in the Seychelles (adapted from Rand et al., 2000).

Criteria	Our assessment	Limitations of the study
Institutional		
A solid waste management system, comprising a controlled and well-operated landfill, has been functioning well for a number of years.	Partially fulfilled. Landfill has been operated for several years, certain environmental issues exist.	Current environmental issues of landfill not analysed. Refer to (Baumgartner et al., 2016).
Consumers and public authorities are able and willing to pay for the increased cost of waste incineration.	According to survey results only one third would be willing to pay more for waste management, more people would be willing to pay for a more sustainable approach.	Study gives some indications; small number and not statistically randomized survey.
The authorities responsible for control, monitoring, and enforcement are independent of the ownership and operation of the plant.	Government intends to tender a contract for construction and operation (A. de Comarmond, personal communication, July 12, 2018), would be fulfilled like this.	
Skilled staff for plant operation is available to the plant owner at affordable salaries. Otherwise, there must be long-term reliable operation and service contracts.	Given the current situation in Seychelles, an operation and maintenance contract including workforce should be established.	No in depth analysis.
Waste as fuel		
The average annual lower calorific value must be at least 7 MJ/kg and must never fall below 6 MJ/kg in any season.	Fulfilled. Calorific values between 11.7–13.4 GJ/t found for the two Scenarios.	
Assumptions regarding the delivery of combustible industrial and commercial waste to an incineration plant should be founded on an assessment of positive and negative incentives for the various stakeholders to dispose of their waste at the incineration facility.	Partially fulfilled.	LWMA assesses waste delivered to the landfill, however no incentives prevalent to sort combustible from non-combustible waste.
The annual amount of waste for incineration should not be less than 50,000 tons, and the weekly variations in the waste supply to the waste incineration plant should not exceed 20 percent*.	Fulfilled. Smaller incineration plants exist and are viable. Expected loads between 57,600 and 67,500 t/yr.	Weekly variations have not been assessed. According to Waldner (2018) normal fluctuations can be buffered.

* In our opinion this criterion is outdated. Modern incinerators in operation and economically viable with smaller loads.

bility of introducing large-scale incineration plants into the waste management systems of major cities in developing countries (Rand et al., 2000). Therefore, the tool can also be applied to the context in the Seychelles, where a possible incineration plant would as well be considered as large-scale, though at the lower limit. The most important factors in assessing short- and long-term viability of municipal solid waste incineration are identified and applied for the case of the Seychelles. Criteria that were not further assessed in this case study can be found in Appendix 5.8.

Table 5.6
continued

Criteria	Our assessment	Limitations of the study
Incineration economy		
When surplus energy is to be used for district heating, the incineration plant must be located near an existing grid to avoid costly new transmission systems.	Not fulfilled at Providence. Huge fractions of energy should be converted to electricity.	Heat consumers not fully assessed.
To be economically feasible, the individual incineration units should have capacities of at least 240 t/d (10 t/h), and there should be at least two separate units.*	Not fulfilled. To our knowledge not necessary or outdated. Smaller throughput can still be economically viable. Expected throughput between 7.2-8.4 t/h for two Scenarios	
If a regular market for sale of hot water (district heating or similar) or low-pressure steam is present, the plant should be based on sale of heat only. This is preferable both in terms of technical complexity and economic feasibility. A certain extent of cooling to the environment during the warm season may be preferable to costlier solutions.	Not fulfilled. We recommend combined heat & power system as not sufficient heat demand exists nearby.	No in-depth analysis.
Project cycle		
To avoid conflicts, the public should be involved and informed during all phases but especially in the planning phase (feasibility assessment and project preparation phase).	Highly recommended, not fulfilled at the moment. According to our survey about 60% of the population has no knowledge on incineration technology.	
Incineration technology		
The technology should be based on the mass burning principle with a movable grate. Furthermore, the supplier must have numerous reference plants in successful operation for a number of years.	State of the art suggested.	Part of specific tender process, not part of this study.
The furnace must be designed for stable and continuous operation and complete burnout of the waste and flue gases (CO<50 mg/Nm^3, TOC<10 mg/Nm^3).	State of the art with European air quality standards suggested. Included in our assumption of an incineration plant.	Part of specific tender process, not part of this study.
The flue gas cleaning equipment must be at least a two-field ESP (basic emission control, dust <30 mg/Nm^3).	State of the art with European air quality standards suggested. Included in our assumption of an incineration plant.	Part of specific tender process, not part of this study.
A controlled landfill must be available for residue disposal. Full leachate control must be exercised at the landfill.	Partially fulfilled at Providence; leachate treatment plant not fully working. Fulfilled at Anse Royale landfill	
Municipal solid waste incineration plants should be in land-use zones dedicated to medium or heavy industry.	Fulfilled at Providence.	

5.4 Discussion

The goal of this study was to investigate the feasibility of an incineration plant in the Seychelles in terms of technological, economic and social aspects. Accordingly, ecological impacts were not given much attention although environmental impacts cannot be fully avoided (e.g., CO_2 emissions or contaminated residues (bottom/fly ash) and should not be neglected when introducing this kind of waste treatment (Sharma & Chandel, 2017).

When assessing the technological feasibility, the characterization of the waste in terms of its type, amount, calorific value, as well as their seasonal fluctuations are crucial. Our technical research showed that enough combustible waste is present for an incineration plant to be viable. Sufficient waste would even be present if suitable organic waste would be treated with e.g., anaerobic digestion. All combustible waste classes present increasing amounts of waste according to the growth factors based on the waste development from 2000 to 2016. Future waste amount should therefore be ensured in upcoming years. The calorific values with and without organics are both much above 7 GJ/t and therefore high enough to maintain the burning process without adding auxiliary fuels. Since incineration plants need to be continuously fed with a more or less homogeneous mixture of waste, a well-developed and controlled waste management system is considered a prerequisite for an incineration plant.

The tropical marine climate affects the structure of an incineration plant. Salinity and humidity in the Seychelles are relatively high and might lead to increased corrosion. Problems resulting from humidity can, however be prevented by protective coatings, and salinity should not be a problem when vulnerable equipment is protected from salt by proper isolation (M. Waldner, personal communication, May 14, 2018). Thus, humidity and salinity should not impair incineration technology. Since humid waste has a lower calorific value, additional wetting should be prevented by implementation of closed bins and covered waste bunkering in order to reduce drying expenditures.

Because the Seychelles is an island state, expected transport costs are comparatively high, since no local production of incineration plant components exists. The same problem arises for ensuring supply of spare and wear parts. IOT, the biggest tuna canning factory in the Indian Ocean, responsible for the management of the tuna industry in the Indian Ocean located on Mahé, confirms that spare parts handling is a real issue involving huge costs (M. Benoiton, personal communication, July, 2018). A possible approach for this problem could be an operating contract usually lasting for 20 to 30 years and including administration of company, workforce, equipment, disposal of residues, spare parts and other maintenance costs. The contractor will be responsible for efficient operation and thus guarantee annual throughput of waste and production of energy, in this sense also being responsible for timely delivery of spare parts. Decision-makers should think of realizing such a contract for building and operation of an incineration plant, as currently sufficient experience is not available on Seychelles.

When considering pure money flows, the investment as well as the operation and maintenance costs are higher for incineration than for simple landfilling. However, this is mainly the case because future cost and consequences of landfilling cannot easily be quantified and land reclamation is probably not reflected in the overall costs so far. The cost of incineration may be recovered through a combination of a tipping fee usually paid by trade and industry and a general waste manage-

ment charge paid by households (Rand et al., 2000). Substantial saving possibilities accrue due to energy recovery after incineration, preventing thereby combustion of fossil fuels. Additionally, operation costs for landfilling could be significantly reduced. We estimate that only due to omitted landfill operation and fossil fuel expenses, between 60 to 70 percent of the investment and operation costs could be covered during an expected lifetime of 25 years for an incineration plant.

The acceptance survey indicates that many Seychellois have a basic knowledge about waste management and are acquainted with sustainable treatment options. Their willingness to pay for disposal is not pronounced though, as more than half of the questioned people stated that households should not pay for waste disposal. When asked about incineration technology, the surveyed people generally considered it as a good approach. However, concerns about reduced air quality, noise, odour and other disturbances were often mentioned. Odour disturbances are not a problem as stinky waste is located inside the building and released gases don't smell bad after combustion. Noise disturbance can be avoided by proper location of plant. In terms of air quality concerns, modern incineration plants have no problems in reaching air quality standards. At some sites released air after incineration is found to be even better than ambient air (A. Sigg, personal communication, May 16, 2018). Such concerns are often coming from a lack of knowledge about the technology and might be corrected by raising awareness through educational campaigns or public hearings. It is necessary to involve the population throughout the project cycle in order to increase acceptance and willingness regarding financial support.

Our GIS analysis revealed that the area around the current landfill in Providence would be suitable for an incineration plant. However, based on the conducted research, we cannot say that this is the best location on Mahé. We can only confirm that, under the basic conditions we assumed, the Providence area is comparatively more suited than other examined areas. For a definitive result, we recommend basing the analysis on more thorough real-world indicators (e.g., data on noise emissions, government properties) and not only on land zones. Additionally, the road network could be used for a waste-generation-weighted network analysis to determine the location on which the lowest transport costs incur.

The current legal framework does not include clear responsibilities and detailed procedural methods, as examined in depth in Chapter 7 of this study. There is no clear directive on the desired technology for solving Seychelles' waste issue. Additionally, the energy market is still heavily regulated and centralized. Once these issues are resolved, it is important that the government maintains the lead in the waste management strategy. This should begin by defining a clear strategy, continue tendering out the project under clear framework conditions, rely on experienced manufacturers and builders and, most importantly, also by controlling and monitoring the operation and maintenance under the tendered conditions.

5.4.1 Limitations and outlook

Overall, our study demonstrates the principal feasibility of an incineration plant as major element of waste treatment activities. Nevertheless, our study also comprises some limitations. For example, the technical feasibility relies heavily on the assumptions of the waste composition suggested by a study (Source confidential) which itself may have some shortcomings,

and it lacks technical specification such as the design of a plant. Furthermore, the costs reflect rough estimates and need further investigation. Detailed investment and operational costs can be provided only after the technical design of the plant has been specified. In addition, survey results must not be overinterpreted as the sample is low and does not reflect a full representation of the population. Irrespective of these flaws we think our study does provide a sound basis for an informed decision i.e., to decide if incineration is an alternative to landfilling, the current waste treatment practise in the Seychelles.

The present examination focusing on technological, economic and societal feasibility can be seen as basis for more detailed analyses. The assessment of waste treatment methods needs to be elaborated within a bigger picture, whereupon a number of questions need to be answered. The list below gives some ideas what such questions might look like:

- What are the full costs if there is no change in the current waste management system in terms of ecological consequences, impacts on tourism, or building of further landfills?
- Which waste streams should be treated separately and have high recycling potential?
- How can costs be saved with an improved collection system? Could money be generated for a more sustainable waste treatment by not collecting on a daily basis and by enhanced separation?
- What is the added economic value of an incineration plant by avoiding fossil fuel purchasing, creating additional job opportunities, or reducing ecological damage?
- How can local expertise be gained and improved, and social awareness be enhanced, through campaigns and education?

5.5 Conclusion

Taking into account all analysed aspects regarding incineration technology in general and assessing the situation in the Seychelles, we ascertained that incineration could be an option based on technological, economic and societal feasibility. However, the outcome of the assessment depends on many linkages and needs to be handled with care. Plant layout and energy savings greatly affect expected costs. Recycling, sorting and collection greatly influence waste characteristics and thus feasibility outcomes.

Incineration is a technology expected to exist for at least 25 years, why also sufficient time should be provided for decision making and robust future forecasts. Costs but also benefits of incineration are sizeable and must be balanced within a bigger context for the whole time period of the project. A full cost benefit analysis is therefore required to assess whether the locally obtainable benefits justify the costs. We think, with ongoing developments, that incineration is unavoidable as technical advantages are most pronounced. However, we could not conclude whether or not conditions in the Seychelles are already robust enough to allow proper planning, operation and monitoring of such a technology.

The decision to go towards incineration lies not in our hands, but as many issues exist, an even more cautious approach should be chosen relying on expertise of companies with long lasting expertise. This is crucial as expertise within governmental bodies is widely lacking which makes decision makers highly dependent on reliable partners.

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6 Financial mechanisms: Money flows

Juanita von Rothkirch, Marc Chautems*, Djani Djamil***

6.1 Introduction

Providing good solid waste management services while ensuring a financially sustainable system continues to be a major challenge in many Small Island Developing States (SIDS) (Mohee et al, 2015). Even though municipal waste management systems (WMS) exist in most urban areas, it is frequently one of the most neglected areas of municipal services. The management system is assigned with a low priority, resulting in issues such as inefficient operation and lack of human resources (Khajuria et al, 2010; Kumar et al, 2017). With economic and population growth and the modernization of waste management systems, the cost of waste management is likely to increase. However, municipal officials nor the public seem to be aware of the magnitude of the costs involved, and how to finance these expenditures (Appasamy & Nelliyat, 2007).

Even though challenging, it is evident that a financially sustainable system is key for enabling good waste governance. We define financial sustainability as the ability to grow and maintain the delivery of a service with short- and long-term economic stability. In the waste sector, the quality and coverage of solid waste management (SWM) services are determined to a large extent by the amount of funding available for the collection, transport, disposal, and recycling of waste (Woodruff, 2014).

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Furthermore, improving the transparency in accounting systems can become an important catalyzer in the mobilization of financial resources from citizens or external sources (Woodruff, 2014).

In the Seychelles, government officials have stated that the development of the WMS of the country is constrained by the limitation of economic resources. Considering the issues of land scarcity and increasing landfilling rates (Lai et al, 2016), different stakeholders state that new financial resources are needed for the construction and operation of high-priced treatment plants, such as incineration, biogas, or recycling facilities. However, citizens complain that funds do exist, but that there is a lack of transparency and accountability in the system.

In consequence, a review of the state and potential changes in the waste financial system is crucial to improve the quality of the current waste management services and to make future related projects move faster and further. This implies that in order to enhance cost efficiency and, eventually, capital recovery, a detailed cost structure of the waste management service accompanied by appropriate measures for improvement is important (Lohri et al, 2014).

This research project aims to analyse the structure of the waste management financial system. This comprises the actors, money flows and instruments that are part of the system, as well as the processes that repeatedly modify it. With this exercise, we aim to describe the structure, identify weaknesses and recognize economic instruments that are potentially appropriate for the local context. The questions that guide our research are:

- How does the current waste financial system work?
- What are the main weaknesses of the current waste financial system?
- Which instruments would be context-appropriate for collecting funds and/or steering the waste related behaviour of individuals?

Table 6.1
Sources of financial data and estimations.

Source	Data extracted
Programme Performance Based Budget Statements, 2017	Budget of the LWMA and MEECC (2018)
Receipt of waste collection (landfill tipping fees and commercial waste collection, 2018)	Partially fulfilled. Collection and transportation of waste to the landfill works, however number of contracts is enormous, leading to lack of control.
Breakdown of the budget, LWMA, 2018	Breakdown of the budget of the LWMA
Accounting software LWMA, 2018	Payments from the LWMA to STAR
Summary of Financial Statement (unaudited), ETF, 2017	Revenues of the ETF
Financial Statement, WMF, 2017	Revenue and expenses of the WMF
Financial Statement, WMF, 2017, and Levy Scheme	Money retained by redeem centres and Refund to informal collectors (deducted)
Weighbridge database, Providence Landfill, 2016	Waste quantity per waste class
Seychelles in figures, 2017	Population of the different islands
Population and Housing Census 2010 Report	Number of households per district

6.2 Methods

To address our questions, we employed data from the report of Lai et al. (2016), public financial reports, and interviews. First, we extracted the budgeted income and expenditures of different actors from the budget reports of the Ministry of Finance, and from financial statements of the MEECC and LWMA. Interviewees from LWMA and the MEECC provided context and assisted us in the clarification of data, budget lines, and functioning of the economic instruments in place. Second, we conducted a literature review of economic instruments based on the Polluter Pays principle. We discussed with private and public interviewees the weaknesses of the current system and applicability of alternative instruments to the local context.

6.2.1. Structure of the financial system

We identified the main actors of the WMS in the document 'Solid Waste Management in the Seychelles' (Lai et al, 2016) and in the 'Seychelles Solid Waste Assessment Report 2017' (Gonzalves, 2017). We extracted information about the allocation of funds, the financial interactions between actors, and the money flows of the waste management subsystems from the documents listed in Table 6.1. We then mapped the interactions between actors and money flows of the economic instruments in a Sankey diagram.

6.2.2 Interviews

We conducted 19 semi-structured interviews in July 2018 with consultants, waste collectors, members of the private sector, representatives from the civil society, and members of the government (for full list of all interviewed experts see Appendix 6.1). Based on their field of expertise stakeholders were interviewed about the following topics of the waste financial system:

1. Context, past experiences and future plans.
   a. Particularities of the local context and effects of the 2008 financial recession on the waste sector.
   b. Learnings from past experiences.
   c. Plans – short, medium and long term.
2. Main income sources and expenses of public entities.
   a. LWMA.
   b. MEECC.
   c. WMF and ETF.
   3. Financial details of subsystems.
   a. Tipping fees for waste disposal at the landfill.
   b. Fees for commercial collection and disposal via LWMA.
   c. Levy on cans and PET bottles.
   d. Projects of the ETF.
   e. Household and commercial waste collection and landfilling by STAR.
4. Processes that modify the system.
   a. From planning to implementation and financing.
   b. Tender process.
   5. Weaknesses of the current system.
   a. Money allocation and distribution.
   b. Breakdown of financial statements.
   c. Responsibilities: autonomy, division of tasks, and efficiency of waste management.
   d. Transparency: accountability, conflicts of interest, and irregularities in former tenders.

6.2.3 Economic Instruments

We conducted literature research regarding several economic instruments. We focused on instruments which are based on the polluter pays principle, which is one of the guiding principles of the Seychelles Solid Waste Management Policy 2014-2018. We reviewed the general advantages and disadvantages of the systems and described countries that already use the

system to manage their waste. Following that, we asked two consultants, two members of the civil society, and additional interviewees about the suitability of different instruments for the local context. Finally, we proposed how current instruments could be further developed, or in which way they could be modified in order to meet the current needs. In cases where we had sufficient data, we calculated the potential supplementary revenue that could be obtained with the new system.

6.3 Results

In this section, we describe the actors of the waste financial system, the financial instruments that are in place, and the money flows that connect them. We also present an estimation of the costs of the system and present the main weaknesses that actors mentioned or were observed by us.

6.3.1 Main actors

The main actors of the waste financial system are governmental bodies that are directly involved in the planning, financing, and implementation of waste management measures, as well as the private actors in charge of the waste collection and management. Their respective responsibilities are described below.

Ministry of Finance (MoF)

In the case of waste management, the MoF is responsible of providing economic resources for the MEECC and the LWMA. Additionally, the MoF receives income from commercial waste collection and tipping fees. The Treasury of the Ministry is also an intermediary step in the levy system between the Seychelles Revenue Commission (SRC) and the Waste Management Fund (WMF). Furthermore, it participates in the system by allocating two employees at the LWMA: The Financial Controller and an employee in charge of the collection of tipping fees at the landfill.

Ministry of Environment, Energy, and Climate Change (MEECC)

The MEECC, under the program of Environmental Protection, is the entity in charge of developing waste policies and obtaining the financial resources for their implementation. The Director of Solid Waste Management is the only employee exclusively in charge of waste management policies. Additionally, the MEECC is in charge of the administration of the Environmental Trust Fund (ETF) and the Waste Management Fund (WMF).

The ETF's objective is to finance projects and programs related to the preservation and improvement of the Environment. It works on a system of grants allocation for capacity building, education and awareness, community projects, and other initiatives (ETF, 2017). For example, in 2017 the fund supported recycling projects in schools. The income sources of the ETF related to waste are the Environmental Fee charged in water bills of households and fines for littering.

