Pantai Project

The Trade-Offs Between Plastic Pollution and the Cost of the Waste Management System for a Household; a Case Study in the Watershed of the Petanu River, Bali

G.H.J. Alberts, A.P. Luteijn, H. de Lange, S.J.S. de Smet, J.E. Terwindt & E. Turhan

Faculty of Civil Engineering

Delft University of Technology

Challenge the future

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by

G.H.J. Alberts, A.P. Luteijn, H. de Lange, S.J.S. de Smet, J.E. Terwindt & E. Turhan

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Preface

Before you lies the report of the Civil Engineering Consultancy Project from the Pantai Project Group 4. This report is in fulfilment of the course CIE4061-09 from the faculty of Civil Engineering and Geosciences at Delft University of Technology. The project took place in Bali, Indonesia from mid February until mid March, from mid March to mid May the project took place in the Netherlands. The team exists of three master students from 'Transport, Infrastructure & Logistics' (G.H.J. Alberts, J.E. Terwindt and E. Turhan), two master students from 'Hydraulic Engineering' (H. de Lange and A.P. Luteijn), and one master student from 'Water Management' (S.J.S. de Smet).

From TU Delft, we would like to thank our daily supervisors: Saket Pande and Maria Alonso Gonzalez. Saket and Maria were there for us to answer any questions during the project. Secondly, we would like to thank Stefan Aarninkhof for reviewing and grading this project. Besides the supervisors we would also like to thank Eric Molin, who has helped us on matters that were sometimes unclear to us. Lastly, we would like to thank our financial sponsor: TU Delft Fast Fund.

From local/regional initiatives, we would like to thank the following people: Tony Manusama (Save Our Sea Indonesia) for introducing us to the Balinese plastic recycling world. Secondly, I Wayan Subawa (DLHK) for helping us understanding the current waste management system in the research area. Thirdly, Emma Sparrow (Ocean Mimic) who gave us some general overview of all waste (clean-up) initiatives on Bali and lastly, Ella Flaye and her colleagues from McKinsey.org for the very interesting meeting at their Bali office. Furthermore, we would like to thank all the banjar and desa leaders that have helped us so much on reaching as many respondents as possible.

We wish you a pleasant reading and we hope you enjoy our research report. If you have any questions afterwards, feel free to contact us at info@pantaiproject.com. Lastly, remember:

Keep the beaches clean, don't buy plastic!

G.H.J. Alberts, A.P. Luteijn, H. de Lange, S.J.S. de Smet, J.E. Terwindt & E. Turhan
Delft, April 2020

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Researched Desas

SABA | BATUAN KALER | MAS | KEMENUH | PEJENG KAWAN | KENDERAN

Abstract

It has been determined that the plastic waste load in the Petanu river (Bali, Indonesia) can be as high as 2015.5 kg/day in the beginning of the rainy season. To restore the ecosystem and protect human livelihood this load should be reduced drastically. The enormous pollution rate is largely due to the massive amounts of mismanaged (plastic) waste at household level. This is the part of the waste that is either burned or dumped by the households, rather than collected or brought to a recycling facility. Extensive mismanagement of waste is an indication of an inadequate functioning waste management system. In Bali, and this watershed specifically, the existing system is decentralised and its waste management strategies rely heavily upon public participation. As a result, in some areas households have limited options regarding waste handling due to a lack of a collection system and other waste services. At the same time, households need to pay for those services. In order to improve the current waste management, it is therefore important to understand the trade-off made by the households between the environmental impact of plastic waste and cost of the waste management system.

In this report, this trade-off is studied by creating a real-world, coupled economic-environmental model, of the Petanu's watershed in the Gianyar regency. The model consists of two parts: 1) a production possibility frontier (PPF) and 2) a utility curve. The PPF is an arc curve that visualises the relation between the plastic waste load originating from households and the average impact on the monthly purchasing power of a household. The purchasing power is impacted since users of the waste management system need to pay for the services. The utility curve, on its turn, visualises a households trade-off between plastic waste load and impact on monthly purchasing power. Coupling these curves gives insights in how well the current waste management system satisfies the preference of the households regarding cost versus pollution rate. If the current waste management matches perfectly with these preferences, the point of tangency of both curves would be the location on the curve representing the current plastic waste load and impact on the purchasing power. If the point of tangency has a lower plastic waste load and hence higher impact on purchasing power, households are willing to invest more in their waste management to improve the environmental quality of the Petanu river.

To gain insight in the trade-offs people make regarding four disposal methods (Self-Service, Pick-Up, Burn and Dump), cost and time, a stated choice experiment was set up. This is done by means of a questionnaire in which respondents were asked to make choices between hypothetical choice situations. The choice sets consist of different combinations of the disposal methods with varying attribute levels for cost and time. The survey has been conducted under 300 respondents from six different villages, located in the watershed of the Petanu river. With the help of data analysing program Biogeme, an open source Python package, the stated choice data has been transformed into the utility curve. Besides a general utility curve for the whole population living in the watershed of the Petanu river, also utility curves have been established for certain segments of the population, based on age, educational level and currently used disposal method.

Hence, the questionnaire contained also questions about socio-demographic characteristics, the currently used disposal method and the corresponding cost. The latter two are not only used for the segmented utility curve but also for the creation of the PPF. The PPF is built-up by defining five different scenarios, i.e. the current situation, three scenarios with an improved waste management system and a scenario without a waste management system. The scenarios with an improved system have an increased waste collection rate or additional locations where recyclables can be handed in, in exchange for money. For all scenarios, the corresponding average cost per household and the

plastic waste load in the Petanu river have been calculated. The quadratic best fit to these data points gives the PPF.

By combining the PPF with the general utility curve it was found that an average household in the watershed of the Petanu is willing to pay more for the waste management system than they are currently doing in order to decrease the plastic waste load in the Petanu river. It was even found that households want to achieve very low plastic waste load values and are willing to invest 47,400 IDR per month to reduce their contribution to plastic waste load by 100 grams per day. An exact equilibrium point is however not found as the PPF entails to many uncertainties at very low plastic waste load values. Nevertheless, the model gives a good indication and it is therefore recommended to increase the current collection rate of household waste. Furthermore, it is recommended to invest in TPS3R facilities in which waste is sorted and send to recycling facilities.

Moreover, the combination of the PPF with the segmented utility curves gave some very interesting insides. First of all, the younger generation (≤ 31 years old) has a higher willingness to pay for the reduction of plastic waste load, than the older generation. This is likely the result of the awareness programs on waste management at schools. Hence, it is recommended to expand this educational program. Secondly, educational level is positively correlated with willingness to pay. Remarkably, income level and gender did not have a significant relation with willingness to pay. Lastly, time is a significant determinant for the choice of disposal method, which corresponds to a certain plastic waste load. Therefore, it is recommended that waste management at household level should be as time-efficient as possible. This means the collection should be as much as possible be done at the doorstep of the houses and recycling bins should be located close-by.

All in all, it has been demonstrated that the households in the watershed of the Petanu river are very willing to pay for the waste management services, however, current waste management options are too limited. It is now the task of the governmental institutions and community leaders to enable collection of waste for every household in every village.

Contents

Glossary

Area Correction Factor (ACF) Fraction of the area of a certain desa located within the watershed.

Banjar Indonesian word for an administrative area of level 5, similar to a neighbourhood.

Bank sampah Indonesian word for a waste bank; a place where recyclables are brought to in exchange for money.

Burn The general term for all waste disposal methods involving open burning of waste at household level.

Daerah Aliran Sungai (DAS) Indonesian word for watershed.

Desa Indonesian word for an administrative area of level 4, similar to a village.

Dinas Lingkungan Hidup (DLH) Environmental agency / ministery of Indonesia.

Dinas Lingkungan Hidup dan Kebersihan (DLHK) Environmental agency / ministery of a regency.

Dump The general term for all waste disposal methods involving illegal waste dumping in the environment by households themselves.

Impact on the Purchasing Power of a Household The change of the financial ability of a household to buy goods or services. A positive impact is defined as an increase of the financial ability, while a negative impact is defined as a decrease.

Kabupaten Indonesian word for an administrative area of level 2, similar to a regency.

Kantor Desa Indonesian word for a village office, comparable to a city hall.

Kecamatan Indonesian word for an administrative area of level 3, similar to a sub-district.

Mismanaged Plastic Waste at Household level (MPWH) Part of the plastic waste that is either burned or dumped in the environment directly at household level. Is expressed in (kg/day).

Mismanaged Plastic Waste Load at Household level ending up in the Petanu ($MPWLH_{Petanu}$) The plastic waste load that is either previously burned or previously dumped at household level. Is expressed in (kg/day).

PE-HD Polyethylene (high density), a type of plastic mostly used juice and detergent bottles.

PE-LD Polyethylene (low density), a type of plastic mostly for bags around products, garbage bags and 'paper' milk cartons.

Pemelung So called 'scavangers'. Mostly Javanese immigrants who collect recyclable waste and sell it to the pengepul.

Pengepul So called 'middleman' or 'collectors'. They buy recyclable waste from the pemelung and sell it to recycle factories on Java.

PET Polyethylene terephthalate, a type of plastic mostly used for drink bottles.

Pick Up The general term for all waste disposal methods involving either collection of waste household waste directly at houses or at pickup points. .

Plastic Waste Concentration (PW-Concentration) The amount of plastic waste per cubic meter. Is expressed in (g/m^3).

Plastic Waste Load (PW-Load) The plastic waste in a certain river reach. Originating from a village or more upstream river part. Is expressed in (kg/day) or (g/s).

Plastic Waste Load Reduction (PWLR) The reduction of plastic waste load compared to the current, baseline scenario. Is expressed in (kg/day).

Plastic Waste Production (PW-Production) The plastic waste produced by a certain village. This value does not necessarily have to be equal to the plastic waste load, since probably not all plastic waste ends up in the river. Is expressed in (kg/day) or (g/s).

PP Polypropylene, a type of plastic commonly used for food containers and luggage.

Production Possibility Frontier (PPF) A curve that illustrates the cost-effective combinations of two commodities , which share the same limited resource.

PS Polystyrene also known as styrofoam, a type of plastic used for take-out containers, cups and plates.

PVC Polyvinyl chloride, a type of plastic commonly used for toys, plumbing pipes and clear food packaging.

QGIS Open source Geographical Information System (GIS), meant to visualise and analyse geospatial information.

Reduction Factor of the MPWH (RF_{MPWH}) Fraction of the MPWH that ends up in the river as plastic waste load.

Satuan Wilayah Sungai (SWS) Indonesian word for river basin.

Self-Service The general term for all waste disposal methods involving bringing your own recyclable household waste to a waste recycling facility.

Step Loading The assumptions that a loading rate of for example a river changes from 0 to a constant value at a certain moment in time.

Tempat Pembuangan Akhir (TPA) Indonesian word for landfill site.

Tempat Pembuangan Sampah Terpadu (TPST) 'Integrated Waste Disposal Place', where waste is sorted in organics and non-organics.

Tempat Pengelolaan Sampah Reduce Reuse Recycle (TPS3R) Waste Management site with focus on reducing, re-using and recycling of waste.

Utility Curve A curve that illustrates the population's trade-offs between two commodities.

Willingness To Pay (WTP) The maximum price at or below which consumer will buy a product or service.

Yayasan Pemilahan Sampah Temesi (YPST) Waste Collection Foundation Temesi, place where the waste gets sorted on the TPA of Temesi.