The WMF is in charge of coordinating the Levy system for PET bottles and aluminium and tin cans. The Levy is collected by the SRC, transits by the treasury of the Ministry of Finance and is collected in the WMF. Subsequently, the WMF gives money to the Redeem centres according to the quantity of collected bottles and cans.

Landscape and Waste Management Agency (LMWA)

The LWMA is the agency of the MEECC in charge of organizing the cleaning of public spaces and waste collection. Therefore, it is the main governmental body in charge of implementation of policies, plans and strategies of the MEECC in this respect.

The agency receives its financial resources from the Ministry of Finance. In the case of waste management in Mahé the only contractor is STAR. The agency allocates its resources in landfill management, municipal waste collection, and

a partial subsidy for commercial waste collection. The LWMA has also the role of supervising its contractors.

Société de Traitement et d'Assainissement Régionale (STAR)

STAR is the private company in charge of municipal waste collection, a large part of commercial waste collection, landfill management and cleaning of roads and beaches in Victoria. It has been in place since 1997, when it signed a contract with the government for 20 years. In 2017, STAR was supposed to withdraw from these tasks, which is why the government issued a tender for waste collection. We learned from the tender records, that the process was annulled for irregularities in the evaluation process, and the contract of STAR was extended one more year.

The main governmental body with which STAR interacts is the LWMA. The agency is in charge of the payment for STAR's services, as well as its supervision. Additional to the contract with the government, STAR has direct contracts with hotels and stores.

6.3.2 Secondary actors

Apart from the aforementioned actors, other companies and governmental entities participate in the financial system of waste management. These actors manage smaller amounts of economic resources and accomplish specific roles in their respective subsystems. In the following, we briefly describe their roles.

Small commercial collectors

According to the LWMA there are seven licensed companies that are certified to collect commercial waste. However, according to the owner of one of them, only four companies operate regularly. Several interviewees explained that these companies establish direct contracts with hotels or businesses for the collection and disposal of their waste. Additionally, they are occasionally subcontracted by STAR for road cleaning or waste collection.

Seychelles Revenue Commission (SRC)

The SRC is in charge of the levy collection of PET bottles and cans at the port of entry. This money collection can happen right after the products enter the country or at a later stage. The second case occurs when imported products are stored in the bonded warehouse which, by definition, suspends the payment of taxes until the goods are cleared (SRC, 2011).

Redeem Centres

Redeem centres are the establishments in charge of receiving PET bottles and aluminium and tin cans from citizens and transferring them to exporters. In this process, they receive money from the WMF, retain a part, and give the refund to citizens. Many of these citizens are informal collectors, i.e., people who earn their livelihood by collecting respective waste at bin sites and the landfill and bringing them to the redeem centres.

Exporters

Exporters take the material collected and sell it on the international markets. According to the coordinator of the WMF and the exporter of scrap metal, in the past, government was giving part of the levy money for the export of cans. However, currently none of the exporters receive financial support. According to the recycling group (see Chapter 2, Feasibility of recycling: an appraisal methodology), only the materials whose value is higher than the shipping costs are being exported.

6.3.3 Subsystems

Subsystems correspond to sets of actors and money flows that operate around financial instruments. Financial instruments, in turn, are mechanisms intended to collect money for the functioning of the WMS and/or to steer behaviour of residents and producers towards waste separation. Currently, there are five subsystems in place: the tipping fees for waste disposal at the landfill, the fees for commercial collection and disposal via LWMA,

the environmental trust fund, the levy on cans and PET, and fees for waste collection and landfilling by STAR (see Figure 6.2).

Landfill tipping fee

The tipping fee corresponds to the tariff that is applied on waste collectors at the landfill weighbridge, depending on the weight of the discarded material. This fee varies depending on the source, nature of the waste, and/or collection company. According to the LWMA, under the current waste classification scheme, tipping fees are differentiated into twelve categories.

As shown in Table 6.2, the current scheme at the landfill does not charge any fee for the disposal of municipal and commercial mixed waste collected by STAR. Green waste and scrap metal are also free of charge. According to the statistics collected at the weighbridge, in 2016 those waste types (Classes 1, 3 and 6) accounted for a total of 29,919 tons, which represents 42% of the total disposed waste. Therefore, tipping fees were charged for 58% of the waste, with amounts that range between 50 and 1,204 SCR/ton.

However, mixed commercial waste is only free of charge if it is collected by STAR in the framework of the contract with LWMA. STAR also has direct contracts with clients and therefore outside this framework. Mixed commercial waste under these contracts is classified under Class 2. Mixed commercial waste brought to the landfill by other collectors is classified under Class 5. (See Appendix 6.2 for further clarification on waste types and tipping fees).

The staff in charge of collecting the fees are one operative from STAR and one operative appointed by the Ministry of Finance, who works closely with the LWMA.

The money collected at the weighbridge is transferred to the Ministry of Finance (See Figure 6.2). Since this money flow is accounted for under the same item as payments from commercial waste collection contracts, the LWMA is not able to provide figures about the income exclusively from tipping fees. From the weighbridge statistics and the tipping fees of the year 2016, we roughly estimated that the revenues

Table 6.2
Landfill tipping fees of 2016. Source: personnel of the LWMA. No written document was available to confirm these data.

Waste class		LWMA tariff: W: weighbridge A: administrative fee O: others	STAR W: weighbridge E: export O: others
1	Municipal and commercial contract with LWMA	Free	Free
2	STAR's private clients	W: 50 SCR/ton	Free
3	Green waste	Free	Free
4	Liquid waste	W: 140 SCR/ton	Free
5	Mixed from private trucks	W: <1 ton: 50 SCR W: >1 ton: 100 SCR/ton	Free
6	Scrap metal	Free	Free
7	Putrescent waste	A: 1,000 SCR	O: 431 SCR/ton O: 1,050 SCR/load
8	Waste oil	W: 0.5 SCR/litre	E: 1,200 SCR / litre
9	Construction and demolition	W: <1 ton: 50 SCR W: >1 ton: 100 SCR/ton	Free
10	Inert	A: 1,000 SCR/load O: 200 SCR/ton	W: 345 SCR
11	Hazardous	W: 800 SCR/ton A: 1,000 SCR/load	W: 1,204 SCR/ton W: 345 SCR (Anse Royale)
12	Special (Medical waste)	Free	O: 1,204 SCR/ton

from tipping fees account for 4.6 million SCR/year. The results concerning tipping fees are presented in Table 6.3.

Commercial waste collection

Commercial waste collection corresponds to the subsystem constituted by businesses and waste collectors (STAR or small collectors). It comprises the money flow from the businesses to the Ministry of Finance (See Figure 6.2).

Commercial establishments can organize the collection and disposal of their waste in two main ways: making a contract for collection services with the LWMA, or directly hiring STAR or small collectors.

1. Making a contract for collection services with the LWMA:

In the case businesses opt for this alternative, the LWMA subcontracts STAR for the collection services. According to an interviewee, the monthly tariff for collection and disposal charged by the LWMA varies between 300 and 8,000 rupees per month, depending on the quantity of waste and the frequency of collection. According to the LWMA, this amount does not cover the total costs, and the agency must partially subsidize the collection services. Usually STAR collects commercial waste together with municipal waste. Therefore, both types of waste are mixed and enter the landfill for free as waste of Class 1.

As explained before, the money received from businesses is grouped together with the tipping fees at the MoF. In consequence, the LWMA is not able to differentiate the income by its source and, subsequently, report on the level of the subsidies. If we subtract the estimated revenue from Tipping fees (4.6 million SCR, see Table 6.4), from the combined money flow of 17.8 million SCR, we conclude that 13.1 million SCR/year are paid by businesses to the LWMA (See Figure 6.2).

In turn, the LWMA is paying STAR 16.1 million SCR/year for commercial waste collection (See Figure 6.2). This means that approximately 18% of the costs of the contract are subsidized by the LWMA.

2. Directly hiring STAR or small collectors:

In this case, businesses establish a direct contract with a waste collection company. If the company is STAR, mixed waste enters the landfill as Class 2. In the case of

Table 6.3
Estimation of the revenue from tipping fees of 2016. We assume that (1) the average density of oil is 900kg/m^3 and (2) the average load of trucks bringing less than 1 ton of waste of class 5 and 9 is 500 kg.

Waste class		Tonnage	Fee (SCR/ton)	Revenue (SCR/year)
1	Municipal and commercial contract with LWMA	26,867	0	0
2	STAR's private clients	10,040	50	502,000
3	Green waste	1,982	0	0
4	Liquid waste	10,890	140	1,525,000
5	Mixed from private trucks	19,415	100	1,941,000
6	Scrap metal	1,070	0	0
7	Putrescent waste	1,083	430	466,000
8	Waste oil	249	556	139,000
9	Construction and demolition	177	100	18,000
10	Inert	37	200	7,000
11	Hazardous	20	800	16,000
12	Special (Medical waste)	13	0	0
	Total	**71,841**		**4,613,000**

other collector companies, it is classified as Class 5 which means that, as compared to Class 2, a double amount per unit has to be paid.

Beside those two ways, the shops can decide to bring their waste directly to the landfill with private trucks. Further, interviewees also mentioned that certain shops dispose of their waste in municipal bins, especially shops that produce only little amount of waste. However, this type of disposal is forbidden by the Environment Protection Act.

Levy on PET bottles and cans

Currently, there are two levy schemes in place that seek to promote the recycling of materials: one for cans and one for PET bottles. The funds are collected by the Seychelles Revenue Commission (SRC) as the products enter the country (For PET bottles and aluminium cans it is 70 cents and 1 SCR, repspectively, see Figure 6.1. Then, the money is transferred to the Treasury of the Ministry of Finance and subsequently to the Waste Management Fund (WMF). The Fund transfers money to the redeem centres (65 and 70 cents, respectively, per PET bottle and aluminium can which means that 5 (per PET) and 30 cents (per can) are retained by the WMF), which gather the cans and bottles from consumers and informal collectors and pays them a refund The reedem centres retain 15 (per PET) and 20 cents (per can) to cover their operational costs (Figure 6.1).

The coordinator of the WMF states that in 2017, the amounts paid by the Fund to the redeem centres were 17.3 million SCR for the PET bottles and 12.4 million SCR for cans. This represents a refund for a total of 26.6 million units of PET bottles and 17.7 million units of cans. From those numbers, we were able to calculate the amounts retained by the fund (6.65 million SCR), the redeem centres (7.54 million SCR) and the refund given to the consumers ((22.17 million SCR, seeTable 6.4).

Since in the Seychelles there is no separation of waste at the source, many of the cans and bottles are not refunded. One interviewee stated that only around 50% of the PET bottles are brought back. Therefore, it would be expected that the WMF had an income surplus as almost all PET bottles and cans are imported and should be taxed when entering the country. However, we learned from the coordinator of the WMF that this is not the case.

The Fund only retains a minor amount of money over the course of the year, which is used to cover the administrative cost and for the transport of the PET bottles and cans from Praslin and La Digue to Mahé. This results in expenses of 2.4 million/SCR per year (See Figure 6.2). However, this amount represents only around one third of what the WMF is supposed to retain.

We also learned from the coordinator of the WMF, that the board changed the distribution of the levy at the end of 2017.

Table 6.4
Amount paid/retained by different actors of the levy system in 2017. Source: Waste Management Fund.

Type of material/money flow	Levy on PET bottles	Levy on cans	Total
Number of bottles / cans	26,621,000	17,723,000	44,344,000
Retained by the WMF (SCR/year)	1,331,000	5,317,000	6,648,000
Retained by redeem centres (SCR/year)	3,993,000	3,545,000	7,538,000
Refund to consumers (SCR/year)	13,310,000	8,861,000	22,172,000
Total (SCR/year)	**18,635,000**	**17,723,000**	**36,357,000**

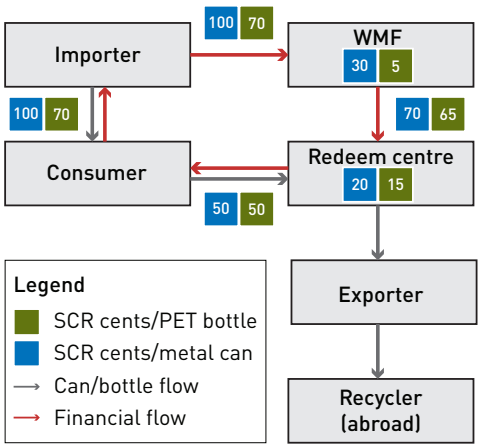


Figure 6.1
Main material and financial flows involved in the levy on aluminium and tin cans and PET bottles. Source: Waste Management Fund.

Previously, the WMF used to pay 0.10 SCR per can to the exporter. This subsidy was cancelled under the new scheme. However, during a discussion with the can exporter we learnt that he was not aware of the decision.

Environment Trust Fund (ETF)

The ETF collects its revenue from an environmental fee in water bills, fines for littering, and from the royalties of 'coco the mer', among others. According to the financial statements of the ETF, the fee in the water bill represents 90% of the income of the Fund. This fee corresponds to 15 SCR/month, which are collected by the PUC in each household.

As mentioned above, another source of revenue of the ETF are fines for littering. According to the Environmental Protection Act (EPA), a person who "throws, deposits or places any waste on any street or public place", is liable on conviction to a fine of maximum 5,000 SCR (National Assembly, 2011). However, an interviewee explains that punishment for littering is not frequently applied.

Financial statements of the ETF indicate that the collected money is employed for the subvention of different sustainability projects, which only occasionally cover waste topics. In 2017, 1.6 million SCR or 30% of the ETF expenses were allocated for five different waste related projects (See Figure 6.2).

Some interviewees stated that the fee in the water bill is exclusively used for waste projects. However, this is obviously not the case. Assuming that the totality of the fines for littering is invested in waste projects, we conclude that 15.1% of the fee in the water bill was used for waste related purposes in 2017. Therefore, each household is directly contributing to the WMS with 15.1% of 15 SCR/month, which equals 2.25 SCR/month.

Municipal waste collection and landfilling by STAR

The financial controller of the LWMA informed us that STAR receives a sum of 48.2 million SCR/year for landfilling and waste collection (See Figure 6.2). Additionally, it receives 3.2 million SCR/year for the cleaning of roads in Victoria.

We learnt that the distribution of the payments for the different services are different than the budget. In total, the difference accounts for 6.9 million SCR, as shown in Table 6.5 (See also Figure 6.2). Since the service of cleaning of roads in Victoria is not part of the WMS, it is not included in the calculations.

Table 6.5
Payments of the LWMA to STAR for waste management services in 2018. Source: LWMA.

Service	Budget (SCR/year)	Payment (SCR/year)	Difference (SCR/year)
Municipal waste collection	31,800,000	14,000,000	17,800,000
Commercial waste collection	16,200,000	15,300,000	0,900,000
Landfill management	7,100,000	18,800,000	–11,800,000
Total	**55,000,000**	**48,100,000**	**6,900,000**

Different interviewees are confused about the sum and form of the payment of landfilling services. This confusion arises from the fact that STAR used to receive 1,000 SCR/ton and, since the extension of the contract for 2018, it receives a fixed payment per month. If the amount that STAR receives for landfill management is divided by the tons of landfilled waste (71,241.23 tons, according to the weigh-bridge data of 2016), we conclude that the

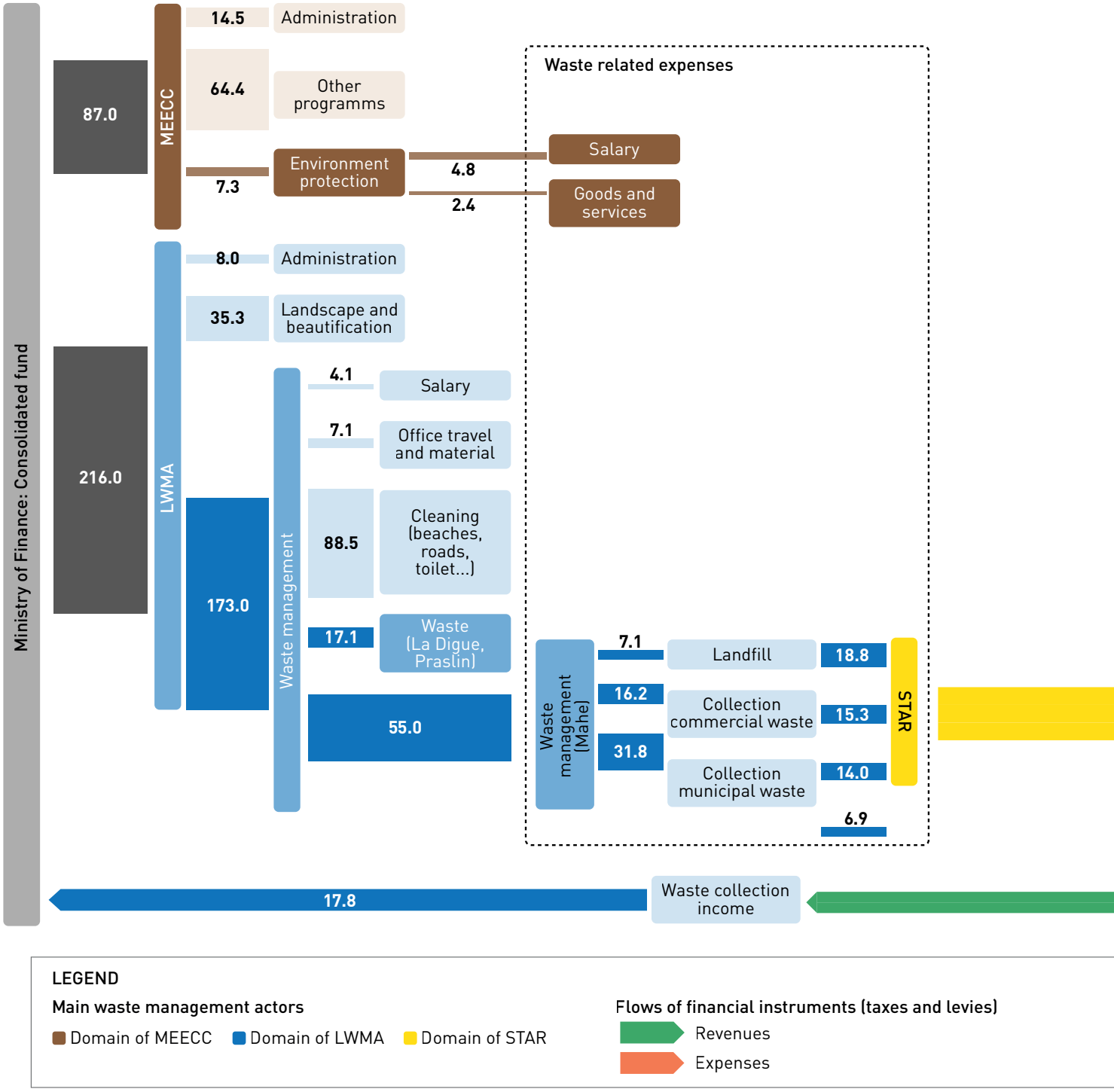
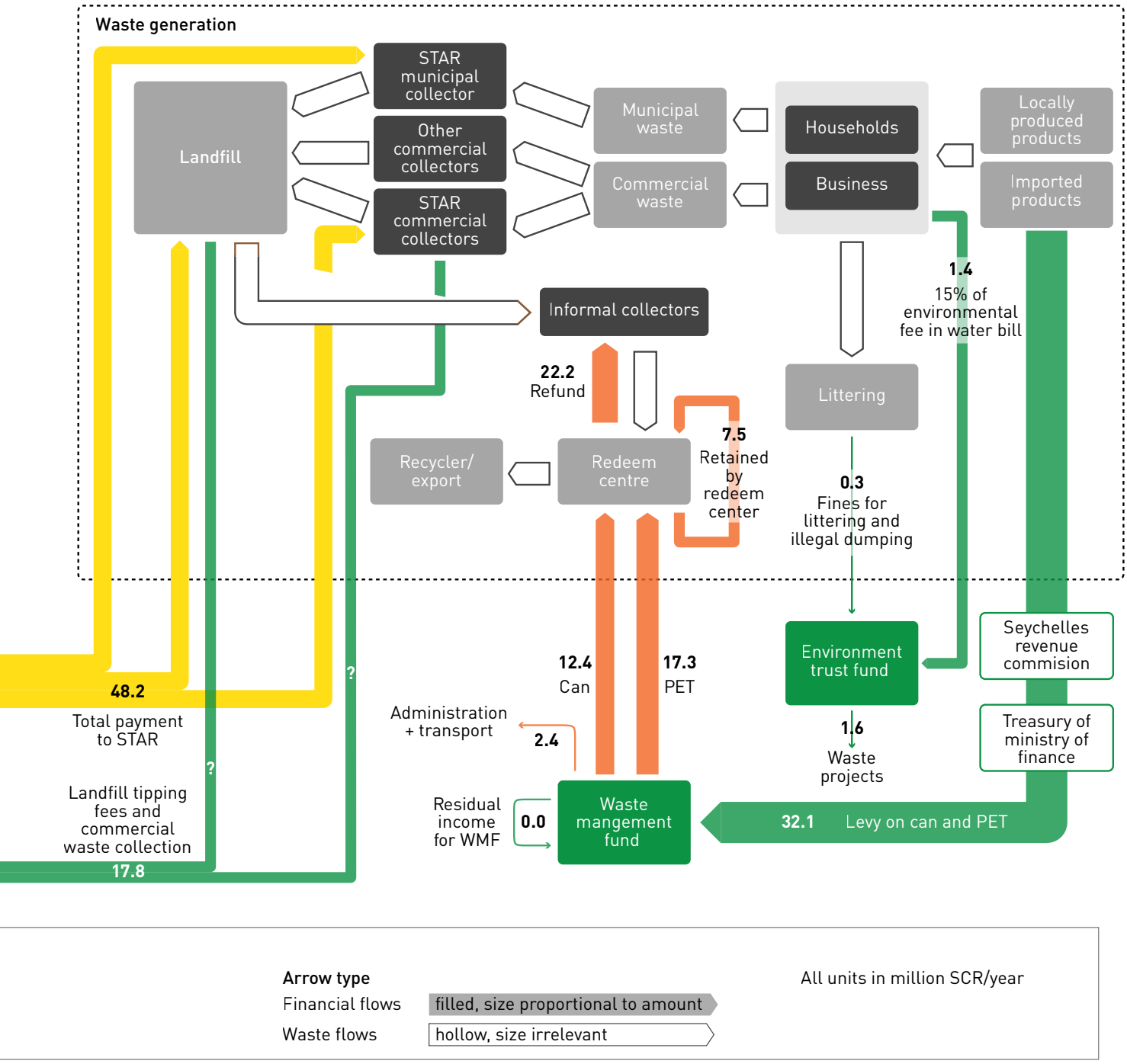