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1
INTRODUCTION

Economic growth, population growth, and changes in consumption and production patterns, have resulted in a significant increase in plastic production over the last 70 years [1–3]. While in 1950, 1.5 million tonnes of plastic were produced, the amount rapidly increased to 359 million tonnes in 2018 and is still growing [4]. The increased production of plastic is followed by an increase in plastic waste. Less than half of the globally produced plastic is recycled or brought to a landfill. The remaining part is either still in use or litters the continents and oceans [5]. Besides an aesthetic impact, plastic has a potentially negative influence on human livelihood and aquatic organisms [6–8]. It has been estimated that 86% of the marine plastic waste is originated from Asian rivers [9]. This can be explained by the high population density combined with a large portion of mismanaged plastic waste and periods of heavy rainfall [9]. Indonesia is one of the major contributors of marine plastic waste with an annual plastic emission of approximately 200,000 tonnes [9, 10]. This is 14.2% of the global input [9]. Of this annual plastic input, 33,000 tonnes are emitted by Balinese rivers [11].

The improvement of the water quality by reducing the plastic concentration in rivers, is of upmost importance in order to restore its ecology and to protect human livelihood [7, 8]. Although it is clear that plastic in rivers is unwanted, the direct risks of plastic on human health and environment are largely unknown [8]. In general the most recognised problems associated with plastic pollution are loss of aesthetic value, ingestion, entanglement and suffocation [12]. These reasons are sufficient to strive for plastic free waterways and oceans. Plastic pollution reduction can either be achieved by decreasing the plastic waste production, e.g. through a ban on single-use plastic, by creating awareness, e.g. through education, or by improving the waste management system [10, 13, 14]. A ban on single-use plastic is already in place on Bali since the 23rd of June 2019. This means that plastic straws, plastic bags and styrofoam are now prohibited island-wide [15]. It sounds like a very promising measure, as plastic of low value, like single-use plastic, is more likely to end up in the oceans than high-value plastic [10]. However, the ban is barely regulated in reality [16], meaning that single-use plastics are still widely used. Therefore, the ban is not enough to reduce the plastic pollution and other measures are needed.

1.1. RESEARCH GAP

As a response to the large contribution of Bali to the marine plastic waste, the non-profit student-initiative Pantai Project was set up in Bali in 2018. Several student groups from the Delft University of Technology in the Netherlands, have researched macro-plastic (>5 mm) emission and the plastic waste management system on Bali. The focus on macro-plastic emission has been chosen as most researches to date study the effects of micro-plastics in marine systems [7]. The first group of students studied the main source of plastic waste on the beaches in Southwest Bali. It was concluded that most of the plastic originated, as expected, from the rivers. The type of plastic that litters the beaches the most is single-use plastic [17]. The second group followed with a research on the plastic pollution in 31 rivers across Bali and determined the most polluting ones. In addition, the most efficient catchment device for suspended plastic in river systems was determined [18]. Lastly, the third group studied the feasibility of a small-scale recycling business. Starting from three different locations, the most adequate place for the facility was sought. Besides location, also all economical and technical features of the business were discussed. Moreover, the social feasibility was determined. This included the determination of the composition of plastic waste produced by households [19].

Although during the three researches a lot of information has been inquired, a crucial step is missing: research on the behaviour of the local inhabitants of Bali. So far, only little is known about the willingness and motivation of the Balinese people to change their behaviour regarding waste management. This is, however, of upmost importance as waste management is the responsibility of the people themselves. There is no country-wide trash collection service in place [20]. Decentralization is reinforced by the Indonesia Waste Management Act (UU18/2008) which granted power to local governments to encourage waste management strategies based upon public participation [21]. Only the landfill sites are the responsibility of the provincial government [21]. Bruce and Storey [22] found that decentralization leads to an uneven and ineffective solid waste management strategy at local level. In order to improve the current waste management it is therefore important to understand the trade-offs that Balinese people make. Not only the disposal possibilities need to be researched but even more so, the willingness to pay for a waste management network. Without any motivation of local people the plastic waste problem in Bali will not be solved.

1.2. OBJECTIVE AND RESEARCH QUESTIONS

The aim of this research is to build a real-world coupled economic-environmental model of a watershed on the island Bali, Indonesia. In this specific case environmental quality will be based upon the plastic waste load in the river originating from local households, whereas the economic activity will be represented by the impact on the purchasing power of that households. The model will consist of two parts; 1) a production possibility frontier and 2) a utility curve. Whereas the production possibility frontier simulates the effect of different waste management systems, the utility curve gives the preferences of the Balinese people. In this way it is possible to determine the equilibrium of both, i.e. the most ideal situation resulting in the highest environmental quality. Hence, in this research the impact of improving the solid waste management system is estimated solely. In other words, the impact of policies and education programs to plastic waste pollution are not taken into account. Moreover, the research will only focus on household waste, rather than municipal waste as a whole.

The main research question underlining this objective is the following:

What are the trade-offs between the environmental quality regarding the prevention of plastic pollution versus the economic activity of the households in a specific watershed in Bali?

To be able to answer this question the main research question is divided into the following subquestions:

- Which region on Bali has the highest need to improve its waste management system and thus is most suitable for this research?
- How much and what types of (plastic) waste are generated in Bali and the research area specifically?
- What does the current waste management system of Bali, and of the research area specifically, look like?
- What are people's preferences regarding the trade-off between the environmental quality, expressed in terms of plastic waste load, and the economic activity, expressed in terms of average impact on purchasing power of a household, corresponding to the waste management system in the researched watershed ?

- What is the average amount of money households in the research area are willing to invest in order to improve their way of disposal?
- What preference differences are there between various segments of households in the research area. regarding their trade off between environmental quality and economic activity?

1.3. RESEARCH STRATEGY

To obtain both, the production possibility frontier and the utility curve, a lot of information needs to be inquired. To start off in Chapter 2 the most adequate study location will be discussed. This is followed by a thorough research, via literature review and expert interviews, of the waste generation (Chapter 3) and the waste (mis)management (Chapter 4), respectively in Bali and in the study area. Moreover, the local people needed to be questioned. To do so, a questionnaire has been set-up, which consisted of a number of choice sets and some general questions. The methodology of the fieldwork can be found in Chapter 6, which follows after the explanation of the general methodology in Chapter 5. The data obtained from the questionnaire is then combined with the literature review and expert interviews to model the production possibility frontier (Chapter 7) and the utility curve (Chapter 8). Furthermore, the sensitivity of, and statistics behind these curves is elaborated upon within each chapter. The utility curve and production possibility frontier are combined in Chapter 9 to create the results of the coupled economic-environmental model. The coupling is done for the general utility curve as well as for the utility curves of different segments of the population. With the help of these results and all other chapters the research question and the sub-questions can be answered, which will be done in Chapter 10, the conclusion. Furthermore, the research has some delimitations, assumptions and limitations which will be discussed in Chapter 11. Finally, recommendations are given in Chapter 12.

2

Study Area

This chapter will elaborate upon the reasons to select the Gianyar region, and specifically the watershed of the Petanu river, as the study area. It will start off with the selection procedure for the study region. Afterwards, the choice for the watershed of the Petanu will be explained. All important characteristics, e.g. climate, hydrology and land use, will be discussed. The last part of the chapter will focus upon the socio-demographic situation in the watershed and will zoom in to six villages, i.e. Saba, Batuan Kaler, Mas, Kemenuh, Pejeng Kawan and Kenderan, within the watershed.

2.1. Region

Previous research by the Pantai Project [18] has shown that the plastic pollution in rivers on Bali is highly variable. Large differences between rivers were found. As can be seen in Figure 2.1, in total 31 rivers were investigated throughout Bali. On average the plastic flow, in pieces of plastic per hour, was measured to be 55 pieces per hour. [18]. The rivers with quantities of plastic pollution above this average were found in the Jembrana (river 1, 4 and 7 in the figure), Denpasar (river 16), Gianyar (river 17, 19 and 20) and Bangli regencies (river 29 and 27) [18]. These measurements are compared with a research of The Bali Partnership Assembly [11] to select the most critical region. The parties involved in this assembly are private organisations, governmental agencies, NGO's and community leaders concerned with the policy and management of Bali's waste management system. Rivers 1 and 7 were not indicated by The Bali Partnership Assembly [11] as highly polluted rivers and as a result these rivers are not of interest.

Figure 2.1: Overview of Researched Rivers in Bali by the Pantai Project [18]

Furthermore, The Bali Partnership Assembly [11] implied which regions are most critical regarding waste management (Figure 2.2). The selection of critical areas was based upon 1) highest volume of plastic ending up in water (70%), 2) highest volume of plastic ending up in the environment (20%) and 3) lowest level of income per capita (10%) [11]. This combination of factors indicated the areas around river 17 and 19 (Sukawati and Blahbatuh and upstream areas), the area around river 4 (Negara) and almost the whole Bangli regency as critical areas (Figure 2.2).

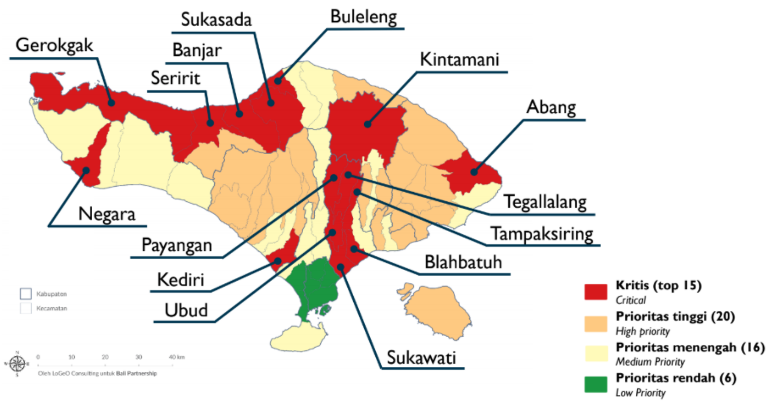

Figure 2.2: Overview Critical Areas Regarding Waste Management in Bali [11].

After a multi-criteria analysis of these three critical areas, the Gianyar regency (Kabupaten) was selected, based upon socio-demographic and geographic characteristics and the amount of tourists visiting the area. Kabupaten Gianyar was chosen since it is a good representation of the island Bali as a whole. The complete multi-criteria analysis can be found in Appendix A.

2.2. WATERSHED

There are 401 rivers on the island Bali of which 162 rivers flow into the ocean [23]. The area in which water runs-off in one specific river is defined as a watershed. The selection of a watershed is necessary in order to estimate the amount of plastic waste in that specific river. According to Regulation of the Minister of Public Works No. 39/PRT/1989 all these rivers belong to one large river basin, Satuan Wilayah Sungai (SWS), indicated as SWS 03.01 Bali Penida [24]. SWS 03.01 is sub-divided into 235 watersheds, Daerah Aliran Sungai (DAS), of which 12 are located in kabupaten Gianyar (Figure 2.3) [25]. The largest DAS in the regency are the DAS of the Oos river (12,970 Ha), the Petanu river (9791 Ha) and the Pakerisan river (9514 Ha) [26]. The DAS Ayung is also a very large watershed, however its outflow point is not located in kabupaten Gianyar and therefore it is not of interest.

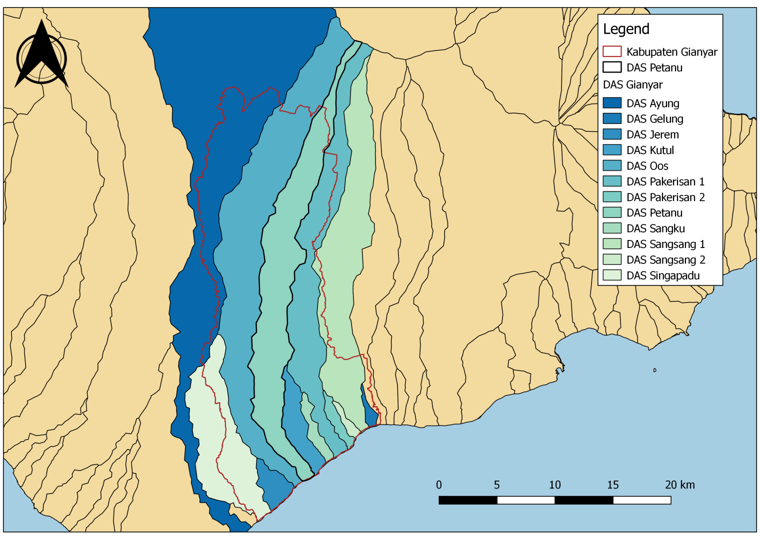

Figure 2.3: Overview DAS in the Kabupaten Gianyar

Although the Oos river has a bigger DAS it has been chosen to focus on the Petanu river. The reason for this is that this river flows through five of the six critical sub-districts (Kecamatan) of kabupaten Gianyar according to [11] (Figure 2.2 and 2.4). Hence, to make this project applicable in multiple critical kecamatans, DAS Petanu is a logic choice as research watershed.

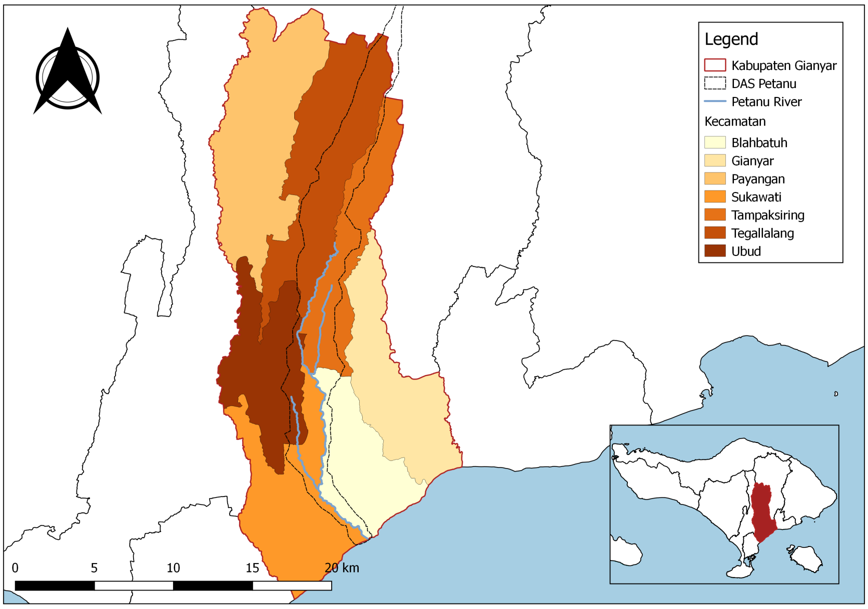

Figure 2.4: Overview Kecamatan Around the Petanu River

In total the main channel of the Petanu river is 37 km long [27]. It has, however, been chosen to focus on the downstream area of the Petanu river as the identification of which sidestream flows eventually into which main river is impossible in the upstream part. Furthermore, more upstream there is a higher possibility of side streams which do not have a consistent flow and therefore have less of an interest. The part of the Petanu river that is taken into consideration can be seen in Figure 2.4, indicated by the grey line. Including the side streams, 38.13 km of the Petanu river is taken into account. In other words: 24.88 km of main channel of the Petanu river is considered and 13.25 km of side streams.

2.2.1. CLIMATE AND HYDROLOGY

Kabupaten Gianyar has, like most of Bali, a tropical sea climate with occurrence of monsoons. Because of this, Gianyar has a dry season from approximately April until September and a rainy season from around November until February with in between transitioning seasons [27]. In 2016 the total annual rainfall was 2259 mm in Gianyar [23]. On Bali the average annual rainfall is 1934 mm [28], which is approximately 2.5 times as much as in the Netherlands. Up to 80% of the annual rainfall occurs in the rainy season [29]. Moreover, the average temperature is 27 °C with an average minimum temperature [1] of 24 °C and an average maximum temperature [1] of 30 °C [30].The average humidity is 75.5 % [30]. This leads to a potential evaporation, ranging between 59.1 to 139.0 mm/month or approximately 1361 mm/year [29].

[1] With average minimum/maximum temperature, the average of all minimum/maximum temperatures measured in the different weather stations in Gianyar is meant.

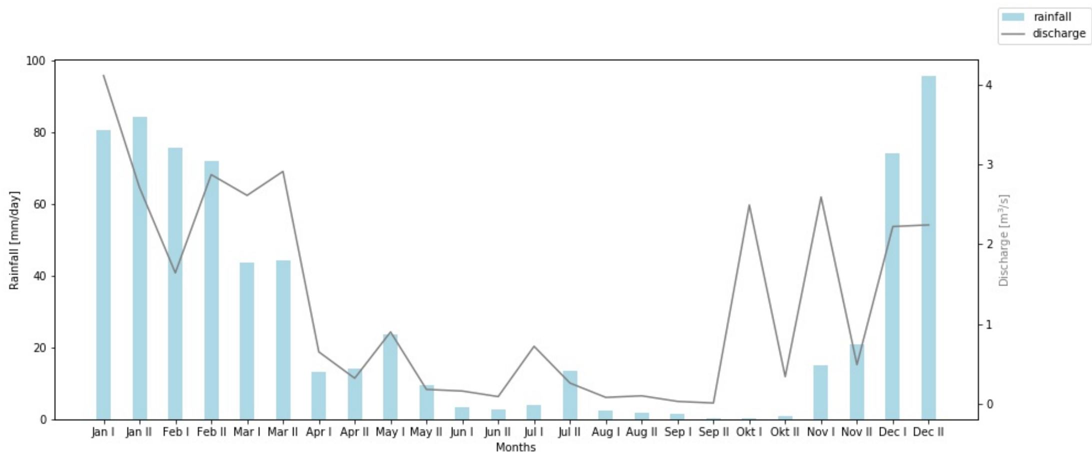

Figure 2.5: Rainfall and Discharge with a Probability of Occurrence of 80% , based upon [31].

Ardana *et al.* [31] conducted a thorough research on the DAS Petanu. They used the rainfall data of 10 years (2009-2018) to calculate the effective rainfall amount of every half a month with a probability of occurrence of 80%. Furthermore, also the discharge with an 80% possibility was calculated. Figure 2.5 shows the results of these calculations. What can be seen in Figure 2.5 is that the discharge graph shows some large peaks in October and November which cannot be explained by looking at the rainfall data. This can, however, be explained by the geology and topography of the DAS Petanu. The geology is mostly characterised by volcanic rock, which means the storage capacity within the watershed is very limited [27].
As can be seen in Figure 2.6, kabupaten Gianyar is composed of volcanic deposits of the extinct volcano Buyan-Bratan and the existing Batur volcano [27, 32]. The volcanic deposits consist of volcanic breccia, volcaniclastic sandstone and Lahar deposits [27]. The low infiltration rate is confirmed by the research of Teketel [33], who determined that the infiltration rate in almost the entire kabupaten Gianyar is 0.0047 m/day. Moreover, the DAS Petanu is very steep upstream, causing a fast surface runoff of rainwater (Figure 2.7) [27]. In other words, a rainfall event leads almost immediately to a peak discharge. As a result, the discontinuously measured discharge values are very susceptible to a single previous rainfall event. This is amplified even more by the fact that the discharges were measured infrequent, i.e. bimonthly and only for 10 years.

Corresponding with the assumption made here, Teketel [33] found that there is almost a direct relation between rainfall and discharge in the DAS Petanu. On average, the baseflow is approximately 2 m^3/s and the discharge peaks can go up to 10 m^3/s [33].

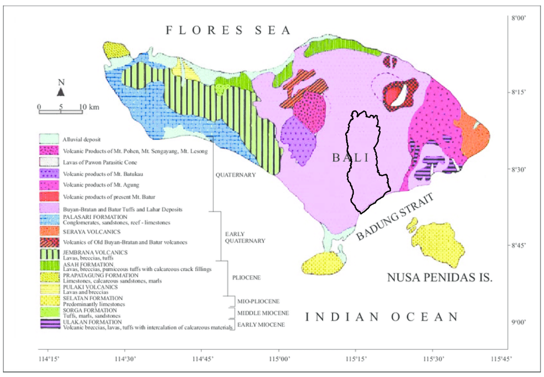

Figure 2.6: Overview Geology Bali [32]

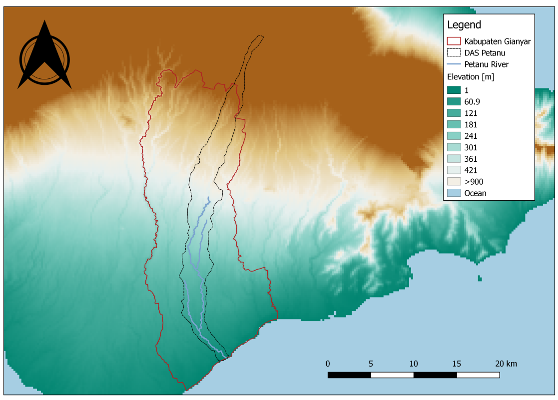

Figure 2.7: Overview Elevation Kabupaten Gianyar

2.2.2. LAND USE

Based on data from 2012, kabupaten Gianyar has one of the biggest areas of paddy rice fields of the Bali province, only kabupaten Tabanan has a larger area [29]. In total 14.71 km^2 is used for rice production. As can be seen in Figure 2.8, the paddy rice fields are mostly located in the southern part of kabupaten Gianyar. In the northern part other agricultural lands, which have a total area of 11.25 km^2, are located [29]. Besides land for agricultural practices, a small part is forest (1.12 km^2) and only very limited space is used for housing and roads (0.17 km^2) [29].

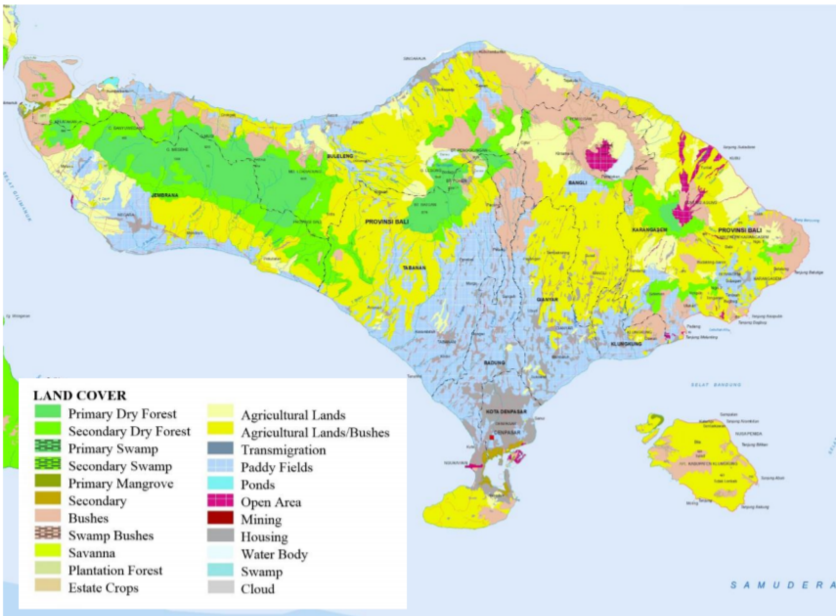

Figure 2.8: Land Use in Bali in 2012 [29]

2.3. SOCIO-DEMOGRAPHIC SITUATION

In 2019 521,200 people where living in kabupaten Gianyar [27]. However, these people are not equally distributed over the entire kabupaten. Since kabupaten Gianyar is seen as a rural area, the individual kecamatans are subdived in villages (Desa). These desas are on their turn divided into neighbourhoods (Banjar), all with their own banjar leader. The full overview of the administration levels can be found in Appendix B. Large differences in population density can be found between individual kecamatans or even desas. Sukawati is the most densely populated kecamatan of kabupaten Gianyar. This is due to the large city Sukawati, which is located in this kecamatan. Tegallalang on the other hand, which is located more upstream in the river reach, is very sparsely populated. A total overview of the population in the five kecamatan of interest is given in Table 2.1.