Figure 6.2
303 million SRC are provided for the WM system by the MoF. In return, 17.8 million SCR flow from the WM system back to the goes to the LWMA and around one third (87 million SCR) to the MEECC. While only a small part of the MEECC's resources is this money is spent by the LWMA for symptomatic activities such as beach or road cleaning (88.5 million SRC), almost a third financial mechanism with the Waste Management Fund as the central financing pool. The financial resources of the fund million SRC), which is mainly funded by the environmental fee in water bills and with that by households and businesses.

company receives 264 SCR/ton. However, since STAR accomplishes a variety of roles, we cannot confirm that the funds paid by the LWMA for each service are allocated by the company in such way.

6.3.4 Structure of the current system

The relations between actors, waste material flow, and subsystems are represented in the Figure 6.2. The four main actors with their respective budget and



MoF (Landfill tipping fees and commercial waste collection). Around two thirds of the MoF's expenditure (SRC 216 million) allocated directly to waste (SRC 7.3 million), this share is with 80% larger for the LWMA (SCR 173 million). While about half of (48.2 million SRC) goes into the management of waste, which is handled by STAR. Recycling is financed through a separate primarily derives from levy on cans and PET (32.1 million SRC) and to a lesser extent from the Environment Trust Fund (1.6

expenses are located on the left side of the figure. On the right side of the figure, the material flow is illustrated, i.e., the trajectory from products to waste. This flow is divided into five different stages: Goods production or import, consumption, waste production, collection, and disposal at the landfill. In the middle, the figure connects both main actors and material flow through subsystems. These are the financial instruments and money flows that operate in each stage of the material flow, mobilising resources through and to different actors.

Expenses and Revenues

The net cost of the waste management system in Mahé for the year 2017 is estimated at 37.6 million SCR/year, which represents 44.8 SCR per capita per month. The expenses account for 66.9 million SCR/year and the revenues for 29.3 million SCR/year, which represents a recovery of 44% of the money (Figure 6.3). For more details refer to Appendix 6.3.

The expenses include the rubric of Environmental protection of the MEECC, the payments from the LWMA to STAR, the investment in waste projects from the ETF, and the net expenses of the levy system. Since a more detailed breakdown of the budget of the MEECC is not publicly available, and since the 'Environment Protection' program distributes money to areas other than waste, the expenses of this division are overestimated. In the case of the LWMA, the real payment to STAR and not the budget is used for the calculation. The net expenses of the levy system include administrative costs and the money retained by the redeem centres and exclude the money that is reimbursed to the customers.

The revenues include the flow of money that the MoF receives from landfill tipping fees and commercial waste collection as well as from portions of the revenues of the ETF and WFM. We calculate the approximate respective share of the two items from the revenue of the landfill tipping fees (Table 6.3). According to that, tipping fees generate a revenue of 4.6 million SCR/year and commercial contracts 13.2 million SCR/year. It also includes the money that the ETF receives from the fees of littering and 15.1% of the PUC fee in water bills. Finally, it contains a share of the levy, that will be later allocated in administrative expenses and will be retained by redeem centres.

It is important to notice, that the revenues of the system could amount to 33.5 million SCR/year (50% recovery), if there were no irregularities in the levy system, namely, if the WMF could retain funds. The WMF is supposed to retain in total 6.6 million SCR/year of which 2.4 million SCR are spent in administrative and operational costs. This should leave a total of 4.2 million SCR/year in the fund.

If we focus on the direct money flows of the government (exclude the ETF and WMF), the net cost of the WMS is 37.6 million SCR/year. This includes a recovery of 32% of the resources via the revenues of the MoF from landfill tipping fees and commercial waste collection.

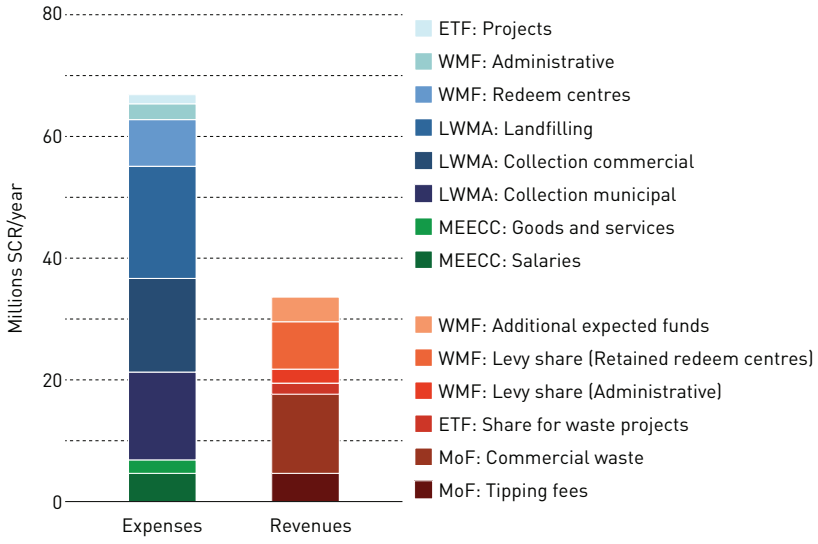


Figure 6.3
Annual revenues and expenses of the WMS. The division of the revenues of Commercial contracts and Landfill tipping fees are rough estimates from the available data (see Table 6.3).

Procedures

The waste management financial system is mainly modified by two processes: the procedure of planning to implementation and financing, and the tender process. In the first one, the three governmental actors of the system, i.e. the MEECC, LWMA and MoF, modify the income, expenses and incentives of the system. In the second process, the system is open to the introduction of new private actors.

From planning to financing

According to members of the MEECC, the process of planning in the WMS is as follows: First, the LWMA identifies needs and informs the MEECC. The MEECC transforms those needs into policies and strategies. In the process of policy drafting, there is assistance from international institutions. Then, the plan is submitted to the Cabinet of Ministers for approval. (See Appendix 6.4: current state of the WMS policies)

The employees of the MEECC also affirm that the approval of the policy is independent of the financing of projects. The MEECC is responsible to find the funds of the initial investment. It can do so in three ways: it submits a request for investment to the Cabinet of Ministers, it searches for partners from the private sector, or it applies for resources from funds such as the ETF. The LWMA is then supposed to cover operating and maintenance costs. Ideally, the MEECC provides an estimate of those costs to the LWMA. The LWMA integrates those costs in the budget, which is then approved by the National Assembly. Members of the LWMA state, that there is a lack of communication in the process, and that the ministry sometimes decides to start projects which the agency is unable to afford.

Tender process

Since the destination of a large share of the WMS resources are private actors, it is important to understand how the assignment of contracts occurs, i.e., how the tender procedure works. According to the Procurement Oversight Unit the process is as follows.

The LWMA identifies the need to establish a new contract for a service, such as waste collection. It writes the tender document and hands it to the Procurement Oversight Unit, which is in charge of the approval of the document. Then, the tender is made public and bidders apply. The Independent Evaluation committee evaluates the bidders and provides a recommendation to the approval authorities, which vary depending on the amount and type of tender. These authorities revise the recommendation and approve it. Then the results, in form of the letter of notification of the best evaluated bidder, are made public. If somebody disagrees with the outcome, the challenge procedure starts, otherwise the contract is signed, and the procedure is closed (See Appendix 6.5 for further details).

A member of the Procurement Oversight Unit affirms that this process of selection seeks to follow the principles of transparency and meritocracy. He also states that it is difficult to control for conflicts of interest in a small island, or making sure that companies which are not allowed to participate in a tender do not do so in form of another company.

6.3.5 Weaknesses of the current system

In this section, we discuss the main weaknesses that were identified in the financing of the solid waste management system. The weaknesses are listed in Table 6.6 and placed in our map of the financial flows (Figure 6.4). We identify weaknesses in most parts of the system. Some are very detailed whereas others are related to the general system.

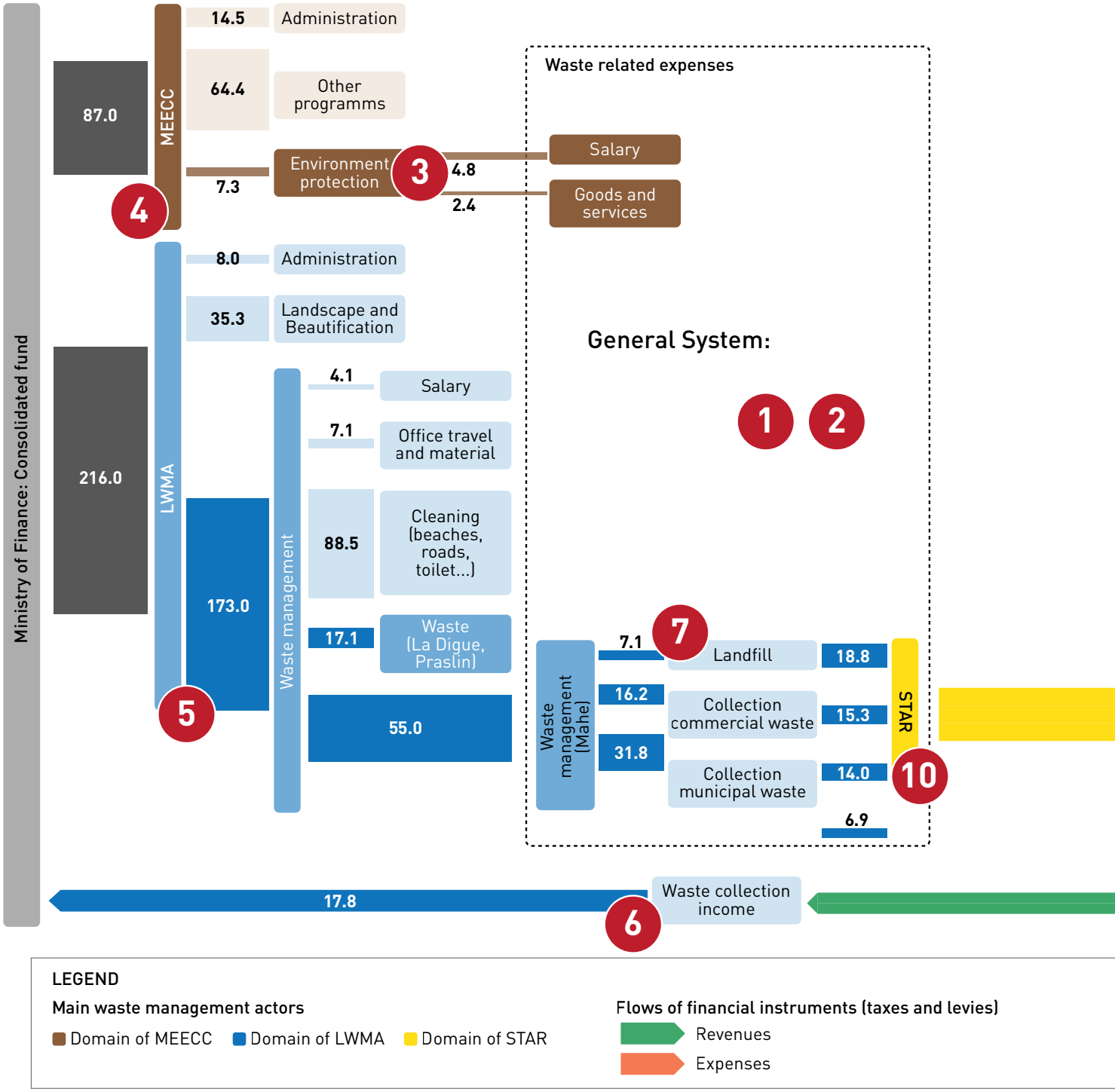


Figure 6.4
Map of the financial flows where the positions of the identified weaknesses (see Table 6.6) are indicated by red dots.

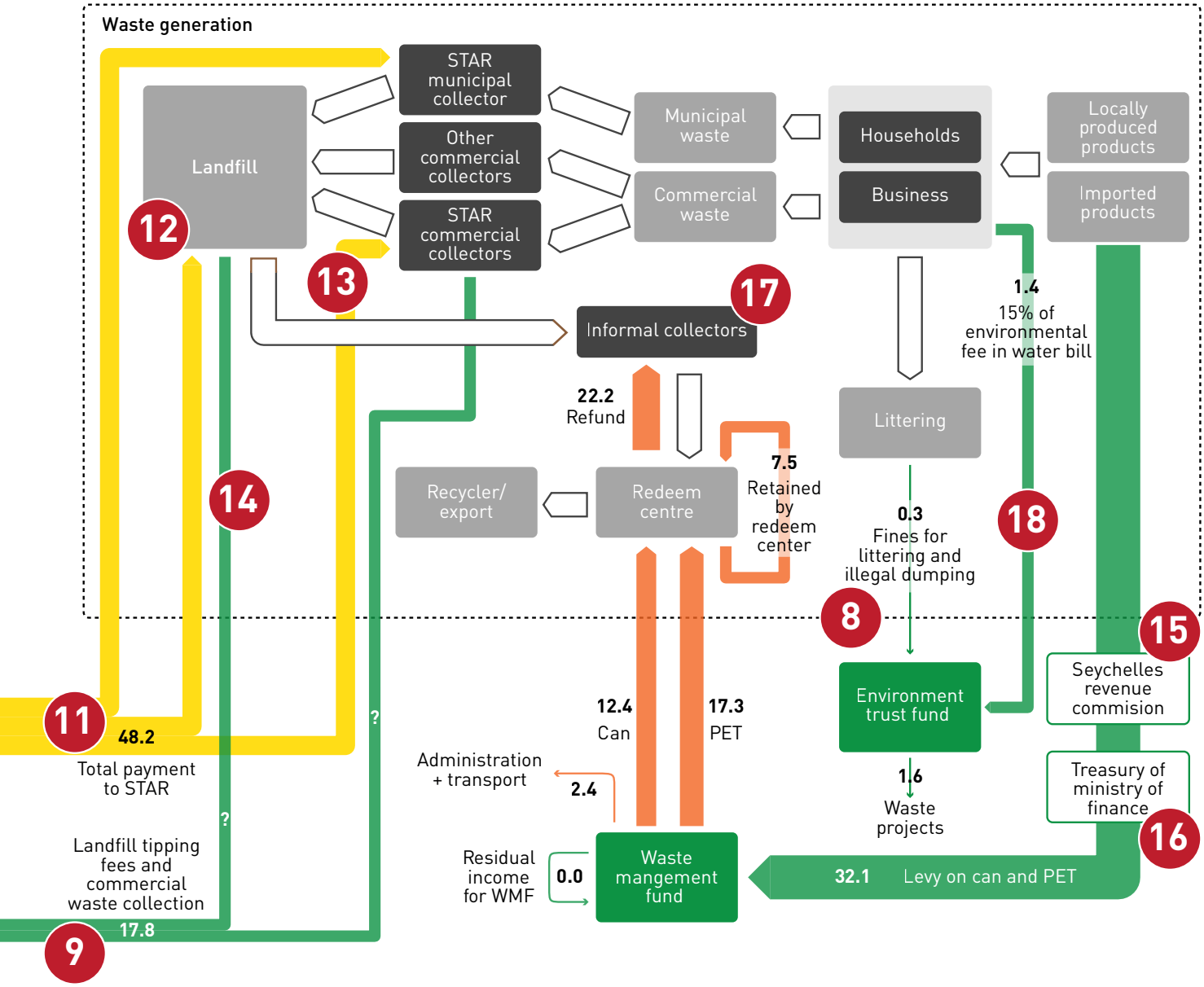

Waste generation
STAR municipal collector
Other commercial collectors
STAR commercial collectors
Landfill
Municipal waste
Commercial waste
Households
Business
Locally produced products
Imported products
12
13
17
Informal collectors
22.2
Refund
1.4
15% of environmental fee in water bill
Littering
Recycler/ export
Redeem centre
7.5
Retained by redeem center
14
0.3
Fines for littering and illegal dumping
18
8
15
Seychelles revenue commision
Environment trust fund
12.4
Can
17.3
PET
Administration + transport
2.4
1.6
Waste projects
Treasury of ministry of finance
16
11
48.2
Total payment to STAR
Residual income for WMF
0.0
Waste mangement fund
32.1
Levy on can and PET
Landfill tipping fees and commercial waste collection
17.8
9
Arrow type
Financial flows
filled, size proportional to amount
Waste flows
hollow, size irrelevant
All units in million SCR/year

Table 6.6
List of weaknesses identified in the financing of the solid waste management systems. Numbers in this table are related to Figure 6.4.