Table 2.1: Overview Population Characteristics Kabupaten Gianyar for Every Kecamatan [27, 30]

Kecamatan	Area [Ha]	Population Count			Households	Population Density [pp/km^2]
		Men	Women	Total		
Sukawati	55.02	56,914	55,243	112,157	19,050	2038
Blahbatuh	39.70	33,765	33,141	66,906	14,517	1685
Tampaksiring	42.63	23,689	22,846	46,535	10,939	1092
Ubud	42.38	35,586	34,821	70,408	14,954	1661
Tegallalang	61.80	25,714	25,398	51,112	10,846	827

Not only the amount of people living in each kecamatan, but also average income, education level and occupation differ between each kecamatan or even between each desa. Occupation is largely influenced by the amount of tourists visiting the kecamatan, which also has a large influence on the average income of the local people [30].

Within the DAS Petanu several desas are located. Around the river six desas, i.e. Saba, Batuan Kaler, Mas, Kemenuh, Pejeng Kawan and Kenderan, have been chosen as research area, located in five different kecamatan (Figure 2.9). The selection of these desas has been based upon geographic location and socio-demographic characteristics. In this way the best representation of the population in the watershed is established. Socio-demographic information is of importance as it could be directly linked to their knowledge, attitude and practices towards waste management [34, 35]. The population information in this section is based upon the last census in 2015.

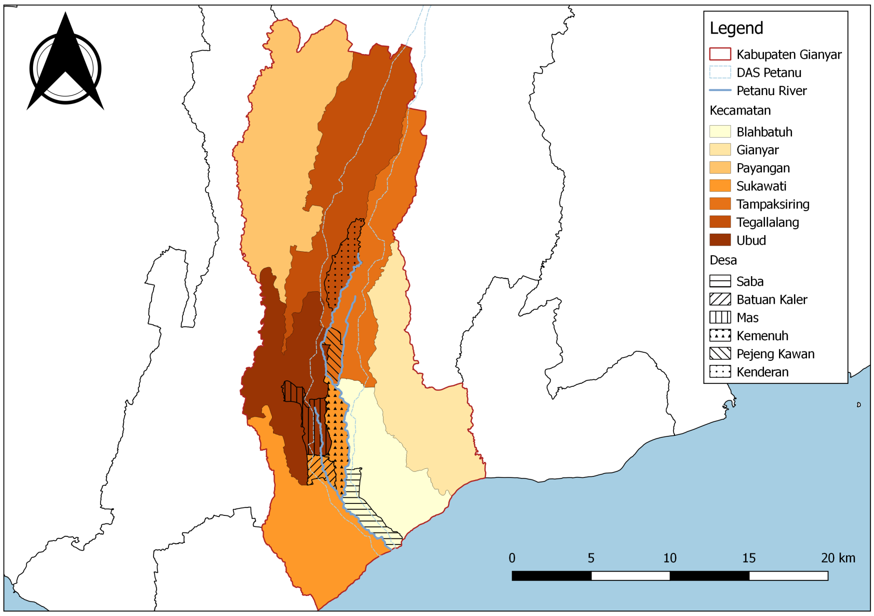

Figure 2.9: Overview Researched Desas

2.3.1. Desa Saba

Saba is a coastal village of kecamatan Blahbatuh and the Petanu river streams into the ocean at this location. In total Saba has an area of 6.29 km^2 and 10,156 inhabitants [36]. With the help of Geographic Information System (GIS) data and the program QGIS[2] it has been calculated that almost two-third of the desa is located within the DAS Petanu, i.e. 4.19 km^2. The population density is 1615 inhabitants/km^2, which is below the average population density within the kecamatan Blahbatuh (Table 2.1). The number of households belonging to these population numbers is 2031, which means on average there are five people in every household. More than half of the population in Saba relies on agricultural practices as main source of income, followed by 14.2% relying on trade (including restaurants) [36]. There is no record of any practices in the tourism sector. This leads to almost 80% of the area of Saba being used as agricultural land. The main crop that is grown, approximately on 60% of the agricultural land, is rice. Besides rice corn and soy beans are grown. The productivity of the rice-fields is now 67 kg/ha/year [36]. Saba also has the highest percentage (36.2%) of uneducated inhabitants of kecamatan Blahbatuh. However, according to the latest report (2016) all children between 7 and 12 are now attending school in Saba. This means the most uneducated people are of an older generation [36].

2.3.2. Desa Batuan Kaler

Desa Batuan Kaler is located in kecamatan Sukawati and a big side stream of the Petanu river flows through this desa. Batuan Kaler is a relatively small desa with an area of only 2.77 km^2. However, not the entire desa is part of the study area. An area of 2.20 km^2 is located within the DAS Petanu. 4148 people are living in the desa, in other words, the population density is 1497 inhabitants/km^2 [37]. In total there are 830 households, which means the average size of a household is five people

[2]QGIS is an open source GIS, which can be used to visualise and analyse geographical data

[37]. In contrast to desa Saba, most people in Batuan Kaler work in the trade sector (31.3%), government/service sector (27.7%), however still quite a large percentage (24.2%) works in the agricultural sector [37]. Most people in desa Batuan Kaler have at least finished senior high school (29.1%), however there are still 543 people who are uneducated [37]. Fortunately, the children between 7 and 12 years old are all attending school.

2.3.3. Desa Mas

Desa Mas is located in kecamatan Ubud and is very densely populated: 1966 inhabitants/km^2. Desa Mas has an area of 6.87 km^2, where 13,512 people are living [38]. However, only half of the desa, 3.53 km^2 lies within the DAS Petanu. Moreover, there are 3001 households with an average size of four people [38]. By far most of the people (58.7%) work in the manufacturing sector, where they mostly produced household articles and crafts (especially wood carvings). Only 15.5% of the people earn their living with agricultural practices. Surprisingly, still almost 60% of the area of desa Mas is agricultural land [38].

Desa Mas has been assigned to be a tourism village since 2012 [39]. A tourism village is defined as "A rural area which offers countryside authenticity, including local architecture, culture, traditions, customs and daily life of the residents" [40]. Tourism is now the main driving factor of the economy, as tourists buy most of the crafts. Moreover, the change from a 'normal' to an official tourist village had quite some effect on desa Mas. First of all, roadsides are planted with flowers and houses are renovated to improve the experience of the tourists. Furthermore, weekly clean-ups of the environment have to be held in order not to scare tourist away with an environment full of waste [39]. Lastly, the economy of desa Mas has grown, as more and more people are opening home-stays and other facilities for tourists [39]. As could be expected the education level in desa Mas is relatively high, almost 35% of the people have at least finished high school. Nonetheless, still almost 11% is uneducated [38].

2.3.4. Desa Kemenuh

The main channel of the Petanu river is located along the boarder of the desa Kemenuh. Kemenuh is part of the kecamatan Sukawati and with an area of 7.29 km^2 the largest desa in the research area. Moreover, the whole area lies within the DAS Petanu. The desa has 11,777 inhabitants, i.e. the population density is 1616 inhabitants/km^2 [37]. Like desa Saba and Batuan Kaler the average size of a household is five people. In total there are 2355 households in desa Kemenuh [37]. Although, Kemenuh is located in the same kecamatan as desa Batuan Kaler the division of income source is different. The main sector is agriculture (29.6%) followed by trade (23.7%) and manufacturing (22.7%) [37]. In desa Kemenuh 9.0% of the population is uneducated, which is a very low percentage compared to other desas in kecamatan Sukawati. Although most people only have finished primary school, 31.8% of the population finished at least senior high school [37].

2.3.5. Desa Pejeng Kawan

Just north of Kemenuh in the kecematan Tampaksiring, the Petanu river and its sidestream flow along the borders of desa Pejeng Kawan. With an area of just 3.14 km^2 it is one of the smaller desas in the study area. As can be seen in Figure 2.9, the whole desa is located within the watershed of interest. Moreover, the desa is quite sparsely populated with only 1226 inhabitants/km^2 [41]. This could be expected as Tampaksiring is one of the kecamatan in kabupaten Gianyar with a lower population density (Table 2.1. In total there are 3851 people living in desa Pejeng Kawan divided over 731 households. This means there are on average five persons in every household [41]. The main source of income in this desa is coming from the trade sector (34.1%), followed by the manufacturing (21.7%) and agricultural sector (19.5%). The trade sector consist of only food stalls in desa Pejeng Kawan [41]. The education level of the inhabitants of the desa is relatively low with almost 32% of the people being uneducated and 25% who only finished primary school. Luckily, all children between 7 and 12 are attending school at this moment [41].

2.3.6. DESA KENDERAN

The most upstream desa of the study area is desa Kenderan in the kecamatan Tegallalang. Although it was expected from Table 2.1, Kenderan is not the most sparsely populated desa within the study area. In total 8425 people were living in the desa with an area of 6.59 km^2, meaning that the population density is only 1278 people/km^2, just a little bit more densely populated than desa Pejeng Kawan. In desa Kenderan there are 1694 households with again on average five people in every household [42]. The entire desa contributes to the Petanu river. Comparable with desa Mas, most people in desa Kenderan work in the manufacturing sector (53%), followed by the agricultural sector (23%) [42]. The manufactoring sector in this desa consist mostly of wood crafting. Contradictory to desa Mas, desa Kenderan has, compared to all other researched desa, the lowest education level. Almost 56% of the people is uneducated [42]. Nevertheless, 17% has at least finished high school.

3
Waste Generation

This chapter elaborates on the waste production in Bali and kabupaten Gianyar specifically. First an overview of the total generated waste is given. In the second section the different types of waste are discussed, distinguishing between plastics, organics and other waste. The remainder of the research will solely focus on plastic waste.

3.1. Waste Generation

In 2019, 4.4 million people were living on Bali [11]. Bali is a well-known tourist destination, with 6.4 million international tourists and 10 million domestic tourists visiting the island every year [11]. As a result, tourists contribute significantly to the waste generation on Bali. In fact, tourists generate more than three times as much plastic waste per day than local people; whereas an average Balinese person produces 0.5 kg plastic per day, a tourist produces 1.7 kg per day [11]. In kabupaten Gianyar the plastic waste generation of local people is even lower, with on average a production of 0.38 kg plastic waste per day [27].

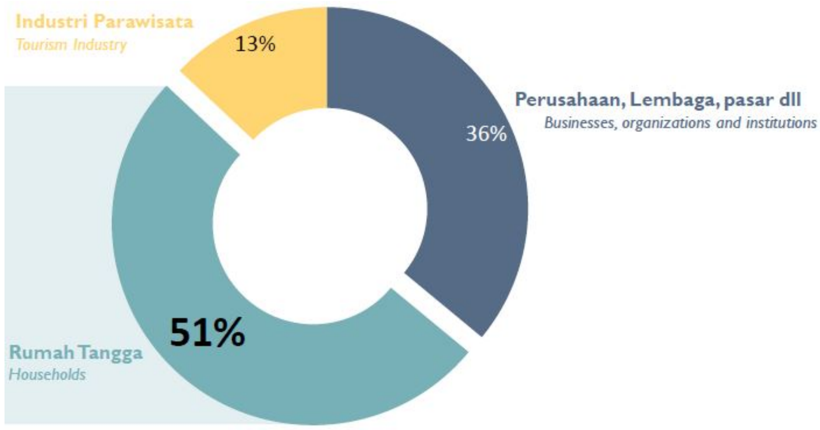

Figure 3.1: Contributions to the Total Waste Generated in Bali [11]

In Figure 3.1 it can be seen that the largest part (51%) of the waste is produced by the households, whereas 13% of the waste is generated by the tourist industry and 36% of the waste by businesses, organisations and institutions. The total waste production in Bali is about 4281 tonnes per day [11]. Tourists produce more waste per capita than the households per capita, however the waste produced by all the households still holds the largest part in the total waste generation. The focus of this research is on plastic waste generated by households, therefore the remaining part of the chapter will elaborate on household waste generation.