	Weaknesses	Description
	General system	
1	Lack of overarching financial knowledge	From the different interviews with governmental members, it became clear that some of them were not able to provide details of the financial statements of their own institutions, as well as related economic incentives of different parts of the system. This is due to a lack of written documents of the financial structures and flows. Therefore, we got the impression that the system is highly dependent on the knowledge of particular individuals. Also, there is lack of communication between institutions, which leads to difficulties when it comes to aligning economic strategies and incentives.
2	Conflicts of interest	A member of the Procurement Oversight Unit affirms that in the current tender procedure, government members are not allowed to participate as bidders, but their first-degree relatives are. Information about conflicts of interests of members of the government is not public.
	MEECC	
3	No budget line is dedicated to public awareness	One study group (see Chapter 7, Implementation of plans: barriers and the way out) identified the lack of public awareness as a main reason for lack of implementation. One interviewee mentioned that the lack of a specific budget line for public awareness is a reason why there is a lack of initiative in this domain.
4	The budget allocated to waste management within the ministry is low	Only one employee of the MEECC is specifically working on waste. One interviewee mentions that more people are needed to coordinate all the waste related activities. A consequence of this is, for example, that the current Waste Master Plan is outdated, and that the development of a new one is only at an early phase.
	LWMA	
5	Lack of autonomy	The Ministry of Finance is involved in the tipping fees and levy systems, assigns some personnel at the LWMA and is in charge of the collection of revenues from the LWMA (tipping fees and commercial collection via LWMA). The participation of the Ministry in the different areas reduces the flexibility of the agency to modify structures.
6	The breakdown of income of the LWMA is insufficient	The revenues of the LWMA are classified under the same item, called 'waste collection revenue'. A breakdown of the revenues of the LWMA is necessary to establish to which extent the commercial waste collection is subsidized.
7	Difference between LWMA budget and actual payments	There are large gaps between the budget and the payments from LWMA to STAR. This reflects miscoordination between the planning and the financing stages of policies.
8	Enforcement of fines for littering and illegal dumping	One interview stated that even though some citizens have reported illegal dumping cases to the concerned authorities, consequences against offenders are not observed. Since the revision of the EPA in 2016, the LWMA is also entitled to impose fines for small delicts. However, employees from the LWMA state that the personnel of the agency have no capacity or training to accomplish such tasks.
9	LWMA has difficulty collecting money from its creditors	Some companies are not paying their invoices for waste collection contract or the landfill tipping fee. Because of this, a debt of around 18 million SCR has accumulated. Some of the shops stopped paying because they dispose their waste into municipal bins and argue that they are not producing waste. The licensing authorities are not cooperating with the LWMA by punishing these debtors.

Table 6.7
continued

Weaknesses		Description
		STAR
10	Conflicts of interest	Documents provided by the Registration Office confirm that members of government are or used to be until recently closely linked (e.g. shareholders) to STAR. We conclude that there is a lack of mechanisms to control such conflicts of interest.
11	Roles of landfill management and waste collector	Since STAR has multiple roles in the system, it is not clear whether they have incentives to divert waste entering the landfill.
12	Differentiation of commercial waste sources at the landfill weighbridge.	It is unclear whether personnel at the weighbridge can differentiate between commercial waste via LWMA and commercial waste of STAR's direct contracts. This is problematic, because one type of waste (Class 1) does not pay tipping fees and the other one (Class 2) does. Therefore, STAR might be having a price advantage in terms of tipping fees in comparison with small private collectors. One interviewee stated that the current monitoring methodology consists on a visual differentiation of the trucks that are used to collect the different two types of waste. This monitoring method does not seem to be robust.
13	Subsidy to STAR for collection of commercial waste	The LWMA subsidizes part of the costs of the collection of commercial waste. Subsequently, it contracts STAR for performing the tasks. A small collector stated that this gives a price advantage to STAR, hindering other collectors from making a profit and having a larger participation in the system.
		Tiping fees
14	The functioning and fee per waste class are unclear	The procedures that are used to characterize waste and charge tipping fees at the weighbridge of the landfill are ambiguous. There are no documents that provide a description of the fees per waste class, and only one employee at the weighbridge was able to provide oral information.
		Levy system
15	Insufficient money collection by the SRC	The levy on PET bottles and cans is collected at the port of entry by the SRC. Members of the MEECC stated that the SRC lacks workforce to effectively collect the levy. Therefore, some imported products enter the country without paying the levy. They also affirm that expired products from the bonded warehouse go directly to the landfill without paying the levy. From there, informal collectors collect the containers, bring them to the Redeem centres and get a refund.
16	Participation of the Ministry of Finance in the Levy system	The participation of the Ministry of Finance in the Levy system introduces an additional step in the system and might hinder the traceability of money flows.
17	Insufficient incentive for businesses to sort	The current levy system is mainly working based on informal collectors. A hotel representative stated that the financial incentive of the levy is not high enough to cover the logistical costs of bringing the containers to the Redeem Centres.
		Environmental Trust Fund
18	The environmental fee in the water bill is perceived as waste related	Many interviewees stated that households are already paying for waste management by mentioning the fee in the water bill. Most interviewees were surprised to learn that the money is assigned for different purposes as well.

6.3.6 Actions planned: short term plans of the LWMA and MEECC

All the interviewees from governmental bodies stated that they are aware of some of the weaknesses and that there are plans for improving the organization of the financial system.

In the following months (summer 2018), the LWMA will prepare new contracts for waste collection and landfilling which will modify the structure of the WMS. In 2018, the contract between the government and STAR will definitively end, and the LWMA will stop subsidizing the commercial waste collection. Subsequently the LWMA will issue a tender for municipal waste collection services. The tender plans to divide Mahé in different zones, where different collection companies will operate. With this, the government diversifies the participation of companies in waste collection and separates the roles of waste collection and disposal. In 2019, the LWMA also plans to take the responsibility of landfill management and issue a tender where different companies perform different tasks, e.g., security, compaction. This way, the LWMA separates the roles of the companies that handle municipal waste collection, commercial waste collection, and landfilling. Additionally, the LWMA is clarifying the accumulated debt of businesses and collector companies.

On the other hand, a member of the MEECC stated that the ministry plans to modify some regulations for providing LWMA with better enforcing tools. Additionally, they will delegate employees from the ministry to supervise the collection of the Levy at the SRC. Finally, they stated that they are willing to improve the waste classification scheme, which would facilitate the modification of tipping fees as needed (see Appendix 6.2).

6.3.7 Future financial instruments

In this section, we present the results of a literature review about three different financial instruments that were identified as potential instruments to implement the Polluters pays principle. This principle is one of the guiding principles of the Seychelles Solid Waste Management Policy 2014-2018.

Pay as you throw

Households usually indicate willingness to separate waste, provided that there are financial incentives and accessibility to waste separation facilities (Finnveden et al, 2007). However, many households either cannot afford or, by virtue of cultural norms, do not place enough value on collection to pay a fee for the service, when the alternatives of dumping or burning trash is culturally acceptable and poorly regulated (APEC, 2016). Therefore, financial mechanisms need to be in place for steering the behaviour of individuals towards separation of waste.

According to the pay-as-you-throw model, individuals are charged according to the quantity of mixed waste that they present for collection. Within this model, households are steered towards increased waste diversion by providing free collection services for recyclable waste and compost.

This system was successfully implemented in Switzerland, covers around 36% of the cost of the waste management system, and has reduced unsorted waste by 40% (Carattini, Baranzini, Lalive, 2016).

The main advantages of this model are that separation and recycling are increased, and therefore the waste stream

going to the incineration is minimized. Hence, there should be a reduction on the load of landfills. Additionally, waste collection costs are proportional to the amount of waste produced, which introduces a dimension of fairness into the system. The main disadvantage of this system is that it might generate opposition from the citizens and result in a rise of illegal dumping.

Extended Importer Responsibility

A fee is imposed by the government on new purchases of products and the revenue that comes from it may be used to establish and maintain the corresponding disposal services. This mechanism is part of the extended producer responsibility (EPR) system, a policy approach where manufacturers or brand owners become responsible for the products that become waste. The objective is to encourage producers to reduce the costs associated with end-of-life products and/or to subsidize recycling services or waste exportation.

It has been estimated that there are 400 EPR systems around the world, designed especially for electronic waste, packaging, tires, end-of-life vehicles, and batteries (OECD, 2016). For example, EPR is used for tire disposal in Tennessee, United States, where a fee of U$1.35 per unit is charged. In California and Ontario, EPR applies for electronic devices such as cellphones, televisions and computers, where fees range from U$0.05 to U$25 (EPRA, 2017. CalRecycle, 2018). In the United Kingdom, EPR is used for packaging, electrical and electronic goods, batteries and cars. In addition to these waste classes, France EPR also includes infectious healthcare waste (The Guardian, 2017).

One of the main advantages of this fee is that it motivates producers to design products that last longer or are easier to recycle. Furthermore, it might help to diversify the actors involved in the management of different waste streams and open new exportation markets. Nonetheless, producers, importers, and consumers might oppose these measures.

Visitors' tax

Tourists contribute substabtially to the production of waste in small islands. However, they do not feel responsible for the waste issues and are less responsive to recycling incentives than locals (Chen et al, 2005). Following the-polluter-pays-principle, visitors should bear the management cost of their waste. There are different ways how tourists might contribute, such as paying a fee in tourism businesses or an entrance tax in airports and ports proportional to the duration of their stay.

In the island of Gili Trawangan, Indonesia, a non-governmental organization collects a fee of six USD in tourism businesses on behalf of waste management projects. With the money collected, counselling for planning and management of waste has been financed (Willmott & Graci, 2012). Additionally, many other touristic destinations have implemented accommodation taxes earmarked for environmental protection (do Valle et al, 2012).

Tourist fees might be an easy way for governments to collect money for investments, infrastructure, and social services (WTO, 1998). However, depending on the size of the fee, tour operators and hotels might claim that these levies damage their level of competitiveness (Aguiló et at, 2005). Additionally, two of our interviewees stated that general costs for tourists are already high, and that waste services are already included in hotel tariffs.

4 Discussion

In this section, we discuss critical points of the waste financial system that affect its functioning and potentially impede the transition to a transparent and efficient WMS. After this, we discuss the current and potential future instruments.

Our results indicate that there are considerable money discrepancies in the waste financial system. In the LWMA, the final destination of 12.5% of the annual budget of waste management is unclear. Additionally, the WMF is currently holding only 36% of the funds it is supposed to retain. These discrepancies show the need for a thorough monitoring of the money flows as well as a correct planning ensuring a matching of budget lines and real payments.

Furthermore, we could not verify certain flows, simply because the data is not public or available. That is the case of the combined flow of commercial waste collection and tipping fees, the expenses of the MEECC in the WMS, and the allocation of money by STAR in the different services it provides. A better organization and accountability of these points are key for understanding the system and identifying potential irregularities.

Apart from the issues of accountability, our results show that collaboration between governmental bodies is key for running the economic instruments or reminding offending payers and eventually fining them. Communication between the WMF and the SRC is necessary to detect issues in the levy system on PET and cans and agree on solutions. The same applies to the LWMA, who should work with the licensing authorities to decide on the procedures to fine debtors. The LWMA should also work more closely with the MEECC in the alignment of planning and financing processes. The collaboration between entities should be enforced by the parent ministries (MoF and MEECC), who should empower and provide autonomy to the fund and the agency to establish communication channels with the respective authorities.

Another important deduction from our results is that the system lacks economic incentives that would foster effectiveness and the recycling of waste. STAR has the monopoly of municipal waste collection services and therefore has the resulting competitive advantage in commercial waste collection. Additionally, there are no incentives for the diversion of waste from the landfill. Even though stakeholders expect to solve some of the incentive problems with the coming tenders and a new system of tipping fees, there is no guarantee that some of the current (problematic) intertwinded relations between the public and the private sector will remain.

Despite the fact that many of our interviewees consider that conflicts of interest are unavoidable in the small island context, they should be avoided as far as possible or otherwise made public. The tender process should include disclosure requirements, where companies' shareholders state if they have first or second-degree relatives in the government. Furthermore, it is the duty of citizens to oversee the results of tenders and demand higher transparency.

Another element that might hinder the transition towards a transparent WMS is the existence of 'old wine in new bottles'. The tender process should be able to identify previous actors that camouflage in future tenders under new company names. The respective authorities should decide whether they allow the participation of such companies. For example, the company Wastea, whose director is also STAR's CEO, is operating since 2017. According to its CEO, Wastea would like to provide waste collection services for the government after STAR stops existing.

In terms of economic instruments, our results show that only the levy system for cans and pet provide incentives to sort.

Currently, households contribute directly only with a fixed fee of 2.26 SCR/month, which is easy to collect but does not give any incentives toward waste reduction or separation. With the transition towards a more complex WMS, the system of tipping fees should be updated and other economic instruments put in place.

With a new system of tipping fees, there should be incentives for waste collectors regarding waste separation, and the collected fees should at least partially cover the costs of waste treatment or export. Additionally, tipping fees should cover the operation costs of the landfill. In order to achieve this, trucks bringing mixed waste should be charged a higher fee than trucks bringing in sorted waste. During discussion with one interviewee, we learned that already now collectors are sorting scrap metal from the mix waste in order to save 50SCR/ton. This statement may indicate that economic incentives can efficiently convince collectors and commercial establishments to sort their waste.

Moreover, a system of pay-as-you-throw should be put in place to create an incentive for households to sort waste. There are several challenges that would need to be addressed when implementing such system. First, the system would need to switch from communal to individual bins, or make residents pay and use special garbage bags for the disposal of mixed waste. Then, communal bins for compost and recyclable material would need to be provided. This system will probably increase illegal dumping of waste, especially in remote areas. Therefore, the LWMA would need to strengthen its monitoring functions and cooperate with other authorities in the enforcement of rules. An educational strategy is also key to inform and discuss such changes with the public.

Another strategy to increase the proportion of sorted waste in the country is an extended importer responsibility system. Here, importers would become responsible for proper disposal of the product they are importing. Therefore, they would transfer the related costs to the product prices, and prove that they treat an amount of product equal to the amount they are importing. In the Seychelles this fee could help to reduce, among others, the amount of electronic waste, scrap metal, and tires that go to the landfill. To fulfil these goals, the LWMA should analyse the corresponding measures together with the Bureau of Standards. Since some people might complain about the commodities' price increase, the application of the fee must be accompanied by an information dissemination strategy aimed at producers, importers, and consumers.

In contrast to the last two strategies, a visitor's tax is not likely to be a viable strategy for the Seychelles. In the future, the government plans to completely privatize the commercial waste collection, which means that hotels will no longer be partially subsidized. Therefore, visitors will already pay for waste services in the hotel tariffs.

6.4.1 Limitations of the study

One of the main limitation of this study is that most findings, especially the one regarding the weaknesses, are based on oral statements. Not all of the oral statements could be verified with subsequent interviews. Additionally, not all our numbers are backed by official documents.

A further limitation is that certain actors of the system could unfortunately not be interviewed. Such actors are for example representatives of the Ministry of Finance, the Seychelles Revenue Commission, the redeem centres, and the recycler/exporters.

A last limitation is that the availability of financial and waste related data is limited. Therefore, some calculations combine information from different years.

6.5 Conclusion

The waste management system in Mahé has a net cost of approximately 37.5 million SCR/year, which corresponds approximately to 45 SCR per capita per month. From the total expenses of 66.9 SCR, 44% is recovered via the revenues of the LWMA from landfill tipping costs and commercial waste collection contracts. The largest expense of the system is the combined payment to STAR for the services of landfill management and municipal and commercial waste collection.

After examining the structure of the waste management financial system, we conclude that there are several weaknesses in the way economic resources are assigned, managed, and monitored. The involved stakeholders lack an overarching understanding of the structures, partially because there is a lack of supporting documentation and communication between the concerned parts. This results in a lack of accountability of the financial subsystems regarding, for instance, (i) landfill tipping fees, where there is an unclear waste classification scheme and a lack of monitoring mechanisms of the money flows, (ii) the commercial waste collection, where it is unclear how STAR differentiates the payment of tipping fees of waste from direct clients and waste from the LWMA's clients, (iii) the money flows of the levy on PET bottles and cans, where not sufficient funds are collected, and (iv) the enforcement of fines for littering. A better organization in the accounting systems would provide greater transparency in the money flows and enable better monitoring. The small island context makes it challenging to control for conflicts of interest. For example, we learned from official documents at the Registration office, that a member of the government or his first-degree relatives have been STAR's main shareholders during the last few years. Even though there are plans to replace STAR by new contractors, the same actors might stay in the system under new company names. Strengthening the tender process is key for avoiding such conflicts of interest or making them public. However, it is the duty of citizens to oversee the results of tenders, revise the information of the involved companies in the Registration Office, and hold their government accountable.

Members of the LWMA, the WMF and the MEECC are aware of several of these weaknesses and are working to overcome them. In 2019, new contracts for waste collection and landfill management will reshape the waste management system. Once the government improves its basic financial organization, they might consider the modification of current financial instruments and implementation of new economic incentives. For example, a revision of the landfill tipping fees has the potential to increase the share of sorted waste and create recycling markets in the short term. Additional instruments, such as Pay-as-you-throw or Extended Importer Responsibility systems may have the potential to influence the behaviour of households and businesses and enable the development of new funds.

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7 Implementation of plans: barriers and the way out

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7.1 Introduction

Research on solid waste management (SWM)-policies shows that it can be challenging to implement comprehensive and long-term working SWM-systems (Zurbrügg, 2013). This difficulty is especially visible in SIDS which have limited land, economical, and labour resources at their disposal due to their special geo-economic situation. The Seychelles are no exception and continuously struggles with SWM, as past research and reports show (Gonzalves, 2017; Lai et al., 2016). To address these issues, the Government of Seychelles has come up with several plans and strategies. Amongst others, they include the following three main policy-frameworks: The Solid Waste Master Plan 1995, updated for the period 2003–2010; The Solid Waste Management Policy 2013–2018; and the Seychelles Sustainable Development Strategy (SSDS) 2012–2020. Updates and new plans are expected to follow.

Writing plans and strategies to solve an issue is a first step in public policy. This shows that the issue is recognized and that there is a basic willingness to address it. However, one of the greatest challenges of decision-makers and managers is the implementation of these plans (Kalali, Anvari, Pourezzat, & Dastjerdi, 2011). Looking at the SWM-plans in the Seychelles, past reports indicated that there is a general lack of implementation (Agricole et al., 2016).

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According to the Seychelles solid waste assessment report by Gonzalves (2017), most of the objectives of the three major waste related plans and policies have only been partly implemented or not at all. The underlying reasons for this are not clear.

There is a wealth of literature about public policy implementation in developing countries which can be seen as an indicator of the relevance of the topic (e.g. Ali & Khan, 2006; Cáceres, Silvetti, & Díaz, 2016; Kalali et al., 2011). However, none of these studies provides a simple, universally applicable solution. Rather, they show that each case must be considered individually. General research on waste management emphasises that the understanding of the underlying reasons for a lack of implementation of SWM-plans is a crucial success factor for a stable and long-term oriented waste management (Zurbrügg, 2013). According to Zurbrügg (2013), such barriers can be found on all levels of society and are usually highly interlinked.

SWM is usually managed or at least coordinated by governmental authorities (Zurbrügg, 2013). This is also the case for the Seychelles, where solid waste management (SWM) lies within the responsibility of the government, mainly the Ministry of Environment, Energy & Climate Change (MEECC), and is executed in collaboration with the Landscape and Waste Management Agency (LWMA) and private partners (Dine et al., 2016). However, barriers to the implementation of SWM-plans never only lie within the realm of the public authorities. Zurbrügg (2013) shows that private industry, public participation, and acceptance are important factors for a functioning SWM-system. Furthermore, Eckelman (2014) emphasised that it is also important to consider foreign influences, e.g., in the form of financial aid.

Based on these findings our research team investigated current barriers that hamper or even prevent the implementation of SWM plans in the Seychelles. First, we identified barriers in a comprehensive manner and investigated how these barriers are interlinked. Then, we identified and analysed possible starting points and actions with which these barriers possibly can be over-come. Accordingly, we formulated the following two research questions:

- What are the barriers to implementation of SWM-plans in the Seychelles?
- What actions could be taken to over-come these barriers?

7.2 Methods

To answer the research questions, a combination of methods was used. These included a literature review on implementation of SWM-plans and implementation of public policy in general as well as main policy-frameworks for SWM in the Seychelles. Additional methods were semi-structured interviews and a half-day workshop with a group of stakeholders.

7.2.1 Literature Review

For the first part of our research we conducted a literature review on SWM-plan implementation and its failure. Since specific research on this topic is rare, we also looked at more general research on policy implementation failures in developing countries and SWM in other SIDS. Specifically, we used combinations of the keywords such as policy, implementation, failure of implementation, reasons, SIDS, waste, waste management, plan, and strategy to conduct our search in the web of science. We then aggregated our findings into a list of potential barriers to implementation. This list served as a basis for semi-structured interviews. Additionally, we used these findings to formulate a question on barriers for a public survey.

Furthermore, we analysed the most recent policy frameworks regarding waste management in the Seychelles: the 'Solid Waste Master Plan 1995' (updated for period 2003–2010), the 'Solid Waste Management Policy 2013–2018', the 'Seychelles Sustainable Development Strategy 2012–2020', as well as the final report of the 'Transdisciplinary Case Study (tdCS) 2016' (Lai et al., 2016). We used this analysis mostly to gain a better understanding of the current policy frameworks and to prepare the field-phase of our research.

7.2.2 Verification and Refinement

In the second part of our research, we verified and refined the previously created list of potential barriers by conducting semi-structured interviews with experts and a workshop with key stakeholders. We involved a selection of experts who are either involved in SWM or policy implementation.

Expert Interviews

Preparation and Execution

The interviews were prepared and conducted as semi-structured interviews. We formulated open questions and included them in an interview guide (see Appendix 7.2). The interview guide contains questions and follow-up questions that allow orientation and adaption towards the interviewee during the interview. Although the systematic structure of the guide does not need to be strictly followed, it encourages and supports a conversation-style of the interview (Przyborski & Wohlrab-Sahr, 2014). As stated before, we derived the questions for the guide from literature research. We tried to avoid closed questions (with the answer being 'yes/no'), so that the interviewees where able to explain their answer and give personal examples of where and why plans have not been implemented.

The primary question of the interview guide is 'What are the main reasons why SWM-plans are not implemented?'. The stated barriers to implementation were then explored in depth. Once the interviewees have explained the main reasons from their point of view, we continued by asking specifically about other barriers from our list. Each interview lasted on average about one hour. Most interviews were recorded.

Processing

All interviews were partially paraphrased and digitalized according to notes we took during the interview. In some cases, also the recording was used to filter for answers to our research questions. The reduction and condensation of interview data was carried out in line with a slim version of qualitative content analysis, a systematic analysis of (fixed) communication guided by rules and theory (Mayring, 2015). We formed four categories to sort the mentioned barriers, derived from literature review: 1) Context, 2) Structure, 3) Content, and 4) Operation. All paraphrased interviews where coded with correspondence to the list of barriers from literature review. The coding was later used to assess which barriers were most mentioned and to conduct a consistency analysis within stakeholder groups.

Sampling

We conducted a total of 15 interviews. The method for sampling was snowballing, asking interviewees for other potential interview partners. The teaching team of the tdCS 2018 and our local team members provided initial contacts of interviewees. We tried to cover a variety of viewpoints throughout all sectors of society, including the responsible policy makers (i.e., the Ministry of Environment, Energy and Climate Change (MEECC)), the executing agencies (i.e., the Landscape and Waste Management Agency (LWMA)), consultants as well as representatives of the private sector, the civil society, and NGOs (for full list of all interviewed experts see Appendix 7.1).

Expert Workshop

Preparation and Execution

The main objective of the stakeholder workshop was, on the one hand, to collect and combine the participants' expertise and, on the other hand, develop a shared understanding concerning barriers to implementation of SWM plans. Additionally, the goal was to identify starting points for possible actions to overcome these barriers and to develop first ideas for such actions. The workshop took place at the MEECC, Botanical Garden, Victoria (July 11, 2018), and lasted three hours. The condensed prepared schedule is shown in Table 7.1; the working schedule in more detail is described in Appendix 7.3.

Table 7.1
Condensed schedule of the workshop.

Duration	Item
15'	Introduction
50'	Collection of reasons for the lack of implementation of SWM-plans, including input from former research and discussion
20'	Compilation and systematization of reasons
10'	*Break*
25'	Presentation and discussion of systematization
50'	Development and presentation of possible actions
10'	Wrap up and end

A brief introduction was used to inform the participants about the overall research project and our research questions. The research team and the participants introduced themselves individually. The collection of reasons started with an individual brainstorming on potential barriers to implementation of SWM plans. This was done to collect the participants' viewpoints on the topic. The barriers that they noted on paper cards were then pasted on a board after a short introduction to the four different dimensions that we already used for the qualitative content analysis of interviews. In the next step, we provided input from previous research (see Chapter 6, Financial sustainability: current structures and potential steps forward) and allocated these barriers on red cards in a random order to the four dimensions on the board. The barriers were briefly explained with examples or quotes from the interviews. The input from previous research was done to put a spotlight on a selection of 14 barriers and to stimulate the succeeding discussion. We selected the barriers of implementation based on the most mentioned ones during the 15 interviews. We added the ones considered to be the most important by the research team, in collaboration with the team Financial Mechanisms. An alphabetical list of the highlighted barriers can be found in Appendix 7.4.

The succeeding discussion about the collection of the barriers on the board was slightly guided by the workshop facilitator. This was done in order to show and debate disagreements or agreements and to foster a shared understanding of the barriers.

In a next step, the participants were asked to systematize the barriers. In groups of two/three, the participants chose up to ten barriers and placed them on a diagram according to their perceived level of importance and ability to change (see Figure 7.1). This step was done to collect the participants' viewpoints on which barriers are especially important and changeable. Additionally, we wanted to find out if the

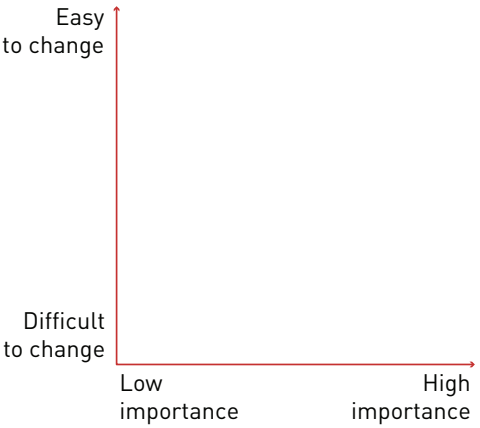

Figure 7.1
Diagram used for the systematization of barriers in the stakeholder workshop.

perception of barriers strongly differs depending on the background and positions of the participants. Because of that, the research team formed groups in advance, ensuring that comparable positions or backgrounds matched. The resulting diagrams of the five groups were briefly presented and discussed in the whole group to foster shared understanding.

The last phase of the workshop entailed the identification of starting points and the development of actions to overcome barriers. Again, in the same groups of two/three, the participants chose the reasons that they previously classified to be important and easy to change. The research team provided an action guide to foster concrete results, which can be found in Appendix 7.5. In line with this action guide, the participants gave a brief description of a possible action, including the necessary procedures to address the chosen barriers and the expected outcome. Additionally, we asked for the institutions and stakeholders involved in the action, the leading stakeholder, the resources required for the actions, the time frame of the action, and indicators to measure and evaluate progress. The possible actions were then briefly presented to the whole group in order to foster shared understanding and make comparisons between different approaches.

The workshop was closed after three hours with a brief wrap-up and a short round of feedback and reflection.

Processing

The whole workshop was recorded. Several observers where present and took notes. The results from the individual brainstorming, the systematization, and the selection of actions were collected and digitalized to be included in our final report.

Sampling

Eleven stakeholders participated in the workshop. They involved (high-level) representatives of the MEECC, the Ministry of Finance, the LWMA, the NGO Sustainability for Seychelles (S4S), and the private sector, i.e., recycling business and consultants. The invitations were sent via mail in the name of the Principal Secretary (PS) of Environment. A list of workshop participants can be found in Table 7.2.

Public Survey

We conducted a household survey of public opinions about barriers to implementation of SWM-plans. The barriers for which we checked the public opinion were deduced from the literature review. Due to time constraints, we included our question in English and Créole into the larger survey conducted by the 'Waste collection and sorting: Consumers' perspective' group (see Chapter 1, Waste collection and sorting: Consumers' perspective). For methodological details, please refer to their respective chapter in the report. The wording of the question in English can be found in Appendix 7.6.

We used a closed question enabling the respondents agree or disagree whether they believe certain barriers hinder SWM-plan implementation. The proposed barriers were the following: the plans are unrealistic, inefficient organisational structures, lack of finance, lack of public awareness, corruption, lack of skilled

Table 7.2
List of Workshop Participants.

Participant	Position/Profession	Organization/Company
Arthur Berta	Private Consultant	MEECC
Alain Decormamond	PS	MEECC
Robert Georges	Co-owner	Navins Paper Company
Sharon Gerry	Senior Legal Officer	MEECC
Cliff Gonzalves	Private Consultant	
Tony Imaduwa	CEO	SEC
Maria Jannie	Coordinator of the Environmental Trust Fund	MEECC
Jennifer Jasmin	Director General Economic Planning	Ministry of Finance
Flavien Joubert	CEO	LWMA
Frederic Kinloch	Director Waste Management	MEECC
Nanette Laure	Director General Waste, Enforcement and Permit Division	MEECC
Marie-Therese Purvis	Chairperson, Board of Directors	S4S

labour, and lack of political will. We used a five point Likert scale ranging from strongly disagree to strongly agree with an additional response option 'I don't know'. The survey included a randomised sample of 148 face-to-face interviews across eight representative districts of Mahé.

Analysis of Interlinkages between Barriers

We counted how often each barrier was mentioned during the interviews and compiled a list of most mentioned barriers. In addition, we also analysed internal consistency of the barriers, i.e., what barriers where mentioned by several interviewees from the same group, thus about which barriers groups of stakeholders agree. For this, we differentiated between Government Officials, Consultants, and Private Sector. This resulted in a list of 17 core barriers that were used to create an interconnected system of barriers. Based on discussions within the research team, the influence from one barrier on another barrier was assessed to be either non-existent, medium or strong. This resulted in a matrix of activity/passivity values for each barrier. While a high activity value means the barriers has a strong influence on many of the 16 other barriers, a high passivity value means that a barrier is strongly influenced by many other barriers. The software Systaim allowed us then to link multiple barriers via connections to which we assigned one of two possible impact-strengths, resulting in a so-called impact structure. For example, we can show that poor communication leads to an increase of aversive working conditions, assuming that communication would have a direct effect on working conditions. Additionally, we can show whether we found this impact to be medium (impact strength 1) or strong (impact strength 2). In a second step we conducted a loop analysis. This means that we analysed if there are closed impact chains. These have no clear starting- and end-points and can have an enforcing or a stabilizing effect in a system. An example would be that we find political will to influence involvement of other actors in the SWM-system, this impacts the public awareness, which again influences political will. Such an analysis can be done directly in the software Systaim. Due to the large number of loops we restricted the number of analysed barriers in loops to five.

7.3 Results

In this section, we elaborate on potential barriers to implementation of SWM-plans. First, we refer to general literature on the topic. Second, we present findings for the SWM-system in the Seychelles more specifically. This includes the results from our expert interviews and stakeholder workshop on barriers to implementation, from an assessment of their interlinkages, as well as from actions to overcome them. In addition, we present the results of the public survey.

7.2.1 Literature review

Literature regarding management and public policy reveals multiple reasons why the implementation of plans may fail in general. Kalali (2011), for example, is focusing in his study on the health service sector of Iran, for which he outlines contextual, content, operational and structural dimensions. Based on his study, we consider the following dimension as a basis for our list of barriers to implementation.

Contextual Dimension: Addresses political, socio-cultural and economic aspects and other features of the environment.

Structural Dimension: Takes into account structural and organizational aspects of the different actors and institutions involved.

Content-related Dimension: Addresses the content of the SWM plans, with the assumption that also the content of the plans themselves can lead to a lack of implementation.

Operational Dimension: Takes into account issues concerning the operational part of the implementation, i.e., the organization and execution of specific tasks.

Since these dimensions overlap and are interlinked, their boundaries are often vague and not absolute.

There is little literature specifically about the failure of plans concerning SWM. Based on the analysis of several case studies, Zurbrügg (2013) identified some common features that are important for the success of SMW projects but often overlooked during planning, therefore creating barriers for implementation:

An effective organizational structure that is based on strong leadership, communication, clearly defined goals, and continuously trained staff that is committed to entrepreneurship and high quality of service as well as accountability and transparency

Viable business models and financially sound setups that are based on solid business plans with the capacity to mobilize investment-capital and mechanisms to recover capital and operational costs in the long-term

Endorsement by government and compliance to legislation that is based on recognition by the government that the project is an integral part of the overall strategy, and that it is in accordance with national regulations and laws

Zurbrügg (2013) conducted a literature review, including 35 scientific reports. It lists main factors causing shortages of SWM projects in developing countries. The first two factors represent the most frequent ones:

- Lack of finances or inefficient revenue collection
- Lack of human resources, weak capacity, or motivation of staff
- Rapid population growth and changing lifestyles
- Lack of public awareness and collaboration
- Weak legislative framework and weak enforcement
- Fragmented inefficient organizational structures
- Inappropriate or insufficient equipment and infrastructure
- Lacking data, monitoring and control

In line with the above mentioned, Terazono, et al. (2005) concluded that specific regulations for SWM are lacking in many low-income countries. In the case of the Seychelles, however, its status as a SIDS has to be considered. These special socio-economical and physical conditions imply some contextual barriers to implementation of SWM plans. Combining the findings of Agamuthu (2014) and Eckelman (2014) the following barriers to SMW projects – specific to SIDS's – can be listed:

- Limited availability of suitable land for landfills, due to limited physical space
- Vulnerability to weather, water, and extreme events, as well as potential large seasonal fluctuations in waste volumes
- High operational and energy costs, due to remoteness of many SIDS, meaning high costs for any products and parts that must be imported
- Lack of capital and financing options in general, but also financing for SWM systems that has not kept pace with growth in waste quantities
- Small market sizes and limiting potential for economies of scale, due to small and sometimes sparse populations
- Limited institutional and human resources capacity, again due to small and sometimes sparse populations
- Changing social norms regarding product reuse, repair, and recycling, due to complex social and political dynamics that stem from often closely knit societies

A full list of barriers that we elicited from the scientific literature and used as a base for the interview guide can be found in Appendix 7.2.

Particularly regarding the SWM of the Seychelles there are no peer-reviewed scientific reports available. However, in the report of the tdCS 2016, Dine, et al., (2016) provided an analysis and discussion of significant legislative barriers that they observed. They involve unclear allocation of responsibilities, financial inflexibility, and a lack of incentives. For more details, please refer to the report of the tdCS 2016.

Some of the national plans and strategies of the Seychelles as well list factors that are critical for the success of the strategy. For example, the SSDS 2012–2020 (page 19) lists political support, ownership of stakeholders, capacity integration into planning process as well as periodical audits.

Furthermore, a consultancy-report drafted by Gonzalves (2017) mentions three reasons why national strategies are not implemented in many countries: lack of political will, deficiency in human capacity, and/or inadequate financial resources. Getting more specific on the issue of waste in the Seychelles, Gonzalves names underlying weaknesses that in the past have led to a lack of implementation of SMW plans and strategies. Amongst others, the privatization of the waste sector was not successfully executed. A contract handed nearly all aspects of SWM to one company, and hindered entrepreneurs interested in waste and resource recovery to enter the sector. In addition, detailed specifications of work and responsibilities remained unclear. The latter holds true also for the division of tasks between the LWMA and the MEECC. In addition, an unclear legislation and implementation process in general is mentioned, as some initiatives like the plastic-bag-ban where not included in any SWM-plan. In general, leadership and expertise are lacking. There are no regular training programs and also no local professional association. Inadequate financing and foreign investment dominated the SWM sector. This led to pitfalls associated with donor-funded programs. A loss of the big picture is described. SWM is pictured as being looked at in an isolated way and as being disconnected to many other sectors.

7.3.2 Barriers to Implementation of Solid Waste Management Plans in the Seychelles

The semi-structured interviews with experts and our workshop revealed that stakeholders perceive a variety of barriers to the implementation of SWM-plans in the Seychelles. For the sake of clarity, we divide them into four dimensions: operational barriers, content related barriers, structural barriers, and contextual barriers.

All the tables of barriers are in alphabetical order, including a brief explanation and an indication of the source. A list of the barriers according to scientific literature can be found in Appendix 7.7.

Operational Barriers to Implementation

The most mentioned operational barrier during our interviews and the workshop is the lack of skilled labour. Especially representatives of the public sector and consultants noted this. It appears that there are too few people who pursue a higher education in waste management and are afterwards willing to work in the public sector. Some of our interviewees claim, that this is mainly due to a lack of capacity building, while others hold the viewpoint that capacity building is not so much the problem but rather capacity retention. Educated people often seem to leave the public sector after a while or prefer to work abroad. This is due to unattractive working conditions in the public sector. Interviewees state that salaries are low and working conditions are frustrating, as working procedures tend to be unclear and communication sometimes lacking. Potentially, this leads to a high staff-turnover. Due to a lack of skilled labour and human recourses in general, people in charge are often overwhelmed with work. Stakeholders working with or within governmental bodies mentioned that single persons hold numerous responsibilities, which may be hard to fulfil properly, leading to a delay of actions.

Another often mentioned barrier closely related to this issue is the lack of written work-procedure guidelines. Interviewees stated that often there are no written documents on how to execute certain tasks, or how to proceed when you take over a new position. This was mentioned to be especially problematic in combination with the high staff turnover and the work overload of the existing staff, because a lot of information gets lost this way. Also, the lack of written documentation, such as minutes, seems to allow that certain stakeholders do not feel responsible for the implementation of SWM-projects. Without written instructions, it appears to be very easy to use excuses and claim that other involved stakeholders were responsible.

The second most mentioned operational barrier is the lack of enforcement. The non-fulfilment of contracts or tasks regarding the implementation of SWM-plans does not seem to be persecuted and penalized. This has several causes, but stakeholders often mention that enforcement is lacking, because the fulfilment of contracts and tasks is not monitored in the first place. Sometimes it is said that there is no systematic assessment of the performance of the involved agencies and contractors, for individual workers and for the implemented projects. Without such data, the ground for enforcement is missing. Furthermore, interviewees state that the lack of this data leads to a lack of learning from the past. It appears that there is no mechanism in place to utilize the knowledge gained from the past successes and failures of SWM-plan implementation to adapt current contracts or to improve new plans.

Another very often mentioned operational barrier to implementation of SWM-plans is the lack of financial resources. The interviewees, however, have differing views on this issue; some highlight that there is generally not enough money available for the SWM-system, while others state that

enough financial resources for an improved system would be available, but that they are currently inadequately distributed. A detailed analysis of the financing of the SWM-system in the Seychelles and its weaknesses can be found in Chapter 6, Financial sustainability: current structures and potential steps forward. To avoid an overlap with this chapter, we will just highlight the key features and results from our research. Interviewees indicate that in the past large investments for SWM usually came from foreign donors. According to interviewed consultants, this creates a potentially problematic dependency on donor requirements. Within the Seychellois system, a large amount of money seems to be spent on collection of waste and cleaning of streets and beaches, rather than on proper treatment. This is unacceptable to some of the interviewees, because it withdraws financial resources from the more important waste treatment and disguises the actual problem. Regarding finance, it is furthermore often mentioned that the available budget is inadequately aligned with the SWM-plans.

A further barrier often mentioned during our interviews and considered to be important also during the workshop is no or poor communication between key stakeholders. According to the interviewees, simple examples of this can be observed, for example that e-mails do not get confirmed and often only get responded to

Table 7.3
Alphabetical list of operational barriers to implementation.

Barrier	Explanation	Source
Actions are reactive to complains	Actions of the Government often appear to be reactive to complaints by the public or by foreign donors, instead of following long-term national strategies.	Interviews / Workshop
Inadequate distribution of financial resources within the budget	The available financial resources are potentially allocated inadequately. Common examples are the strong focus on waste-collection and cleaning where too much seems to be paid for the received services, and little focus on waste treatment, education or incentives for recycling (businesses). See also Chapter 6, Financial sustainability: current structures and potential steps forward).	Interviews / Workshop / Literature
Lack of alignment	Daily actions and working schedules tend to be not or insufficiently aligned with (master-)plans. This results in reactive work based on a day-to-day perspective. In addition, the SWM-plans often lack aligned with budgeting.	Interviews
Lack of data-management	Data, records and reports concerning SWM generally do not seem to be stored in a structed and accessible way. Often there is no data to make informed decisions. Officials often are unaware of the existence of past reports.	Interviews
Lack of education and involvement of the public	The existing ways of education and involvement of the public are inefficient and insufficient. People do not know about best practices (e.g. recycling). There is no polluter pays principle in place. This leads to a lack of public awareness and participation in SWM.	Interviews / Workshop
Lack of enforcement	Often, poor performance in working positions and failure of projects has no or little consequences. Stakeholders state that nobody is held responsible for low performance in fulfilling tasks and contracts. For examples also see Chapter 6, Financial sustainability: current structures and potential steps forward).	Interviews / Workshop / Literature
Lack of feedback mechanisms and learning from the past	Information from former projects and reports is often neglected. SWM-Plans and contracts lack adaptivity to changing circumstances. An often-mentioned example is the contract with STAR.	Interviews / Workshop / Literature

after several reminders. It is said by stakeholders who are working with or within governmental bodies that no minutes are being taken during meetings. Additionally, interviewees state that there is no regular exchange between key stakeholders who are involved in SWM outside of the governmental bodies. This leads to problems, in that some important stakeholders, like main contractors, are not at all aware of the existence of SWM-plans.