3.2. TYPES OF WASTE

A distinction is made between three different types of waste: organics, plastics, and others. On average in Bali, the organics hold the largest part of the total household waste production with 60%. Both, plastics and other waste have a contribution of 20% [11]. For kabupaten Gianyar more precise data is available. The Dinas Lingkungan Hidup Kabupaten Gianyar [27] stated that on average the total waste contains for 58.7% organic material and 17.1% plastic. Although, household waste specifically consists of up to 67.2% organic material and 13.0% of plastic items. The other quantity consists among other things of paper, metal, glass and rubber. In the next subsections the relevant characteristics of these waste types will be discussed.

3.2.1. PLASTIC

The term plastics describes the variety of synthetic materials which are used in a wide range of applications. Plastics are inorganic materials made from raw natural materials like cellulose, natural gas, coal and crude oil [43]. The versatility of the plastics make it a fitting material for a wide range of consumers and applications. The most comprehensive classification of plastic is the division into two groups; the thermoplastics and the thermosets. The main difference between the two different kinds is that the thermoset is a material that strengthens when heated and cannot be reheated or remoulded after the initial forming [44], whereas thermoplastics can be reheated and remoulded after the initial forming without chemical changes [44]. Thermosets are used in components that require high strength-to-weight ratios and higher temperatures at a low cost. Thermoplastics are used in all types of industries as they are resistant to mechanical creep and corrosion, can carrying materials of extreme temperatures and are applicable for fluid transport [45]. As a result of this different characteristics, thermoplastics are relatively easier to recycle than thermosets [46]. Moreover, up to 78% of the plastic waste is thermoplastic [46]. This is why this chapter mainly focuses on thermoplastics.

Thermoplastics, on their turn, can be classified into seven categories according to the international Resin Identification Coding system [47]. The system is based on the recycling properties of plastics and is developed to provide a system to help in the sorting process, making it possible to identify the post-consumer packaging types. An overview of the seven different types of thermoplastics and their application is given in Figure 3.2.

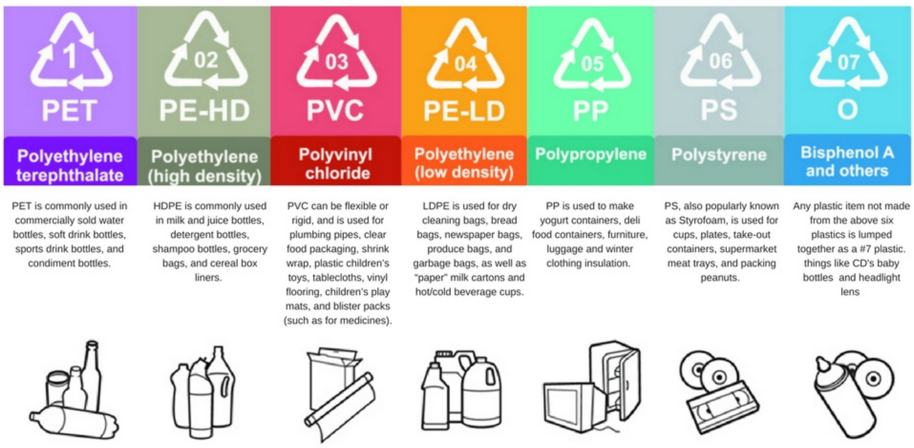

Figure 3.2: Overview of the Seven Different Kinds of Thermoplastics [48]

The thermoplastics are ordered from high recycling potential to low potential. In other words, PET is the most recyclable thermoplastic with almost 90% recovery [10, 47]. Correspondingly, this type of plastic is considered as a high-residual-value plastic [10]. Due to its high-residual-value PET is less likely to leak into the environment than low-residual-value plastic [10]. This was also observed by the first Pantai Project [17], who found that only 4.8% of the plastic waste on the beach were PET items. On the same time, PET consumption has the highest growth rate compared to all other types of plastic, especially because of the increase in PET bottle production [49]. This is also reflected in the percentage of PET in household plastic waste in Bali; up to 30% of the plastic waste is PET, followed by PP (20%), PE-HD (18%), PE-LD (17%) and others (9%) [19]. There were limited amounts of PVC and PS plastic found (both 3%) in household waste [19].

A third of the plastic consumption is in packaging applications and another third is in building products. [50] Plastics provide strength with minimum weight required, and therefore can also have a positive impact on the environment. Packaging beverages in PET instead of glass or metal reduces the energy consumption by 52% [50].

LIFE CYCLE OF PLASTIC

In order to determine the full environmental impact of plastic items on the environment, a life cycle assessment (LCA) should be performed. To be able to understand the life cycle it should be noted that the service lifetime of plastic differs. The life cycle of plastics starts at the production and can end in four different ways: recycling, incineration, landfill disposal or environmental disposal. In Figure 3.3 a simplified plastic life cycle is given from the production to the different methods of disposal.

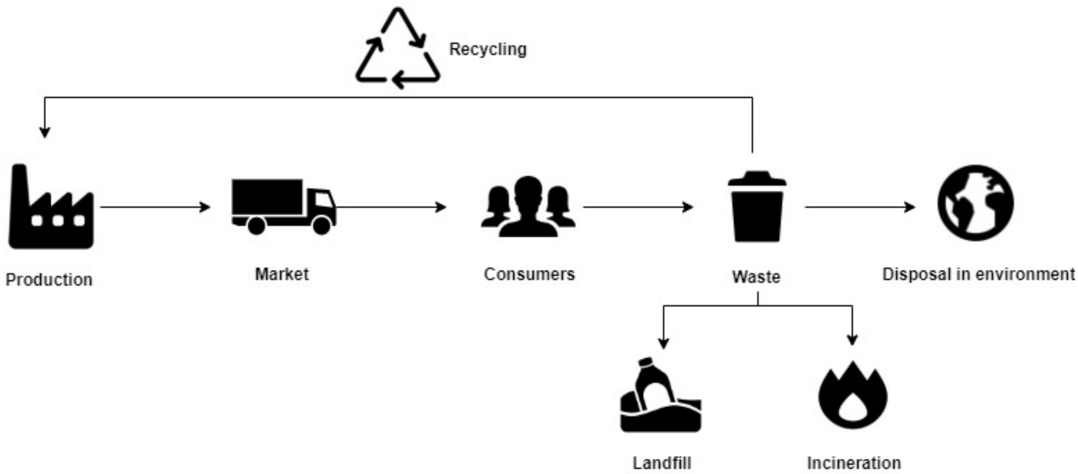

Figure 3.3: Plastic Life Cycle

The different stages of the life cycle each have different implications on the environment. The production stage is the first step in the life cycle and the methods of disposal are the last steps. In order to reduce the environmental impact, each of the implications of the stages require appropriate measures. Although, implications in earlier stages of the plastic life cycle have the largest impact on the environment [51], this research focuses specifically on the lasts steps: waste, recycling, incineration and the effect of it on the disposal in the environment.

3.2.2. ORGANIC MATERIAL

The largest part of all waste in Bali is organic, with a contribution of 60% of the total waste, and even 67.2% in an average household in kabupaten Gianyar[11, 27]. In 1989, 87% of the total waste consisted of organic materials [52]. However, since then the total waste generation increased, therefore it is unlikely that the total amount of organic waste has decreased [52]. Some of the reasons for this large amount of organic waste is improper handling of food products and a rapid deterioration of food products due to the tropical climate [53]. Organic materials are well suited for recycling, by means of making compost of the organic materials. Composting is a process which speeds up the natural decay of organic materials by providing ideal conditions for organisms to thrive upon. The residue from composting can be used in the garden or on land as fertiliser. However, indicated by the high percentage of pick-up waste being organic material, composting is rarely done at household level [27].

3.2.3. OTHER TYPES OF WASTE

The other types of waste contribute to 20% of the total waste. This waste consists of 11% paper, 2% metals, 2% glass and 5% others. Paper, ferrous metal and glass are recyclable materials. Ferrous metal is the most profitable and recyclable material. Also the non-ferrous metals are well-suited for recycling by melting. Glass can be reused and recycled in multiple ways. Glass fibre can be made from recycled glass, which is used in thermal and acoustic insulation. Other applications of glass recycling are: the implementation in tiles, asphalt in roads, aggregate in concrete and recycled windows. Paper can be recycled into new paper by purification [54] .

4

Waste (Mis)Management

This chapter describes the current waste mismanagement and waste management situation in Indonesia, Bali and Kabupaten Gianyar. The level of focus in this chapter is at Kabupaten Gianyar, since the DAS Petanu is located mainly in this region. The first section describes the mismanaged waste streams in Bali, after which the second section describes the waste management system in Indonesia. The latter section starts with the governmental waste management system, followed by the non-governmental waste management system.

The information in this chapter is acquired from expert interviews, literature research and experience in the field. The expert interviews are conducted with Tony Manusama (Appendix C), Ella Flaye (Appendix D) and I Wayan Subawa (Appendix E). The literature is retrieved from the The Bali Partnership Assembly [11], the Dinas Lingkungan Hidup Kabupaten Gianyar [27], the Bandung institute of Technology [16] and previous Pantai Project reports ([17–19]). Furthermore, it is based on the many conversations with inhabitants, banjar leaders and NGO's employees in the field. In addition some other sources are used, which are cited when applicable.

4.1. Waste Mismanagement

Of the 4281 tonnes of waste produced on Bali every day, 48% is managed and thus the largest part of 52% is mismanaged. Four percent of the managed waste is recycled and the rest of the managed waste is brought to a landfill. Mismanaged waste is either burnt, retained in the environment or retained in the water. Figure 4.1 shows the streams of managed and mismanaged waste.

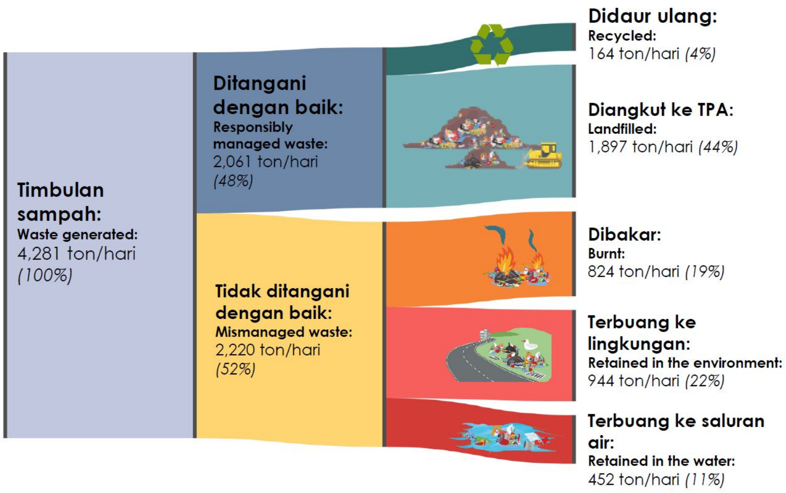

Figure 4.1: Responsibly Managed Waste and Mismanaged Waste on Bali [11]

BURNED WASTE

Research of The Bali Partnership Assembly [11] shows that on average 19% of the total waste is openly burnt. People often do this in front of their house, on the side of the road. Both, organics and non-organics are burnt together. This type of burning, i.e. open burning, causes smoke and toxic pollutants,including green house gasses, being directly released to the environment. Two of these pollutants are PCDD and PCDF, which are strong environmental air pollutants [55]. Open burning is the most significant source of these pollutants in many countries [55]. Furthermore, burning of plastic has two types of by-products; airborne particulate emission (soot) and solid residue ash. Both have potentially severe health risks when directly inhaled or indirectly digested via food and water in which toxins from combustion have settled [56]. Moreover, incomplete burning of PE-HD, PE-LD, PP, PS and PVC can lead to production of smoke with hazardous substances (e.g. carbon monoxide) [56]. Besides the effect of plastic burning itself, the burning of the additives used in plastic production also has a negative effect. With some even linked to cancer and reproductive problems [56]. Many people are not aware of these dangers. Generally, the amount of residual materials (e.g. particulate matter) after open burning represents 20-30% by mass of the original waste [57].