Another barrier, often mentioned especially by representatives of the public is the lack of involvement of the civil society in the SWM-system. Public involvement would be especially important regarding sorting of waste and a reduction of littering. On the operational side, this appears to be due to a poorly working educational program regarding SWM. It is not clear to interviewees within governmental bodies who is responsible for the coordination of educational programs on these issues.

Some of the interviewees state that responsible authorities simply do not take plans seriously. It is stated that they often have their own personal agenda or set it according to short-term complaints from the public. An example is the ban of plastic bags, which was not part of long term SWM-planning but which was strongly promoted by NGOs. Some of our Interviewees see the ban of plastic bags as not being well thought through concerning side effects. Table 7.3 provides a list of operational barriers to implementation.

Table 7.3
continued

Barrier	Explanation	Source
Lack of monitoring and performance measures	The implementation of plans as well as already existing projects often are not properly monitored. Performance is not assessed or at least not on a regular basis. Data collection is generally described as weak. See also Chapter 6 Financial sustainability: current structures and potential steps forward).,	Interviews / Workshop / Literature
Lack of procedures	In general, a lack of written procedures is perceived. Often only oral agreements are used instead of official work-procedures. Additionally, there seems to be no habit of taking minutes during meetings which allows e.g., to trace back earlier agreements.	Interviews / Workshop
Lack of skilled labour	In-house experts on SWM are missing in nearly all involved bodies. Skilled labour for SWM is hard to find and to retain. This leads to a strong reliance on external (and often foreign) consultants and technicians.	Interviews / Workshop / Literature
Lack of time management	Efficient use of time and clear prioritization of tasks seem to be insufficient or lacking for staff who are involved in processes of SWM, as stated by stakeholders working with or within governmental bodies.	Interviews
Limited financial resources	Funding for SWM-projects is limited in the Seychelles, being a SIDS. In the past, funding for large SWM-projects usually came from foreign donors. See also Chapter 6, Financial sustainability: current structures and potential steps forward).	Interviews / Workshop / Literature
People in charge are overwhelmed	Officials working in SWM are often overloaded with work and appointments. Single persons frequently combine too many responsibilities and lack time and attention to fulfil all their duties properly.	Interviews / Workshop
Poor communication between key stakeholders	SWM involves many stakeholders, but they do not communicate on a regular basis. In addition, information-flow is described to be non-existent or very slow, also within an institution. Emails and letters often get no confirmation or response.	Interviews / Workshop / Literature
Unwillingness to take responsibility and leadership	Stakeholders indicate that key actors in the SWM-system tend to be unwilling to take responsibility for the implementation of plans and execution of tasks. Poor performances are explained by the use of various excuses.	Interviews

Content-related Barriers to Implementation

Literature indicates that SWM-plans themselves can be written in a way that hinders implementation. During the verification phase of our research, we noticed that this indeed might be the case for the Seychelles. Various interviewees state that past plans were not necessarily written to be fully implemented, but rather to fulfil donor requirements and international standards, particularly the SSDS 2012–20. Having the status as a SIDS, the Seychelles received international aid for larger projects in the SWM-sector. This seems to have come with requirements to have a comprehensive policy framework in place. Interviewees mentioned that these policy frameworks were then created in a rushed manner and therefore sometimes seem to partially neglect the local context and specific implications of implementation. Detailed steps on how to implement certain projects step by step as well as a clear allocation of responsibilities seem insufficiently spelled out and scarce. Especially the allocation responsibility within the plans is stated to be problematic, because it leads to a lack of ownership, i.e., nobody feels responsible for the actual implementation of certain projects. Additionally, many of the interviewees believe SMW plans to be overly ambitious. They state that instead of a focus on a comprehensive SWM-system, a number on uncoordinated 'wishes' are stated which sound good but which cannot be fully implemented in the Seychelles. For a list of content-related barriers to implemenation see Table 7.4.

Structural Barriers to Implementation

The structural barriers that are most frequently mentioned are a lack of involvement and shared understanding. Both are related to the third most mentioned barrier, a lack of transparency between key stakeholders. On the one hand, the public and the private sectors do not feel involved in decisions from the government. On the other hand, also within governmental bodies, stakeholders mention lack of transparency and involvement as barriers. For example, the writing of plans is described to happen detached from decision-makers and also without involvement of other departments such as the Ministry of Finance. Staff do not connect to plans they should implement or policies they should enforce. They feel disconnected from the task of their job and have to be reminded and pushed several times.

Other barriers that are considered as very important are corruption and nepotism. Various interviewees referred to ties between members of the Government and contracted companies in the SWM sector. This may result in strong conflicts of in-

Table 7.4
Alphabetical list of content-related barriers to implementation.

Reason	Explanation	Source
Plans focus too little on implementation-specifics	Plans do not give enough guidance in regard to specific mechanisms of implementation. Also, monetary requirements of the proposed measures are often neglected, leaving out operational and maintenance cost. See also Chapter 6, Financial sustainability: current structures and potential steps forward.	Interviews / Literature
Plans focus too much on donor requirements	Often, plans are written in response to donor requirements or international standards. This results in rushed plan writing and/or a neglection of the local context and needs in SWM.	Interviews / Workshop
Too ambitious plans	Some plans cover too many things at the same time or involve objectives that propose highly ambitious projects, rather than focusing on needed basics	Interviews / Workshop / Literature
Unrealistic plans	Some SWM plans do not take local circumstances into account, but rather express wishes or hopes. Stakeholders state that they are written not to be fully implemented, but rather to make a good impression	Interviews / Workshop / Literature

terest. Often the status quo is beneficial to decision-makers, and this may be one of the explanations to why STAR currently is still operating, as some interviewees argue (for the implications of this barrier to the financial system, see Chapter 6, Financial sustainability: current structures and potential steps forward). In addition to corruption, stakeholder often mention incidents of nepotism, e.g., that people in governmental bodies sometimes seem to be hired based on relationship rather than competence. It should also be noted that corruption and nepotism are common characteristics of SIDS, and that this is an issue that the decision makers and interviewed participants are well aware off.

Further, an unclear allocation of responsibilities is considered to be a main structural barrier to implementation. This is mostly the case for aspects of implementation and enforcement of policies and plans. As the workshop involving the MEECC and the LWMA revealed, responsibilities are not clear, for example concerning the education on issues of waste. This situation leads to a lack of execution and a lack of leadership and enforcement in general, as no one feels and can be held responsible. This finding supports conclusions of the tdCS 2016, as described in the previous sub-chapter on literature.

As another central barrier to implementation stakeholders name the domination of personal agendas, particularly from people in leading positions. Often, implementation seems to be based on personalities in charge rather than on an established plan. It is said that a new Minister, CEO, or a new person in another leading position can push aside previous plans and establish a different working schedule based on his/her own personal agenda. This lack of procedures and continuity concerning work agendas also leads to improper delegation of responsibilities when there is a turnover of staff, as stated by stakeholders working with or within governmental bodies. They state that a failure or break down of a project is often due to a replacement of the person in charge.

Another core barrier to implementation, with regards to organizational structure, is the work climate within governmental bodies. Stakeholders working with or within governmental bodies describe inefficient bureaucracy and strict hierarchy. Especially for planning and accessing budgets, many unnecessarily bureaucratic steps in decision-making are perceived, leading to a delay in implementation. In addition, a strict hierarchy in communication hinders information flow. Interviewees describe that when certain persons in central positions, like the PS, are out of the country, several actions get delayed. This has an impact on working conditions. Stakeholders state that the motivation of staff obviously decreases with poor and slow-moving communication and strict hierarchy. For a list of structural barriers to implementazion see Table 7.5.

Contextual Barriers to Implementation

The large majority of the interviewees and workshop participants mention lack of political will as an important barrier to implementation of SWM plans, i.e., a lack of commitment and genuine interest to change by decision makers. Various interviewees perceive that waste management is not prioritized enough by the top most decision makers and therefore does not receive the necessary attention, especially in the form of financial and human resources. Interviewees from the private sector stated that within their businesses support from Government is key for successful implementation of projects. Closely related and also mentioned is the barrier of conflicting goals and priorities between actors. On the top level, this seems to be the case between different departments within the government where some prioritize economic growth, while others care about environmental protection. Similar patterns can also be observed in private businesses, where the sole objective is

Table 7.5
Alphabetical list of structural barriers to implementation.

Reason	Explanation	Source
Corruption and nepotism	There seem to exist affiliations between members of the Government and one or more contracted companies in the SWM sector, which in turn bears the potential for strong conflicts of interest. To them, the status quo might be beneficial. Additionally, it is stated that people in governmental bodies sometimes seem to be hired based on relationship rather than competence. See also Chapter 6, Financial sustainability: current structures and potential steps forward.	Interviews / Workshop / Literature
Dependencies between departments	Stakeholders working with or within governmental bodies name uneven power structures and dependencies between departments, particularly when it comes to budgeting or employment administration. This lack of autonomy inhibits or slows down adaption and flexibility.	Interviews / Workshop
Discouraging working conditions	(Young) local experts move from the public to the private sector, because in the former, there is a perceived lack of recognition and involvement as well as low salaries. The motivation also decreases with poor and slow-moving communication and strict hierarchy.	Interviews
Domination of personal agendas	Personal agendas dominate. Actions often depend on persons in charge, e.g. a new Minister or CEO can push aside plans and go along with the own agenda or set other priorities. Often, when a person in charge leaves, projects stop and structures break down.	Interviews / Workshop
Inefficient bureaucracy and strict hierarchy	There are many bureaucratic steps in decision-making, especially for accessing budget. Responsibilities are split a lot; there is a lack of overview perceived (See also Chapter 6, Financial sustainability: current structures and potential steps forward. A strict hierarchy strongly decreases efficiency of communication.	Interviews / Workshop / Literature
Lack of involvement and shared understanding	Stakeholders from different areas (private and public) state that they are not sitting on one table with the Government. Mainly (external) consultants are writing plans, decision-makers from various departments are not involved. The top down approach leaves no space for bottom up and broader involvement.	Interviews / Workshop
Lack of transparency among key players	Processes are described as hidden, decision-making and information flows lack transparency, especially between MEECC and the Ministry of Finance. In addition, confidentiality of documents and reports is described as disabling the improvement of the situation.	Interviews / Workshop / Literature
Unclear allocation of responsibilities	Uncertainties exist about who is responsible for what, especially in the details. For example, this is the case between LWMA and MEECC concerning education and enforcement. This leads to misunderstandings and duplication of work.	Interviews / Workshop / Literature

profit, or between NGOs and consultants who disagree regarding the ban of plastic bags. In addition to conflicting goals, some of the interviewees mentioned a lack of trust between key stakeholders (for example between governmental bodies), especially concerning finances. Stakeholders mentioned this also in relation to elaborated bureaucratic control mechanism and poor will to collaborate.

Almost all our interviewees and workshop participants mention lack of public awareness, that the public has insufficient knowledge and/or cares little about the SWM-system. According to many interviewees this is reflected in a widely spread unwillingness to actively participate in the SWM-system for sorting or reduction of littering. It is also stated that this might be due to lacking political will, because SWM is not publicly perceived as a problem, and that therefore politicians are not pressured to act on it or see a political benefit for efforts. Some of the interviewees additionally state that there is a hindering attitude of high expectation towards public services within the public, meaning that a large part sees SWM solely as a responsibility of government. The interviewees explain this by referring to the political history of socialism of the coun-

try. In addition, they see an explanation via the current waste collecting scheme, which hides the waste problem to some extent by extensive cleaning and without a polluter-pays-principle in place. Interviewees state that politicians tend to foster this expectation by promises made during election campaigns, which they afterwards do not fulfill. Finally, stakeholders say that politicians are afraid to lose public support and do not want to put (financial) pressure on people to make them aware of the problem.

Table 7.6
Alphabetical list of contextual barriers to implementation.

Timeline	Waste Classes	Model
Conflicting goals and priorities between actors	The focus of work, goals and values differs among stakeholders. Many stakeholders are solely profit oriented and do not care about the environmental impact.	Interviews / Workshop / Literature
Conflicting goals and priorities between Departments/Ministries	Among involved institutions and ministries different priorities are perceived, especially concerning economic growth, i.e. enabling and limiting inflow of cheap and polluting products and on the contrary protecting the environment.	Interviews / Workshop / Literature
High expectations of the public towards public services	A general attitude in the public of waiting for the government to act first, is described in connection to the political history of the country. This seems to be further encouraged by promises during election campaigns, in order to gain voters.	Interviews
Hindering cultural aspects	Cultural aspects might constitute barriers to implementation, such as a weak tradition of following structured plans, or a general unwillingness to change or put pressure.	Interviews
Inappropriate working attitude	On different levels, it is difficult to find engaged workers. Working hours are not kept. Sometimes weekly payments are expected. In operational businesses an unwillingness to work in 'dirty jobs' can be observed.	Interviews
Lack of political will	The commitment of decision makers is not given or very low: SWM is not a priority. There is no genuine interest perceived, to invest real effort. Excuses are used and promises not fulfilled. Additionally, a lack of proactiveness and leadership is mentioned.	Interviews / Workshop / Literature
Lack of profitability for businesses	In the current economic setting of the Seychelles SWM is described to be hardly profitable, especially the recycling and waste to energy sector. Therefore, private businesses lack incentives to participate increasingly in SWM. See also Chapter 6, Financial sustainability: current structures and potential steps forward.	Interviews / Workshop
Lack of public awareness	The public is unaware of the amount of produced waste, the waste stream and treatment. This potentially leads to a lack of public participation in the SWM-system, i.e. no sorting and no reduction of waste and littering by consumers.	Interviews / Workshop / Literature
Lack of regulations and legal framework	There is a lack of legal framework and regulations for SWM, e.g. for waste to energy and for proper enforcement in the SWM-sector.	Interviews / Workshop / Literature
Lack of trust among key stakeholders	When it comes to money flows and fulfilment of required tasks actors lack trust towards each other.	Interviews / Literature
Small island community	The setting of being a small, remote island makes implementation difficult. Personal connections are described to be unavoidable, i.e. people know each other. In addition, the market (for recycled products) is small, there are low possibilities for economies of scale and importing machinery and parts is expensive.	Interviews / Workshop
Uncertain socio-economic environment	Changes in the socio-economic environment makes proper planning for recycling businesses difficult. For example, China and other countries recently stopped the import of recycled plastic, which has negative effects on Seychelle's businesses. Additionally, also within the Seychelles, market access appears not to be secured for recycled products.	Interviews / Literature

Another often mentioned contextual barrier is the fact that the Seychelles is a small island state, a small community with many personal connections, few possibilities for economies of scale and high costs due to import. For example, stakeholders often mention that structural deficiencies, like nepotism, are unavoidable, because it is nearly inevitable that people know each other. Additionally, many stakeholders highlight that the situation of being a small island state makes it practically impossible to turn SWM into a profitable business. Especially with regards to recycling or waste to energy, businesses are perceived to be barely able to survive without governmental subsidies due to the relatively small amounts of waste and the high cost for technical equipment. According to interviewees an unstable, uncertain, socio-economic environment enforces this low profitability within SWM. In recent years, international political and economic changes in the waste sector took place, for example the import ban of recycled plastics by almost all countries. Additionally, interviewees state that governmental support in the form of subsidies (or promises for it) has not been reliable. This results in an unattractiveness to venture into the waste sector as a business. Stakeholders mention that new initiatives receive little support.

Some of the stakeholders express the opinion that there are certain cultural aspects in the Seychelles that might hinder implementation of SWM-plans. For example, this is mentioned with regard to being an oral society with no strong tradition of following written plans, or with a general resistance to put pressure or to change oneself. In this regard, stakeholders occasionally mention an inappropriate work attitude of staff. More specifically, they mentioned that working hours are often not kept or that jobs in the waste sector are regarded as 'dirty' and are therefore undesirable. Also, weekly payments are often expected. For a list of contextual barriers to implementation see Table 7.6.

Interlinkage of Barriers

The analysis of interlinkages among barriers primarily shows that the barriers are strongly interlinked. Figure 7.2 shows 17 barriers (compiled from the list of the most mentioned ones and from a consistency check between stakeholder groups) and their interlinkages. We assessed possible influences between each of the barriers, generating a system of barriers and interlinkages.

In the way we arranged the barriers, there are two barriers that only impact other barriers, but at the same time are not impacted by any other barriers, namely *small island community* and *conflicting goals*. On the contrary, *lack of enforcement* is impacted by many other barriers, but has itself only an influence on *corruption*. In between, there are numerous barriers that are impacted by and have an impact on many other barriers, such as *inadequate budget*, *lack of alignment*, *lack of involvement*, or *lack of human capacity*. This does not necessarily make them more important than other barriers.

The system shows several loops. A loop is a self-sustaining subsystem, where an influence on one element feeds back to the starting point, over multiple linkages (also called edges). In the following section we present four feedback-loops that the research team choose due to their explanatory power. All remaining loops with a maximal length of 5 edges can be found in Appendix 7.8.

Figure 7.3 shows the interconnections between *lack of political will*, *lack of involvement*, and *lack of public awareness*. Interviewees state that one reason for the lack of political will is a lack of pressure from the public to change something, meaning a lack of public awareness of the waste-problem. However, public awareness is stated to be lacking, because the public is insufficiently involved in the SWM-system from the governmental side.

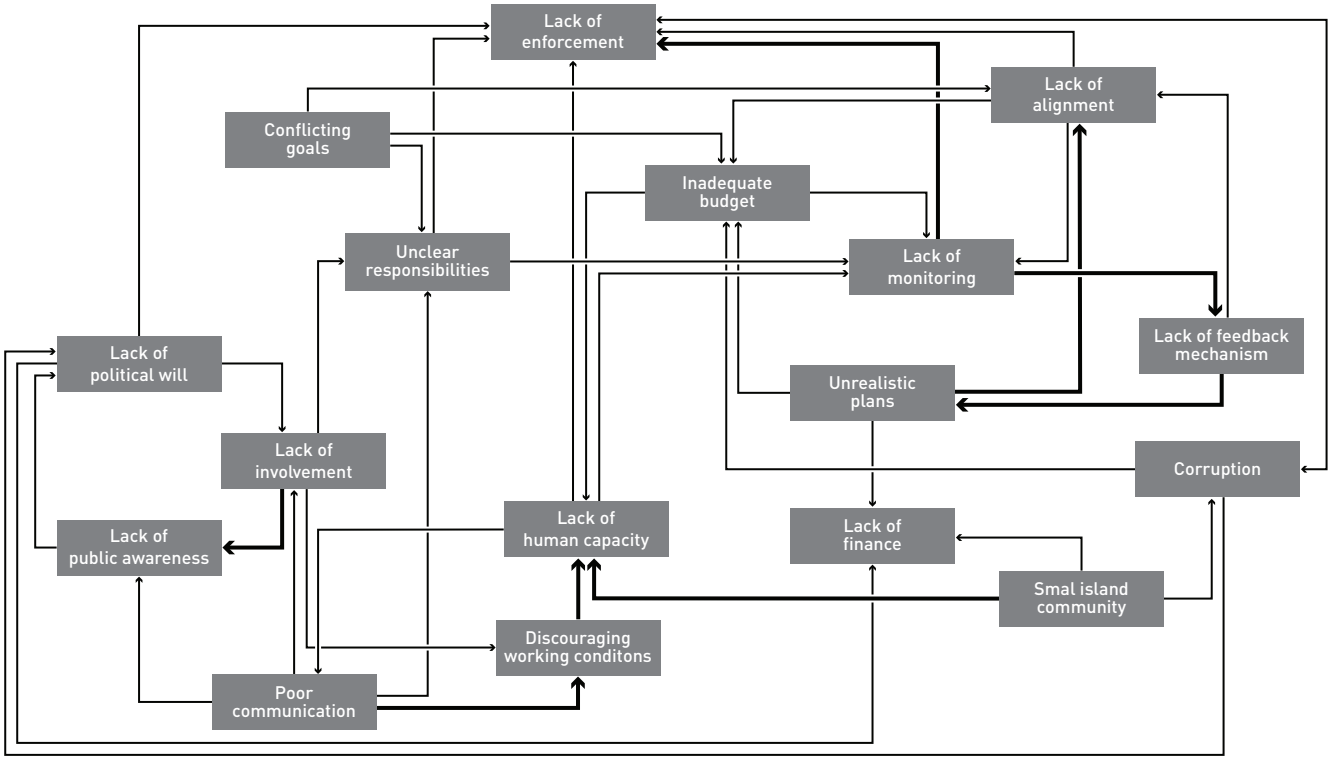

Figure 7.2
Impact Structure of most mentioned barriers.

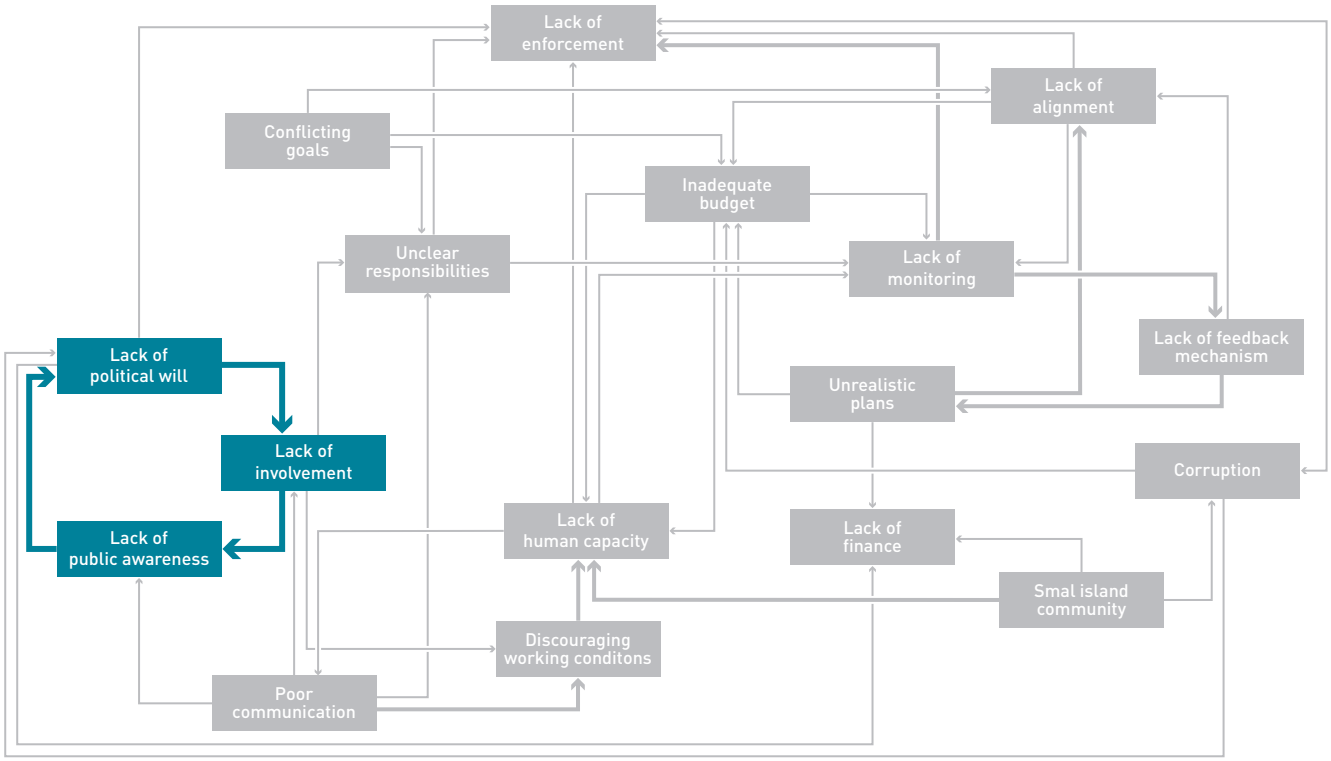

Figure 7.3
Feedback-loop 1 of tree barriers.

This again is said to be due to a lack of political will to tackle the waste problem in a comprehensive manner.

Figure 7.4 shows the feedback loop *unclear responsibilities*, *lack of enforcement*, *corruption*, *lack of political will*, and *lack of involvement*. Various interviewees stated that one reason for poor enforcement is an unclear stipulation regarding who is responsible. Moreover, it was mentioned that a lack of enforcement leads to a toleration of corruption and nepotism within the SWM-system. Corruption in the form of strong conflicts of interest is mentioned to be a reason for the lack of political will to act, as powerful people might profit form the status quo. As explained before, this seems to lead to a lack of involvement – which then again is said to lead to an unclear allocation of responsibilities.

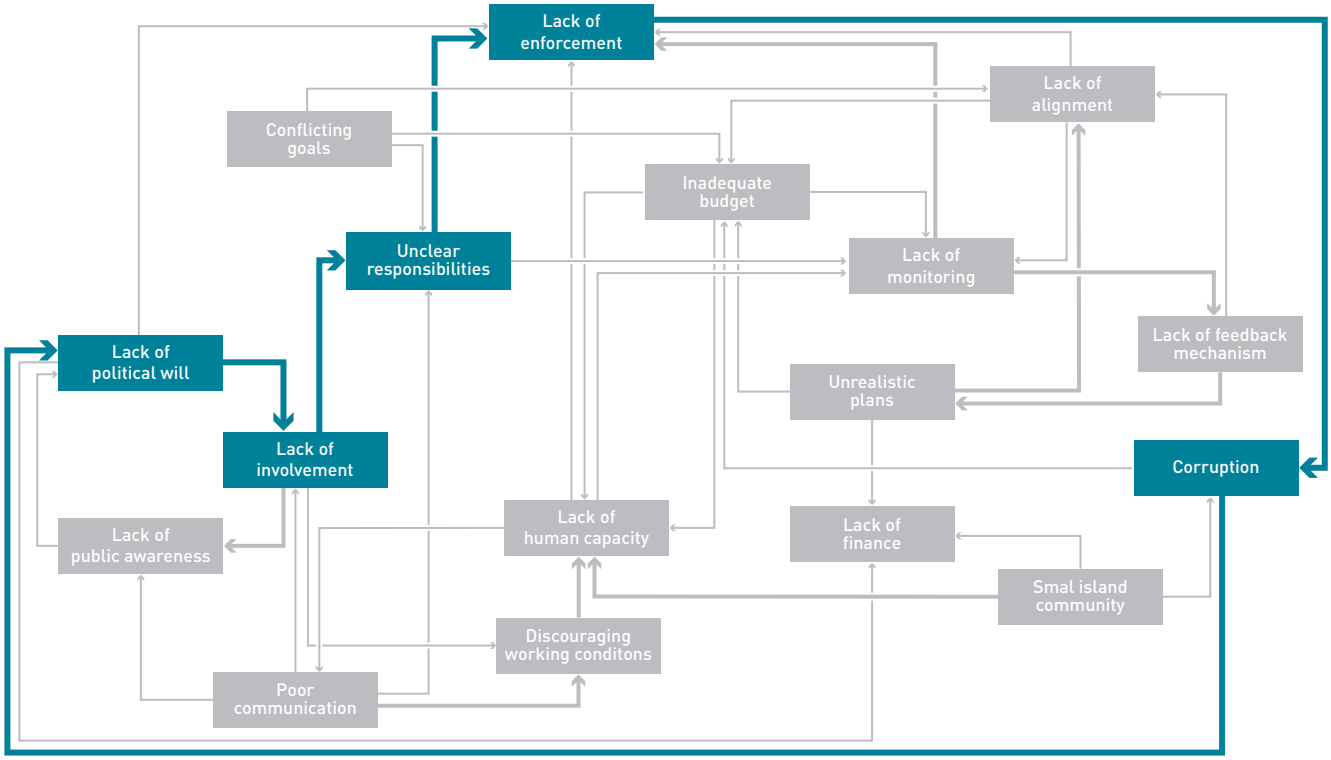

Figure 7.4
Feedback-loop 2.

Figure 7.5 shows another loop of five components: *lack of alignment*, *inadequate budget*, *lack of human capacity*, *lack of monitoring*, and *lack of feedback mechanism*. Interviewees stated that one of the reasons for the lack of human capacity in the public sector is due to insufficient allocation of financial resources to recruit and retain human resources. Often it is stated, that one of the causes for a lack of monitoring is the unavailability of (skilled) personnel for these tasks. However, lack of monitoring is stated to be the main obstacle to better feedback mechanisms for the adjustment of plans and budgets, i.e., for good alignment. The lack of alignment of budget and plans is stated as a cause of insufficient budget; the loop is closed.

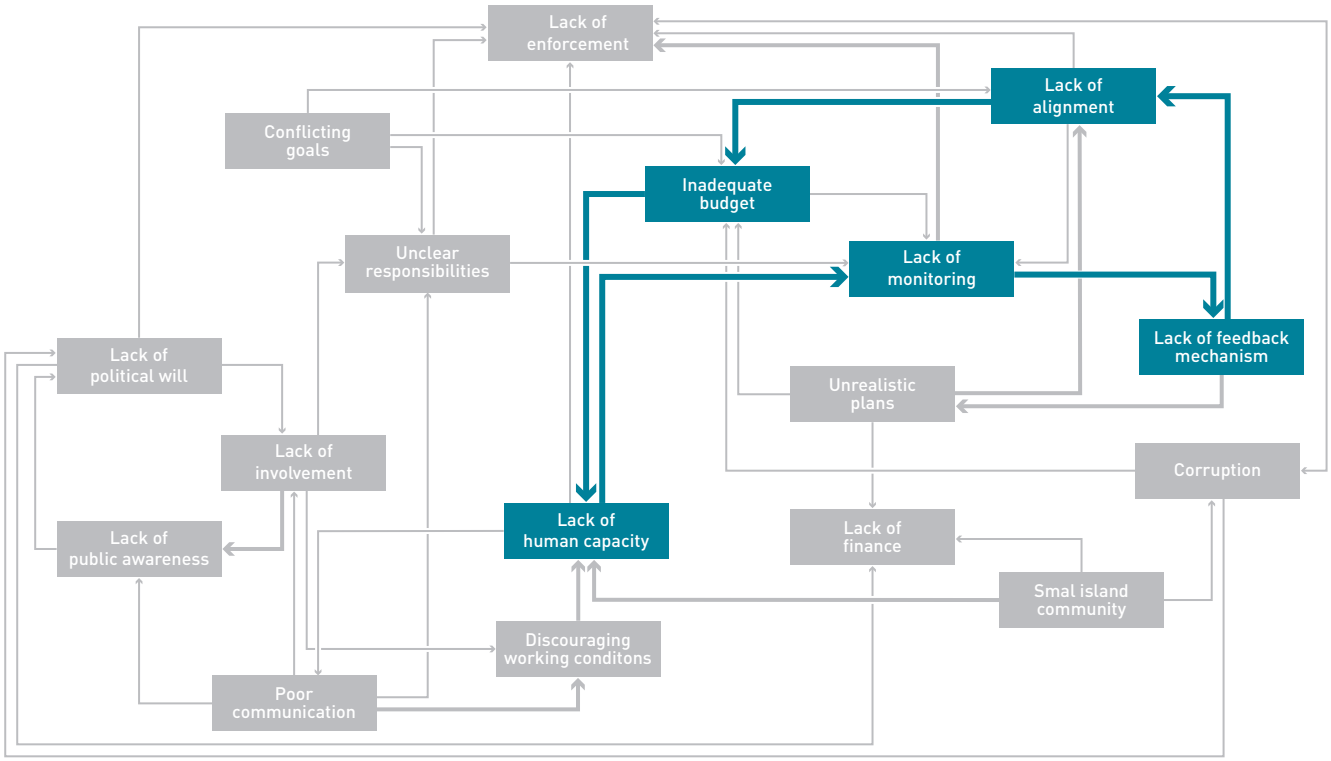

Figure 7.5
Feedback-loop 4.

7.3.3 Results from Public Survey

In this section, we present the results of the public survey which was conducted in close collaboration with the waste collection and sorting group (see Chapter 1, Waste collection and sorting: Consumers' perspective). Since their in-depth data analysis did not show any correlation of results with demographic variables such as age, gender, education, and income we do not explore these details but only present the main findings.

The percentage of agreement and disagreement of the respondents with the proposed barriers is shown in Figure 7.6.

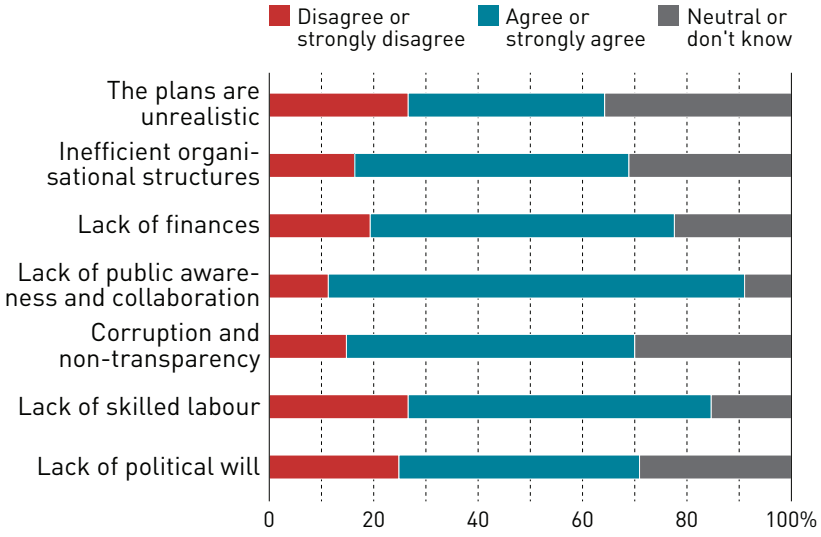

Figure 7.6
Percentage of agreement/disagreement with proposed barriers (n=148).

The underlying data can be found in Appendix 7.9. For all proposed barriers, the combined percentages of agreement are higher than the sum of disagreement. However, considering the responses 'neutral' and 'I don't know', for most barriers the result is not entirely clear. Only for the proposed barrier lack of public awareness there is a clearly visible tendency towards agreement.

7.3.4 Possible Actions to overcome the barriers

The semi-structured interviews and the workshop revealed that the stakeholders who are involved in the SWM-system in the Seychelles have many ideas about how to overcome some of the previously mentioned barriers. In this section, we present a selection of those ideas.

One action that was most frequently mentioned during the interviews was to generate a stable and profitable marked for businesses involved in SWM. Especially when it comes to recycling, stakeholders emphasised the importance of subsidies or import-taxes, but also the increased guarantees from the Government. The perceived lack of profitability is blamed on a lack of incentives from the Government. Thus, the proposed action by stakeholders to overcome this barrier is to provide economic incentives, e.g., in the form of subsidies.

Another very frequently mentioned action by stakeholders is education in schools on the three R's ('Reduce, Reuse, Recycle') and the issue of waste in general. Stakeholders were of the opinion that one should show to the public how big the problem is, e.g., by taking people to the landfill and provide easily accessible annual numbers on the waste streams (possibly per capita). To increase public awareness, also a polluter-pays scheme that makes the generation of waste visible and sensible is mentioned by interviewees and in the workshop.

Further, tackling the lack of involvement is a central topic for many of the interview partners. It is proposed that governmental bodies should increasingly seek contact with business, be it collectors, recyclers or hotels. Especially the latter investment on equipment like glass-crusher and incineration plants themselves, without officials seeming to be aware of this. Generally, bringing people together was often considered crucial for overcoming barriers. Stakeholders also mentioned more active lobbying of civil society as a needed action.

During interviews and the workshop, participants also mentioned several actions connected to the barriers 'lack of monitoring', 'feedback', and 'enforcement'. Amongst others, this involves putting a monitoring and reporting system in place as well as fixed and regulating formats of reporting and communicating, regularly check and revise contracts and set tasks with deadlines. In addition, and especially during the workshop, stakeholders mentioned actions tackling the unclear allocation of responsibilities.

A general observation based on the ideas of actions that were collected during the workshop is that all of them involved several stakeholders. Be it several ministries and agencies or a combination of stakeholders from the public and the private sector. If this holds to be true, this strongly increases the importance of involvement, good communication, and a clear allocation of responsibilities. A list of the mentioned actions can be found in Appendix 7.10.

7.4 Discussion

7.4.1 Discussion of Results

The findings from our literature review show that the problem of lack of implementation of SWM-plans is not unique to the Seychelles. Even some of the local SWM plans already highlight critical factors for success such as political support, ownership of stakeholders, or periodical audits. The report of tdCS 2016 (Dine et al., 2016) states core barriers to implementation, amongst others an unclear allocation of responsibilities, unspecific and non-tangible actions without liable persons responsible for management or enforcement, and lack of skilled labour. We furthermore noticed that all involved stakeholders were already aware of a large number of these barriers. In that sense, our findings might not be surprising.

However, our findings from the refinement of the list of barriers we found in the literature and the analysis of interlinkages provide a comprehensive answer on our first research question 'What are the barriers to implementation of SWM-plans in the Seychelles?' The findings show that the specific case of implementation of SWM plans in the Seychelles fits the definition of a so-called 'wicked problem', a concept originating from social planning (Rittel & Webber, 1973). This means that multiple stakeholders interact in a complex and dynamic environment, while not agreeing on what the exact problem definition is. Some even might not perceive a problem at all. The concept of a wicked problem stands in contrast to so-called 'tame problems' that have a clear and unchanging definition and a straightforward solution (Batie, 2008). In at least three aspects, our findings present the implementation of SWM plans as a wicked problem: first, a high stakeholder dependency of the problem definition; second parts of the problem and solution are highly interlinked; and thirdly, problems and solutions are changing over time.

Our findings show that the relevance of some barriers is perceived in different ways. Our data shows that consultants perceive other issues as core barriers than government officials; and the opinions of NGOs and the public sector differ again from the latter. For example, the public sector and the consultants seem to be more aware of operational barriers, while the private sector notes more structural barriers. This observation is not surprising, as consultants and public-officials are the ones dealing with the operational side of SWM-plan implementation, while the private sector is more involved at a structural level. Whereas some stakeholders see other stakeholders in the obligation to take necessary action, some stakeholders are also self-critical enough to ascribe necessary actions to themselves. In this sense, the results from the public survey appear to be very interesting. While for most statements no trend towards agreement could be observed, the large majority of respondents considered the lack of public awareness to be a cause for the lack of implementation of SWM-plans. This could mean that the public is, to some extent, self-aware that they are insufficiently involved in the SWM-system. Other examples are that different interviewees ascribed education about waste to be a task for the Government, or that a stakeholder from the private sector recognized the need to do more of own research on recycling potential in order to overcome the barrier of unprofitability. Furthermore, government officials realized that it is in their hands to improve the quality of communication, the structure of meetings, or tackle the lack of procedures. The workshop was useful to carve out these differences – and for the participants to recognize that everyone can take ownership of the barriers that are close to them or their position and work on their resolution.