DUMPED WASTE

The Bali Partnership Assembly [11] determined that 22% of the total waste is dumped in the environment. Furthermore, 11% is directly dumped in the water. However, waste dumped in the environment can be re-mobilised during a heavy rainfall event and end up in the waterways [9]. Re-mobilisation occurs by means of surface runoff and flood events resulting from (heavy) rainfall. The polluting effect of re-mobilisation of debris is reinforced by the fact that (illegal) open dumpsites are often close to waterways [10] and, moreover by the characteristics of the rainwater drainage system. Open dumpsites are mostly located close to the river, because this land tends to be cheaper, but more importantly because its capacity is refreshed frequently as during heavy rainfall, parts of the dumpsites gets washed away [10]. These open dumpsites can also be found around the Petanu river; Figure 4.2 shows for example the open dumpsite in desa Mas. Moreover, in Bali the rainwater drainage system is an open drain (so without a storm drain), which means (plastic) debris can enter the system easily (Figure 4.3). Furthermore, the rain drainage system is separated from the waste water system and directly connected to a river. In other words, everything that enters the rain drainage systems flows in a river. The entering of rain drain by debris is eased even more due to most of Bali having a slope (Figure 2.7). Both, the locations of the open dumpsites and the open rainwater drainage system significantly contribute to waste, initially dumped in the environment, ending up in waterways. As a result, Bali's rivers emit annually 33,000 tonnes of plastic in the ocean [11].

Figure 4.2: Example of an Open Dump at the Embankment of the Petanu River

Figure 4.3: Example of Open Drain for Rainwater in Desa Saba

4.2. WASTE MANAGEMENT

The waste management system in Bali, and Indonesia, is considered rather complex by multiple experts (Appendix C-E): it is partly centralised and partly decentralised and to some extent coordinated by the governmental, but also privately coordinated . In fact, waste management systems appear to differ from kabupaten to kabupaten, from desa to desa and even from banjar to banjar. The following sections attempt to give an overview of the waste management situation. First the governmental waste management system, on three levels, is elaborated upon. Thereafter the non-governmental waste management system in Bali is discussed.

4.2.1. GOVERNMENTAL WASTE MANAGEMENT

In this section the governmental structure of waste management in Indonesia, as visualised in Figure 4.4, is explained.

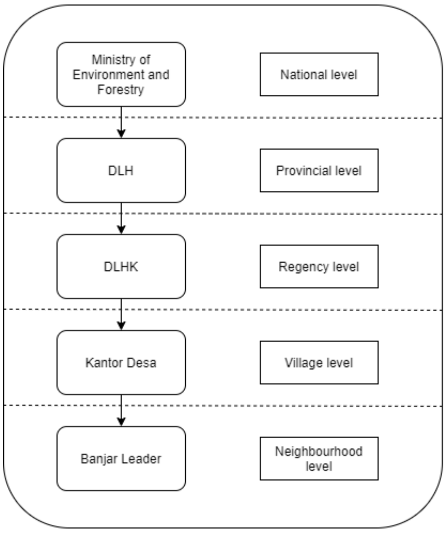

Figure 4.4: Governmental Organisation of Waste Management Agencies

WASTE MANAGEMENT IN INDONESIA

The ministry of Environment and Forestry in Jakarta represents the highest level of the waste management system. The ministry is responsible for assigning the budget to the Dinas Lingkungan Hidup (DLH) offices in the different provinces. The ministry enforced the decentralised waste management system in Indonesia with the Indonesia Waste Management Act (UU18/2008) [21], which granted power to local governments to encourage waste management strategies based upon public participation.

WASTE MANAGEMENT ON BALI

The DLH is the environmental agency of a province, in this case Bali. It coordinates the waste management on the entire island. The DLH assigns the governmental budget to the Dinas Lingkungan Hidup dan Kebersihan (DLHK) of the nine kabupaten, based on the number of inhabitants per kabupaten. The DLH is also responsible for all the landfills in Bali. Bali has ten landfills which serve the nine kabupaten.

WASTE MANAGEMENT IN KABUPATEN GIANYAR

In kabupaten Gianyar the waste management institute is the DLHK kabupaten Gianyar. The DLHK office is the local environment agency. The agency is concerned with the waste management system in the kabupaten Gianyar, besides that they provide waste educational programs for the inhabitants of kabupaten Gianyar. The DLHK's budget consists of two income streams: income from the DLH based on the number of inhabitants in the kabupaten and the tax that the DLHK levies on its inhabitants.

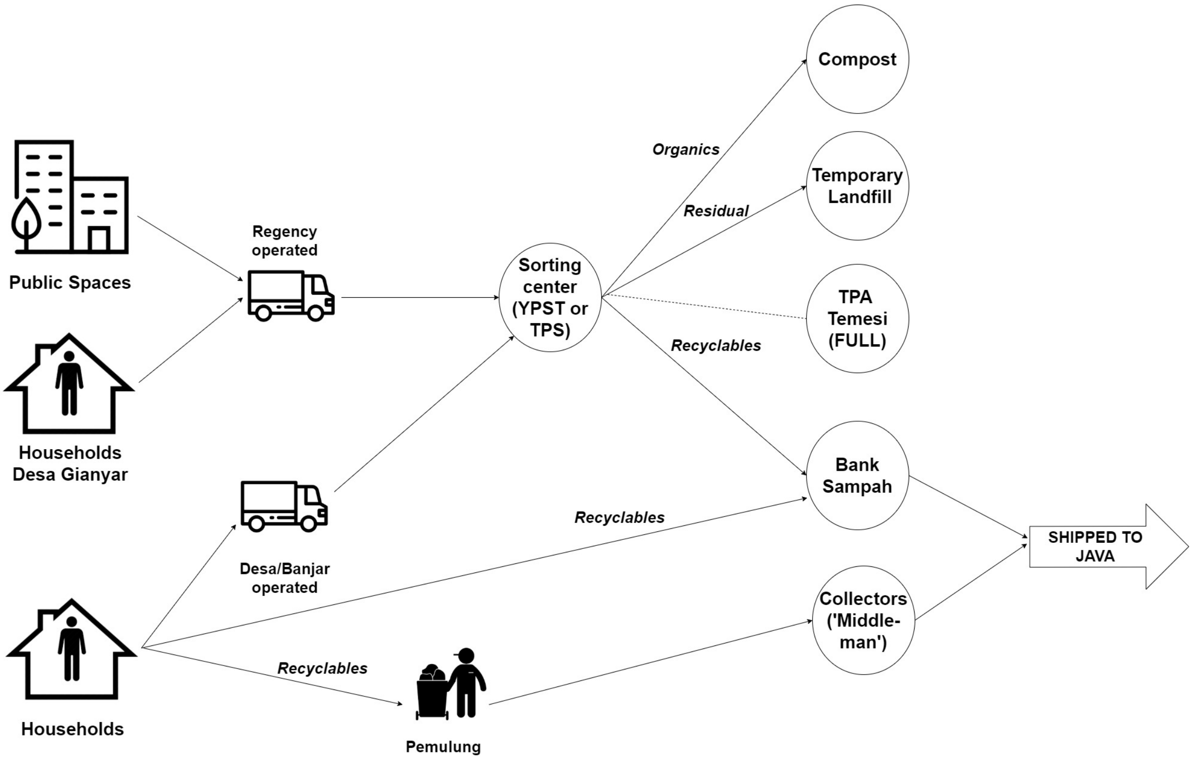

Figure 4.5: Simplified Scheme of the Waste Management System in Kabupaten Gianyar

The DLHK acknowledges that the old use of 'gathering, transporting, disposing' waste will cause problems later on, and is "continuously campaigning the new 3R principles of Reduce, Reuse, Recycle" [27] in educational programs. In accordance with that, the DLHK is responsible for the Yayasan Pemilahan Sampah Temesi (YPST), Tempat Pembuangan Akhir (TPA), Tempat Pengelolaan Sampah Reduce Reuse Recycle (TPS3R) and Tempat Pembuangan Sampah Terpadu (TPST) facillities in the kabupaten. In addition, the DLHK is responsible for the waste collection at public spaces like market places, schools and hospitals within the kabupaten. Waste collection in desa Gianyar, the capital of kabupaten Gianyar, is the responsibility of the DLHK as well. The waste is collected at central collection points and brought to the YPST sorting center by truck. A (simplified) scheme of the waste collection within kabupaten gianyar is shown in Figure 4.5. There are also 43 Bank sampahs in kabupaten Gianyar, which resulted from a collaboration between the government, the public and companies. At a bank sampah, households can bring their recyclable waste for a monetary reward in return. More about bank sampahs can be found in Section 4.2.2.

YPST, TPA, TPS3R AND TPST FACILITIES

YPST In the YPST facility the waste is sorted in three categories: recyclables, organics and other types of waste. The other types of waste are brought to the landfill, organics to the compost heap, and recyclables are sold to Bank sampahs or collectors/middle man. The compost heap has a capacity of 50 tonnes/day. 300 tonnes/day is brought to the heap, so the remaining 250 tonnes/day is also brought to the landfill due to the limited capacity.

TPA In Kabupaten Gianyar there is only one TPA (landfill), TPA Temesi. However, TPA Temesi reached the maximum capacity in 2017. Kabupaten Gianyar assigned a 22,000 m^2 area of land to function as temporary landfill, besides that, waste is brought to the TPA in Denpasar, illegal open dumps or dumped in water.

TPS3R A TPS3R facility operates in a similar manner as the the YPST. The '3R' stands for: reduce, reuse, recycle. The TPS3R collects waste from clients, the waste is then sorted into three categories: recyclables, organics and other types of waste. Recyclables are then sold and shipped to recycle businesses, mainly in Java. Organics and the other types of waste are brought to the landfill/compost heap. Besides waste sorting, a TPS3R also organises educational programs focused on the 3R principles.

The capacity of a TPS3R facility is estimated at 17 tonnes of waste that can be processed on a daily basis. This is based upon the TPS3R facility in desa Sanur Kauh (Appendix C). At this moment 3.4 tonnes of waste is processed every day with profit being made. Households pay about 50,000 IDR per month for the TPS3R service, this includes 20,000 IDR for the waste pick up service at their homes. With the help of these fees this TPS3R facility can operate profitable. This means that the subscription costs of the clients cover all operating expenses. In other words, after initial investment no further financial support from the government or sponsors is required. The investment cost for a TPS3R facility are highly variable and depends on a lot of factors. The average cost is estimated at 100 million IDR, based on literature about a TPS3R facility in Timur and Kediri (Java) [58, 59]. The investment costs are assumed to be amortised over 25 years.

At the moment there is one TPS3R facility in Kabupaten Gianyar located in desa Ketewel. The TPS3R operates on a small scale, they serve client within the desa proximity. The build of seven TPS3R facilities is planned for 2020. The TPS3R facilities are the preferred future waste management improvements of the DLHK, resulting in the hope to realise a TPS3R facility in every desa. This preference also acted as motivation to elaborate to some more detail on these types of facilities.

TPST In a TPST facility, waste is sorted as well, but only in organics and non-organics. The TPST facility operates on a small scale. Currently the only TPST facility of kabupaten Gianyar is located in desa Ubud. Sometimes Pemelung (Section 4.2.2) are working on the TPST to search for high-residual-value plastics like PET in the waste pile.

Dumping by Waste Haulers The TPS3R & TPST & YPST facilities are also known for dumping part of their waste illegally. Research of Widyarsana *et al.* [16] showed that 6.5% of the waste that is brought to a sorting facility ends up in the environment. Some cases are known of garbage truck drivers dumping the collected garbage in the environment to avoid fees at the facilities.