We show that barriers across all four categories (operational, content-related, structural, and contextual) are highly related and impact each other with emergent behaviour. It is insufficient to present barriers separately, as often one leads to another. Additionally, it is impossible to find a

single root cause of the problem of implementation or a single most important barrier. However, the analysis of interlinkages reveals underlying causes of barriers. Taking these into account and being aware of the interconnection is important when designing actions to improve the system with a long-term effect, as addressing one barrier can have positive effects on other barriers. When considering feedback-loops for planning of actions, however, very different time scales and time dependency have to be taken into account. For example, the socio-economical as well as the political context is continuously changing. The shift of power-structure in the Parliament of the Seychelles was mentioned several times. New barriers might emerge and others disappear, e.g., the situation on global waste markets, sometimes without relation to stakeholders of the SWM sector. Lastly, the analysis of interlinkages also reveals the fact that numerous stakeholders are involved in SWM, which contradicts with the sometimes-expressed statement that the implementation of SWM-plans is only in the hands of the LWMA.

On the second research question 'What actions could be taken to overcome these barriers?' we can note that during interviews and the workshop it seemed not too difficult for stakeholders to come up with concrete actions to work on and remove barriers. In fact, all stakeholders came up with possible actions to overcome barriers – often even without asking for it. Partially, this is due to the fact that most of the barriers mentioned already indicate the solution. The obvious solution to a 'lack of data-management' for example, is (good) data-management. However, often it is unclear of how exactly to get there and who is responsible for starting.

Furthermore, we believe that Stakeholder workshops, like the one we have organised, can help to tackle such 'wicked problems', as it brings different expertise and viewpoints together. By involving differed stakeholders with their visions for the problem, it is possible to create a "shared understanding about the problem, and shared commitment to possible solutions" (Conkin, 2006). It is important to underscore that understanding is not the same as an agreement. It is rather about understanding each other's positions "well enough to have intelligent dialogues about different interpretations of the problem" (Conkin, 2006). Thus, meetings and collaborative work between different stakeholder groups, departments and/or ministries are the natural starting points for creating socially shared understanding. In this sense, we observed that the exchanges in the workshop to some extent created a shared understanding on barriers to implementation of plans. We realize that especially the first research question on the identification of barriers is strongly connected to blaming and (personal) accusations. A useful way to avoid this negative component was to have open, but channeled dialogues in a well-structured workshop. This allowed us to guide discussions and make different points of views and opinions transparent in a potentially enriching way. It was motioned by participants that this setting is helpful, also involving a more neutral third party for facilitation.

7.4.2 Limitations

Our study highlights numerous potential barriers to SWM-plan implementation as well as possible actions to overcome them. As the overarching research project was focused on the Seychelles, the results of this study should not directly be generalized to other locations. Yet, we believe that the findings are very strong, in the sense that they still might be partially transferred to other similar situations, e.g., in other SIDS, but also to the lack of implementation of public policy in general. However, the study encompasses certain unavoidable limitations.

First, the data strongly relies on personal views by our interview partners. Due to time constraints we conducted 15

expert-interviews only. For a profound analysis of possible barriers and action, as well as for a better elimination of personal biases of the interviewees, the sample could be increased. Also, the sampling of some of the interview partners and workshop participants depended on initial contacts, especially to the advisory board, and followed a snowball-system. This has the potential to make the representation of sectors imbalanced. Especially NGOs and representatives of the public are underrepresented in the sample. Second, the explanatory power of the public survey is limited, as we were constrained to asking only one closed question and possibly due to language barriers. Third, again due to time constraints, the qualitative analysis of the collected data had to be reduced to a core minimum. This potentially led to missing or misinterpretations of details. Lastly, also the personal biases of the researchers with reagard to sampling, interviewing, and processing have to be mentioned. Asking certain questions potentially influenced the answers of the interviewees.

Nevertheless, all decisions were discussed within the intercultural research team. This enabled an intense exchange of different views regarding the methods and findings which, in turn, hopefully reduced personal and cultural biases.

7.5 Conclusion

The barriers identified in the course of this study are highly interlinked and related to stakeholders. In addition, they strongly depend on stakeholder perceptions. Thus, there is no single most important barrier and also no sole solution to the challenge of implementation of SWM plans in the Seychelles – which under no circumstances means that nothing can be done. Rather, the complex interlinkage of barriers suggests possibilities to address any barrier with simple actions that then positively affects other barriers. Furthermore, our research shows that multiple stakeholders from all sectors already identified barriers that are closely related to their field of work, meaning that implementing SWM plans does not only lie in the hands of the public sector, but is also a question of involvement of actors across all sectors. For such forms of involvement, the creation of shared understanding is key. As problems with implementation of a plan often may result in blaming, we realised that a useful way to avoid this negative component is to have open, but channeled, dialogues in a well-structured and balanced workshop. Our stakeholder workshop showed that it is possible and fruitful to arrive at a shared understanding of barriers and actions to overcome them. Bringing different stakeholders together to agree on problems is a strength of small island communities like the Seychelles and provides a large part of the solution.

In order to be more specific on the reasons for lack of implementation or the failure to maintain implemented projects on the long term, we propose an analysis of more specific objectives of SWM-plans or past projects. As mentioned before, Gonzalves (2017) provided a rudimentary and personal assessment of the status of implementation of, amongst others, the Waste Policy 2013–2018, the Solid Waste Master Plan 2013, or the waste management component in the SSDS 2011–2020. This assessment could be done more scientifically and also be related to the results of this study. In this way, the reasons of failed long-term implementation of specific projects could be analysed in more depth. In the same way, reasons behind the lack of execution of a specific job or delay of specific actions could also be identified. This would help making the results of this study more concrete and the lessons learned more tangible.

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General Conclusions

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In this section, we review the results of both case studies 2016 and 2018 and draw some general lessons from our three years' work on solid waste in the Seychelles. First, tdCS 2016 provides a comprehensive overview of the current waste management system in the Seychelles (focusing on Mahé). At first glance, the system seems to work relatively well. Household waste is collected daily and transported to the landfill, which is the current waste disposal practice. Some waste fractions, such as PET bottles, aluminium cans or scrap metal, are separated and delivered to the international recycling system. Residents seem to be aware of the waste problem, and even a willing to pay for an improved waste management system. However, we also have to report some (fundamental) weaknesses. The current recycling system only works due to the informal sector. The large share of organic waste bears considerable potential for energy recovery, which is not yet exploited. Institutional weaknesses include outdated waste management plans, unaligned policies, and responsibilities and roles that are not always well defined and clearly assigned. The most serious issue is that an increasing generation of all sorts of waste, from organic to highly toxic, fills up the current landfill much faster than projected. Thus, depending on population and economic growth rates, a number of additional landfills to the current Providence II, Unit 1 landfill would be needed over the next 25 years. This would not only require land that is currently unavailable and therefore would have to be reclaimed from the sea at very high costs, but landfills also pose long-term environmental risks, particularly when they lack proper sealing, as is the case of some current landfill sites.

Second, tdCS 2018 builds on and complements tdCS 2016 and studies by other researchers. The new study conducted an in-depth investigation of some aspects of the waste system but without losing the system perspective, and it uncovered previously unrecognised blind spots. In short, we draw the following findings:

- There is a potential for expanding the recycling system. For example, glass is currently not collected separately and goes to the landfill; the same applies to organic material, a waste class that accounts for a large proportion of the total waste volume (see Chapter 2).
- Alternative treatments of certain waste fractions include anaerobic digestion (AD) of organic waste, which would produce energy and fertiliser. Some types of organic waste may be used as feedstock for black soldier fly larvae, a protein-rich species that can be used as fodder in chicken farming, for example (see Chapter 4).
- Our study has also examined waste incineration as another form of waste treatment. Combustion has two main advantages: it substantially reduces waste volume up to 80% and enables electricity generation. Our calculation suggests that if properly done, energy production through incineration would contribute to 10–15% of the Seychelles' total energy consumption (see Chapter 5).

However, all of these different waste treatment options require prior separation of certain waste fractions. Separation is best done at the source, that is, before different waste types are mixed together. Later sorting would be time consuming and cost intensive and would require large-scale sorting plants.

- Although important for some waste fractions, redeem centres currently do not meet the requirements of a well-functioning sorting system, mainly because they currently accept a few waste types only (e.g., PET bottles and aluminium cans) and are located too far from households. Despite this issue, the will to separate waste seems to exist in the population, and some people already practise it (see Chapter 1).
- Our study also shows that Hazardous Waste (HW) is one of the blind spots in the Seychelles' waste management system. An overview of HW is lacking, a gap that our study has started to fill (see Chapter 3).
- New activities, such as the introduction of waste incineration, AD or HW management, need appropriate political guidelines and regulations to ensure a successful and long-term implementation. This matter is all the more important because our study also shows that this was not the case in the past. However, in this report, we propose ways to overcome such barriers (see Chapter 7).
- An important prerequisite for up-to-date policies and regulations involves the finances. Our study shows that the current financing system is rather complicated and consequently, not fully transparent (see Chapter 6).

What conclusion can we draw from these studies? There is a momentum of systemic change. This includes an integrated waste management system with waste to energy as core strategy. The implementation of a long-term strategy needs coordinated and step-wise actions. Coordinated actions can only be realized if key stakeholders communicate and collaborate in a meaningful way. Furthermore, an integrated system requires both respective capacities to manage such as system and the financial means. Leadership and the intention to change the current system are prerequisites of success.

A *momentum* to establish a new waste management system

There is a momentum for the implementation of a future-oriented waste management system. First, the political will to change seems to be present because the MEECC has declared waste management a top priority, which appears as well to find support by the population. Second, initial approaches to waste sorting are available. However, these must be further developed, while taking into account the existing recycling potential. Third, waste treatment methods as alternatives to landfilling are feasible and also financeable, with the necessary governmental support. Finally, the possible reasons for the failure of previously implemented plans and policies have been identified.

We believe that the results of tdCS 2018, together with those of the existing studies, provide a solid foundation for a long-term strategy, with clear objectives that allow well-informed decision making. If this long-term strategy aims to substantially reduce the amount of waste dumped into landfills, then incineration, AD and/or black soldier fly larvae technologies are promising options. These options would also be in line with the change in the waste management strategy from landfilling to waste incineration, undertaken by governmental decision makers in the context of rapidly filling landfills. However, such a new strategy includes many aspects to

consider, such as the sorting infrastructure, collection regimes, public support, financial mechanisms, recycling, expected capital and operational expenditures, to mention a few.

An integrated waste management system

Our studies have spanned the subject widely and highlighted various facets of an integrated waste management system. This integrated vision is necessary and should be implemented, albeit in stages, to facilitate an ensemble of coordinated measures. For example, an incineration or an AD plant is technically feasible, but the implementation is associated with high investment and operation costs. This requires the decision makers to understand waste management as a system of interlinked structures, activities and measures. They need to think about long-term needs, regulations, affordability and capacity. Before any large-scale incineration or AD plant can be implemented, the following points must be taken into account:

- A sophisticated sorting and collection system must be installed.
- A sorting system at the source needs incentives, such as an appropriate and functioning infrastructure, to be accepted by the local population.
- Local capacities/expertise must be built up to enable the operation of a waste management system for a longer period.
- There should be clarification about where to build the necessary new infrastructure and whether the existing infrastructure is sufficient (e.g., grid capacity).
- A long-term solution should be provided for the disposal of residues, such as bottom/fly ashes from waste incineration or the digestate of an AD system.
- A new financing scheme is needed in order to fund such an integrated waste management.

Actions but not blind activism

Obviously, future-oriented waste management cannot be implemented by the existing funding schemes alone. Additional resources are needed. This fact must not be concealed but communicated openly and honestly. The message must be that waste management is the state's basic task, similar to public transport, health and social services, road infrastructure, fresh water supply and so on. Although this service needs to be paid for, whether through a waste fee, general taxes, consumption or import taxes, it must be affordable for all residents. It is important to explain to people what the waste disposal service includes, what it costs and what the direct or the indirect consequences are if this service is not paid for and therefore not implemented (e.g., effect of a negative image on tourism).

What makes a system change difficult is that nobody wants to pay for a service that was previously free of charge. A possible way of taxing could be a system change that would entail the introduction of life-cycle pricing, which would cover the costs of waste disposal. Ideally, this waste tax would be levied directly on the import of goods, according to the expected disposal cost of each item. The Seychelles forms a sink for almost all imported goods; accordingly, waste disposal costs are incurred locally. Nonetheless, such a model cannot be implemented overnight. The same case applies to the installation of waste treatment facilities, such as incineration and AD plants.

It looks like that there are companies/investors which would be willing and eager to build an incinerator or other waste infrastructures. However, these infrastructures would require extensive technical and management expertise and experience to ensure proper specification, implementation and operation. It is therefore indis-

pensable to collaborate with partners that have the necessary know-how. However, there are only very few such companies in the world (one of them provided major expertise for the work reported in Chapter 5). The technical implementation is not easy, particularly in a country with high humidity and salinity in the air, limited financial resources and inadequate technical capacity. The temptation is to fully shift the task to the private sector in the hope that the problem would be solved. However, we believe that it would be expedient to leave the decision-making power to the public authorities because an investor/plant builder has its own (economic) logic. Accordingly, a public–private partnership could be one possibility. The process from planning to construction of such facilities takes time. However, this period would be important and well spent because of the expected longevity of such plants, for example, at least 25 years for a waste incineration plant. Therefore, the already planned Unit 2 of Providence II should be realised, as landfilling will continue to be the most important option for the waste treatment in the next years. However, planning steps must be initiated immediately once the waste management strategy is clear.

Long-term planning also implies pilot projects. This applies particularly to new sorting schemes. The implementation of a well-functioning sorting system is an iterative process. It is impossible to find the right solution directly. To avoid wrong investments in infrastructure, pilot projects that aim to identify the best possible option should be initiated. Such experiments are ideally planned and carried out together with scientists and in close consultation with consumers and the private sector. These pilot experiments would ideally occur in parallel to the planning/construction of waste treatment plants.

Leadership and capacities

We have already addressed the issue of leadership in tdCS 2016, but we recognise the need to do so repeatedly. All the topics investigated in our study are directly linked to leadership (e.g., clear strategy, implementation and enforcement of laws, plans, regulations, ownership, etc.) and to the technical and the institutional capacities that are needed to plan and implement the waste management system. Building up such capacities needs a longer-term engagement. From the outside, we observe a rather hierarchical system. Inherent in any governmental structure elsewhere, it serves a well-operating administration and includes responsibility and accountability. However, a hierarchical system may become dysfunctional if the responsibility is not clear, the scope of freedom (area of responsibility) of the lower administrative level is too small, or operational guidance comes from the topmost level. Whether each issue is intended or unintended, it creates a 'wait for the order and eventually act' attitude or mindset; thus, the necessary actions are delayed or will not be performed at all.

Another observation is that people in charge are overwhelmed by the number of tasks. Compared with the tasks ahead, waste administration appears to be too understaffed or occupied with tasks that are not at the core of waste management. Given that the state's quota or means may not allow creating additional positions, a model comprising bachelor's and master's theses, as well as student internships, may be a short-term solution to strengthen the sector and support the work to be done. This would also help in building up capacities, which are urgently needed.

Outlook

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Given the consumers' entrenched behavioural patterns in relation to waste, the limited resources, the lack of skilled waste managers and other administrative hurdles, waste management in the Seychelles proves challenging and demanding. Nevertheless, the job needs to be done properly if the Seychelles does not want to risk losing its reputation as a clean, well-managed destination among its tourists' countries of origin. Against this background and based on the insights from the three-year project, we address a few points that should be tackled in the upcoming phase of waste management.

We propose that a task force should be set up to implement the masterplan or the measures proposed in our reports in order to reduce the pressure on those responsible for waste management who are already burdened, if not overburdened, with their respective tasks. The task force must be able to understand and use systemic links. Furthermore, it needs to ensure continuity and better coordination among the different waste management bodies and international experts. This task force, ideally a cross-sectoral group with representatives from the MEECC, the LWMA and the Ministry of Finance and in consultation with the private sector and civil society, should become the operational body to plan and push the implementation of the waste management strategy. This body should be equipped with resources and autonomy to work in a goal-oriented and flexible manner. Its tasks should also include conducting small studies, if necessary, in collaboration with scientists to fill existing knowledge gaps and build expertise.

Moreover, for the successful implementation and operation of an integrated waste management system, it is essential that the government assigns it the necessary priority, which also means making available the necessary financial resources. To do so, the financial mechanism should be changed from a back-end, reactive regime to an upfront, lifecycle-oriented one. This means that waste management costs are covered by a surcharge on goods/commodities, which is levied when the goods are imported. Pricing should be based on estimates of the real costs of waste disposal/management per unit. This needs further research and investigation.

Currently, the technical and the operational implementation of sorting at the source is not well understood. We suggest investigating options and testing promising solutions in pilot projects. Pilot projects would ideally be implemented in some districts to learn about the solutions that would gain public acceptance. These pilot projects could be initiated and managed by the previously mentioned task force group and backed by scientific activities.

We are convinced that a new waste strategy cannot be implemented if the public is not onboard. Onboarding requires campaigning and an intensive dialogue with the public at an early stage. Waste management should also become a topic in the syllabi of public and private schools and the local University. People need to understand what should be changed and why. This approach involves a longer-term engagement and should also be in the hands of the task force group. Scientists and non-governmental organisations might be partners here as well.

All undertaken actions and implemented measures require monitoring to continuously identify weaknesses and thus continuously improve the waste management system. Scientists may also help establish the proper monitoring. However, monitoring only makes sense if there is the will to learn, adapt to and optimise the system. This point brings us back to political will and leadership – indispensable prerequisites for change.

USYS TdLab Transdisciplinary Case Study 2018

After transdisciplinary Case Study (tdCS) 2016, the topic of tdCS 2018 was again solid waste management (SWM) in the Seychelles.

SWM is an ongoing and significant challenge for the Seychelles. Landfilling is the currently employed waste management strategy for almost all waste classes. Waste generation has continuously increased over the last years, but landfill construction has not kept up with this increase. Recycling of PET, aluminium cans or scrap metal is in place, and these items feed into international waste streams.

The study focused on waste treatment options and related requirements, such as waste input (sorting), financial mechanisms and implementation measures.

The case study was split into seven groups to gain comprehensive and in-depth knowledge on the following investigated topics: Waste Collection and Sorting, Feasibility of Recycling, Hazardous Waste Flow, Anaerobic Digestion, Incineration, Financial Mechanisms and Implementation of Plans. The methods employed varied across groups and included literature reviews, semi-structured interviews, surveys, stakeholder workshops, multicriteria assessment, material flow analysis, asset dimensioning and cost analysis.

The study's results show the potential for expanding the recycling system to glass and organic materials, for example. Aside from landfilling, alternative treatments include AD of organic matter, which would produce energy and fertiliser. Our study has examined waste incineration as another form of waste treatment. Combustion substantially reduces the waste volume up to 80%, and heat can be used for electricity production (10–15% of the Seychelles' total energy production). However, these waste treatment options are only feasible and work efficiently if certain waste fractions are separated prior to or during collection. Separation is best done at the source. A consumer survey's results show that people seem prepared for such a sorting regime. However, apart from a handful of redeem centres that are widely spread over Mahé, no suitable sorting infrastructure is currently in place. Our study also shows that hazardous waste is one of the blind spots in waste management. An overview of hazardous waste is lacking, a gap that our study started to fill. No matter what new activities may be introduced, they all need meaningful political guidelines and regulations to ensure successful and sustainable implementation. This matter is all the more important because our study's results show that this was not the case in the past. However, there might be ways to overcome these barriers. An important prerequisite i this respect involves finances. The current financing system is rather complicated and consequently, not fully transparent. Overall, our study suggests an integrated waste management system of sorting, collection, recycling, treatment and dumping.

The case study involved 19 ETH master's students with diverse scientific backgrounds and 14 bachelor's students at the University of Seychelles. The research was conducted over six months, including a three-week field phase in the Seychelles. Researchers and teachers guided the students throughout the case study, supplemented by additional support from an advisory board of local experts. The students intensively engaged with numerous stakeholders from the government, public administration, the private sector and civil society.

This teaching-research course is the second tdCS as part of a collaboration agreement between the Transdisciplinarity Lab of ETH's Department of Environmental Systems Science and the University of Seychelles, as well as the Seychelles' Ministry of Environment, Energy and Climate Change.

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