WASTE MANAGEMENT IN THE DESAS & BANJARS

Desas and banjars are responsible for the collection of waste at households and the transportation of the waste to the sorting facilities [21]. How - and if - this is organised differs per desa (and sometimes even per banjar).

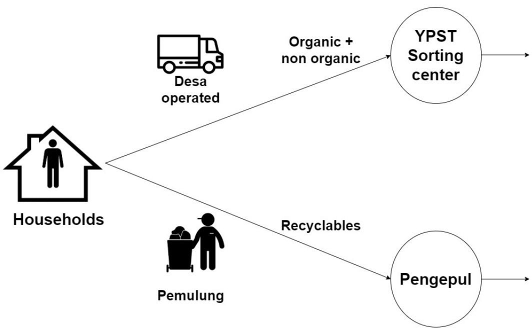

Figure 4.6: Scheme of the Waste Management System in Desa Saba

Desa Saba In desa Saba inhabitants provided information on the local waste management system. On the main roads there are collection points for waste. A truck operated by the desa comes with an irregular scheme to collect the waste. Waste is then brought to the YPST sorting center.

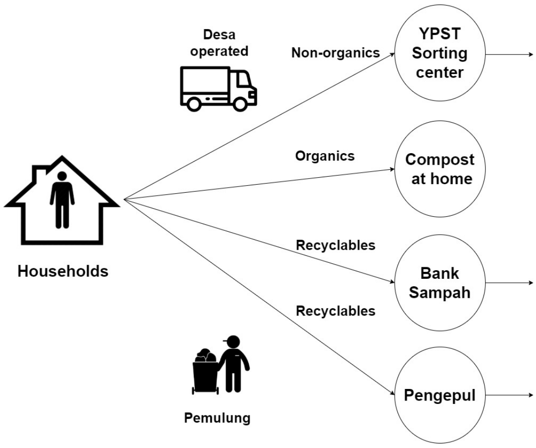

Figure 4.7: Scheme of the Waste Management System in Desa Batuan Kaler

Desa Batuan Kaler In desa Batuan Kaler two volunteers from TOL TOL, a local operated NGO provided information on the local waste management system. In desa Batuan Kaler households separate their waste into organic and non-organic. The organic waste is mostly put into a compost heap nearby the house. Some households or compounds have their own compost heap, sometimes it is a collaboration with multiple houses/compounds in the area. The non-organic waste is collected at households and transported to the landfill by truck, owned and operated by the Kantor Desa. Households pay 10,000 IDR per month for this service. There is also a bank sampah in the desa, where households can bring their recyclables themselves.

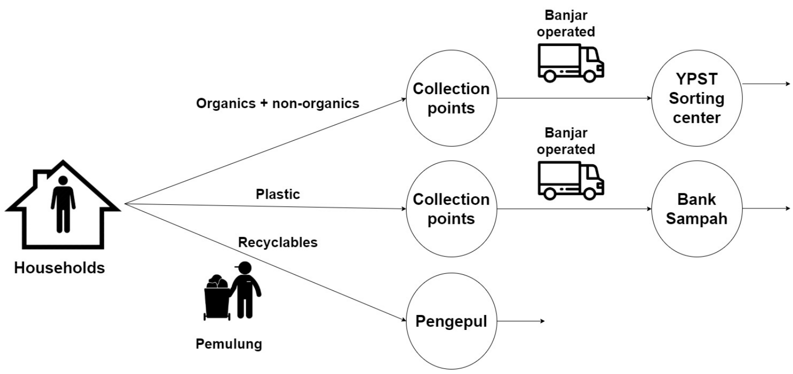

Figure 4.8: Scheme of the Waste Management System in Desa Mas

Desa MAS In desa MAS, Gus Bongkeng, the banjar leader of banjar Tarukan provided information on the local waste management system. In banjar Tarukan households sort their waste at home, they bring the plastic to a central collection point in the banjar and from there the plastic is brought to a nearby bank sampah two times a month. Residual and organic waste is picked-up by a garbage truck, owned and operated by the banjar. Every household pays 35,000 IDR per month for this service.

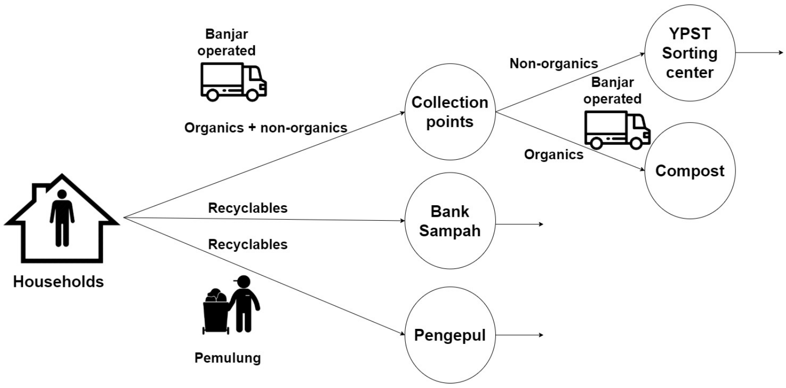

Figure 4.9: Scheme of the Waste Management System in Desa Kemenuh

Desa Kemenuh In desa Kemenuh the informal village head (desa adat) provided information on the local waste management system. In Desa Kemenuh the residents put money in a local cooperation (bank), from the interest on this money the waste collection service is financed. The desa owns and operates a truck, which comes by collection point on the main streets once per day. The waste is separated on the truck, organic waste is put in (illegal) compost heap, non-organic waste is brought to the YPST sorting facility.

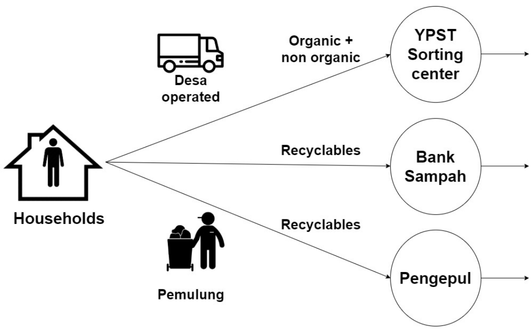

Figure 4.10: Scheme of the Waste Management System in Desa Pejeng Kawan

Desa Pejeng Kawan In desa Pejeng Kawan information on the local waste management system was provided by the banjar leader of banjar Sala. The desa owns and operates a garbage truck. This truck picks up the garbage from the houses which are situated on the main road. Households pay 10k IDR per month for this service. This truck brings the waste to the YPST sorting facility.

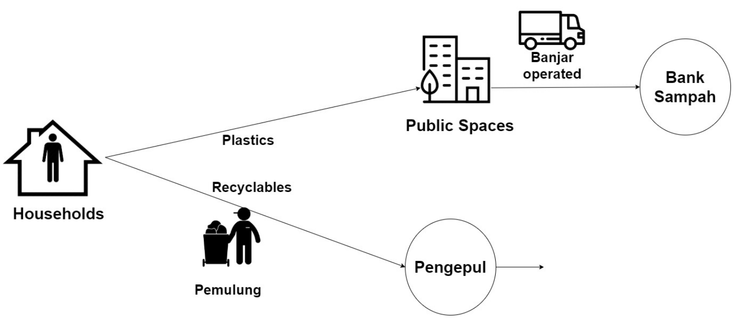

Figure 4.11: Scheme of the Waste Management System in Desa Kenderan

Desa Kenderan In desa Kenderan, Sukendra Made, a local guide and prominent member of the community provided information on the local waste management system. In desa Kenderan there is currently no collection service. Eco Bali, a Private operating service, operates in the Desa, but for normal households this is too expensive, Eco Bali serves mainly businesses (Section 4.2.2). There is no bank sampah in the desa. People mostly burn or dump their waste, or bring their waste to an illegal landfill. From time to time there is a plastic collection in public spaces. This plastic is then brought to a bank sampah in a nearby desa.

Garbage trucks

The waste is transported from households to sorting facilities, by means of garbage trucks. A garbage truck can store about 6 m^3 of waste officially, although often trucks are filled above their capacity (Figure 4.12). Trucks, on average, can carry out two trips a day. They are owned by the desa, and therefore only operate within the desa with the ownership. As a result they are not used to their full potential, especially in desas with less inhabitants. Garbage trucks costs around 350 million IDR, or 23,000 euro and have an average lifespan of 10 years [60].

Figure 4.12: Example of Overfull Garbage Truck

4.2.2. Non-Governmental Waste Management

Besides governmental waste management, there are also privately operated NGOs that handle waste on Bali. Examples are: Eco Bali, Kono BALI and Ocean Mimic. Most NGOs are active in more touristic kabupatens like kabupaten Badung. In kabupaten Gianyar there are two NGOs that offer waste collection services: Eco Bali and Kono Bali. Eco Bali offers a waste collection service for a price that starts at 115,000 IDR per month for an average household [61]. Kono Bali offers a waste collection service at 150,000 IDR per month [62]. In both cases, this is often too expensive for the average Balinese household. In practice, these services are used mostly by companies and expats. Therefore they are left out of the schemes in Figures 4.5 - 4.11.

Pemelung and Pengepul

In most desas in Bali there are also Pemelung (scavengers) and Pengepul (middleman) active. The pemelung and middleman system can be considered as a governmental and non-governmental waste management service. Some pemelung and pengepul are registered at the DLHK office, and the DLHK also provides housing for the pemelung in some cases, but their income is only determined by private market forces. For a large part the pemelung and pengepul are unregistrated. Nobody knows how much there are active exactly. It probably changes with time considering the demand and supply changes, due to for example the tourist season.

The pemelung go around houses and buy recyclables from the households. Also they pick up recyclables from dumped waste in the environment. They sell their collected goods to so called 'middleman', which in turn sell it to recycle facilities on Java. At the DLHK kabupaten Gianyar there are six registered pengepul [63]. Located in desa Buruan, Belege, Bona (Blahbatuh), Kelurahan (Gianyar) and Tegallalang (Tegallalang). Five of them are in close proximity of the research desas. Based on this fact, and on information provided by residents in the desas is concluded that all the research desas are also served by the pemelung.

BANK SAMPAH

As mentioned before, there are 43 bank sampahs in kabupaten Gianyar. Bank Sampahs are a collaboration of governmental and non-governmental organisations. The investment for a bank sampah is sometimes paid by a sponsor, sometimes by the government. Residents of Bali can open a account at a bank sampah nearby. They can bring recyclable waste to the bank, where this is weighed. The corresponding amount is then put on their bank account based on the current market price of the waste type. Some bank sampahs only trade in PET plastic, others in all kinds of recyclable waste types. However the most accepted type of waste in Bank Sampahs is PET plastic, since this type of plastic is relatively profitable and easy to recycle.

Bank samphas in Bandung (Jakarta) typically serve about 470 residents, although there are also (much) larger and (much) smaller branches [64]. In kabupaten Denpasar the amount of residents connected to a single bank sampah is much lower, approximately 130 people [65]. Bank Sampahs are often a community operated businesses, they are profitable, so after initial investment no further tax/sponsor financial support is required. Investment cost for a bank sampah is estimated at 60 million IDR (€3500.-), based on a cost benefit analysis for a Bank Sampah in Malang (Java) [66]. This relatively low amount can be explained by the fact that the infrastructure required is quite simple, just a (small) building where the waste can be sorted by hand. The investment costs are assumed to be amortised over 25 years. Employees of the bank sampah earn 2-4 million IDR per month, depending on the amount of plastic that is collected.

5
METHODOLOGY

In this chapter the structure of the methodology will be explained. The coupled economic-environmental model, as main part of the methodology, will also be discussed. Lastly, an important feature for all parts, the disposal methods, will be elaborated upon.

5.1. STRUCTURE OF THE METHODOLOGY

In order to find the answers to the research questions, multiple methods will be used. The methods have been split up in three parts and will be described in the corresponding chapters:

- Part 1: Fieldwork. Construction of the questionnaire and conduction and results of the surveys (Chapter 6).
- Part 2: Production Possibility Frontier (PPF). Theory on and establishment of the PPF (Chapter 7).
- Part 3: Utility Curve. Data analysis of the stated choice experiments and establishment of the general utility curve and the utility curves of segments of the population (Chapter 8).

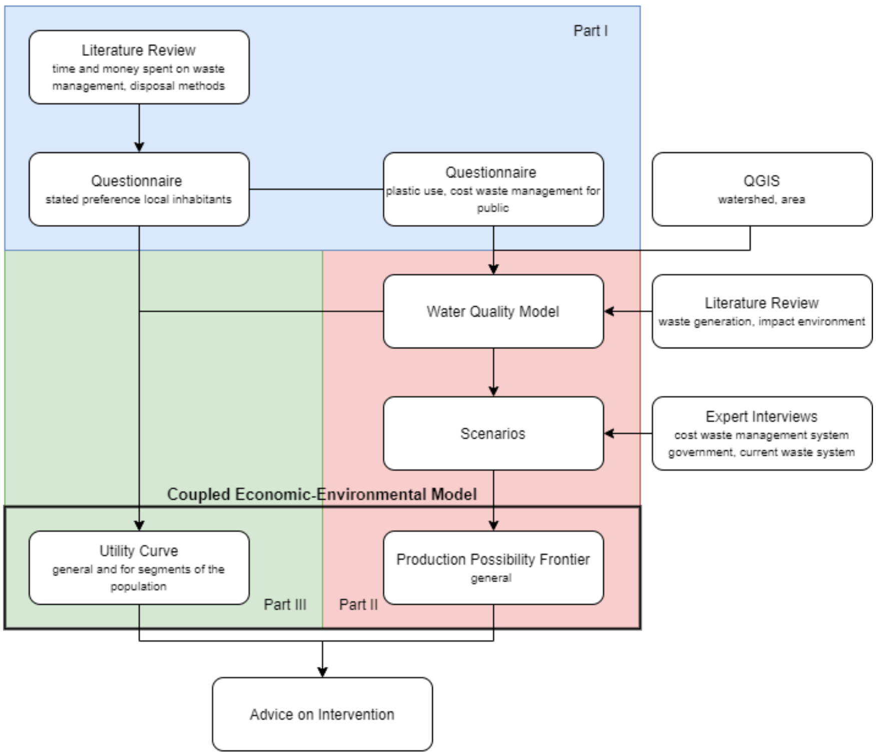

Figure 5.1: Overview Research Steps

5.2. COUPLED ECONOMIC-ENVIRONMENTAL MODEL

Coupling of the PPF and the utility curve results in an economic-environmental model [67]. In economics, the PPF is often an arc curve that shows the different quantities of two goods that an economy could efficiently produce with limited productive resources [68]. However, in some cases a linear line is possible [69]. Both lines indicate that it is not possible to increase the production of one good without a decrease of the other good. The curve indicates the cost-effective combinations of the two objectives with efficient (on the frontier), inefficient (below the frontier) and infeasible (above the frontier) solutions. The PPF method utilises a simulation-based optimisation approach to establish a series of optimum management solutions [70].

Moreover, this economic framework can be used to visualise economic-environmental trade-offs in land-use management [71–74], as it can describe possible combinations of production (e.g. timber and agricultural products) and biodiversity conservation. Apart from biodiversity conservation, water quality can be used [75, 76]. In this research the PPF framework is applied to describe the trade-offs between plastic waste pollution in the Petanu river and the price of the waste management services on the island Bali. In other words, environmental quality is combined with economic activity. In this report, the quantity that is used to describe the economic activity, will be the Impact on the Purchasing Power of a Household, while the quantity to describe the environmental quality will be the Plastic Waste Load (PW-Load); the amount of plastic waste in the Petanu river. These quantities will be exactly defined in Chapter 7 and Chapter 8. Trade-offs exist between these two quantities, as new waste management facilities, which could decrease the plastic waste pollution, cost money. In other words, a decrease in plastic waste load in the Petanu river, implies an increase of the price of the waste management services. Moreover, capital is limited, hence a PPF framework can be used [68].

On the same time, in a closed economy, a consumer tries to maximise its utility subjected to the PPF [77]. This utility maximisation in this setting represents how much are people willing to pay for environmental quality. Thus, the utility curve is set up from the customers viewpoint, unlike the PPF which is set up from an economic viewpoint. The found utility can be graphically shown in a curve. If both axes of the graph represent a good, the utility curve shows what combination of goods gives equal levels of utility [78]. An example is given in Figure 5.2. The utility curve in this figure (U) could illustrate that two coconuts and one fish give the same utility as only three coconuts. The decision what to 'produce': only fish, only coconuts or a combination of both (or in this case, environmental quality or economic activity) could be made by coupling the utility curve to the PPF. Note that, to do so, the PPF and the utility curve should be expressed in the same representative quantities, regarding the economic activity and environmental quality: impact on the purchasing power of a household and plastic waste load, respectively.

The coupling of the PPF and utility curve is an optimisation problem, and everyday practice in economics [78, 79]. The maximum utility that is achievable in a socio-economy is limited by the constraints posed by the PPF [77]. This means, shifting the utility curve into the direction of the PPF curve. In other words, the highest utility is the one, tangent to the PPF. In this research the point of tangency is the general equilibrium and describes the lowest achievable plastic pollution with the corresponding consensual costs for the waste management system at this moment in time. For the utility curve that 'touches' the PPF curve, this point means where the plastic waste load-cost-ratio is optimal, thus the utility for the population is maximised under the corresponding local circumstances . Figure 5.2 shows a simple example of a coupled PPF and utility curve.

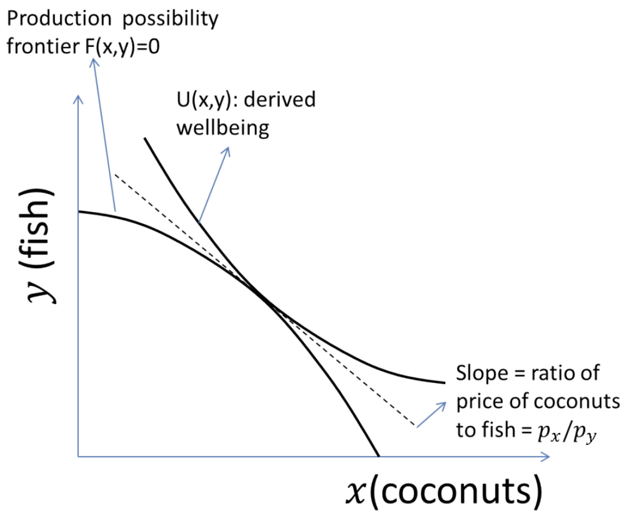

Figure 5.2: Example of a Production Possibility Frontier Coupled with a Utility Curve [80]

This general utility curve assumes homogeneous preference among the population. However, consumer preferences for goods or services are characterised by heterogeneity [81]. This heterogeneity is a consequence of difference in socio-demographic characteristics within the population. Identifying the effect of certain characteristics on the preference can be helpful when formulating a intervention strategy [81]. Therefore, socio-demographic information will also be included in the utility curve. Hence, specific utility curves for certain segments of the population will be created and coupled to the general PPF.

5.3. DISPOSAL METHODS

For both, the utility curve and the PPF, information is needed on the environmental quality related to the different methods of disposing plastic waste: the disposal methods. Given the complex waste management situation of Bali (Chapter 4), it has been chosen to schematise it by making a differentiation into four different disposal methods. These are: 1) Bringing recyclable household waste to a waste recycling facility by the households themselves (Self-Service), 2) Collection of the household waste at the houses or at pickup points (Pick Up), 3) Open Burning of the waste (Burn) and 4) Open dumping of the waste in the environment (Dump). These four methods will be used within the modelling research steps of the following chapters. They have been chosen as they are currently used as disposal methods in kabupaten Gianyar (Chapter 4). It is assumed that the methods cover the entire waste management system of the study area, which means that two underlying simplifications should be recognised. The first important simplification holds the accumulation of the multiple Pick Up and Self-Service disposal methods in practice into two disposal methods: Pick Up and Self-Service. As could be seen in Chapter 4, Bali is characterised by many waste management companies and methods. However, regarding this research it is assumed that every amount of plastic waste that is picked up is described by the same characteristics in terms of costs, effectiveness and pollution and every amount of plastic waste that is brought to a recycling factory as well. The second simplification is that informal waste management services are not considered.

As said before, the environmental quality is defined in the model as the plastic waste load. Therefore, the percentage of plastic waste ending in the river per disposal methods is needed in order to quantify the pollution load associated with a specific method. These percentages have been estimated with the help of the reviewed literature in Chapter 3 and 4. The assumed percentages are shown in Table 5.1. The explanation of these percentage is given in the remaining part of this section.

To start of with Self-Service, it has been estimated that 30% of the plastic waste generated by households is PET plastic [19], which can be handed in at a bank sampah. It has been assumed that the remaining 70% of the plastic waste (of these people that indicated Self-Service) will be picked up by a truck, as during the fieldwork those people appeared to be aware of the consequence of plastic dumping and burning. Unfortunately, 6.5% of the collected waste by waste haulers gets illegally dumped into the river [16]. This means that 4.6% of the plastic waste of people choosing Self-Service as their disposal method ends up in a river. Secondly, as said before 6.5% of the collected waste gets dumped. In other words, 6.5% of the plastic waste that is picked up ends in the river.

However, people can also choose to mismanage their waste and either burn it or dump the plastic waste themselves in the environment. This part of the plastic waste is called the Mismanaged Plastic Waste at Household level (MPWH) and contributes significantly to the plastic waste load in the river. It has been assumed that after open burning of plastic , 25% of the initial plastic amount is remained as solid residue ash [57]. In other words, 25% of the produced plastic waste remains after burning. In case of dumping, regardless if it is dumped on land or water, it has been assumed that eventually all the dumped plastic will end up in the river.

Table 5.1: Overview Percentage of Plastic Waste Production Ending Up in the River as Plastic Waste Load per Disposal Method

Disposal Method	**Percentage of Plastic Waste Ending in the River as Plastic Waste Load**
Self-Service	4.6%
Pick Up	6.5 %
Burn	25 %
Dump	100 %

6

Part I: Fieldwork

In this chapter the methodology and results regarding the fieldwork are explained. The first section will explain the structure of the used questionnaire during the survey. The second one will elaborate on the procedure of the arrangement of the fieldwork. It will also elaborate on the conduction of the survey itself as it appeared to be different in every desa. The last section will present the results of the survey. These results are used as input for the calculations within the following chapters.

6.1. Structure of the Questionnaire

During the survey, the same questionnaire was used in each desa. From the questionnaire, the required data for both the utility curve and the PPF, were obtained. The complete questionnaire can be found in Appendix F. It consists of four parts, carrying a total of 21 questions. An overview of the four parts is provided below, together with an indication of the particular part of the research that is based upon the data obtained within that part of the questionnaire. The location within the report where this research part could be found is given as well. Each part is elaborated upon in the following subsections.

- **Part 1: Socio-demographic questions.** Eight questions about the socio-demographic situation of the respondents. These questions are used to determine the influence of the socio-demographic situation of the respondents on the utility curve and thus the ultimate results. This is done in Chapter 8 and Chapter 9. Furthermore, the questions are used to estimate the representativeness of the sample group, which is done in the discussion (Chapter 11).
- **Part 2: Current waste management questions.** Three questions about the current disposal methods and associated costs and time per household of the respondents. The results of these questions are used as input for the construction of the PPF. This is done in Chapter 7.
- **Part 3: Stated choice experiment questions.** Eight questions containing choice sets, forming a stated choice experiment, to provide the data needed for the construction of the utility curve. The construction of the curve is done in Chapter 8.
- **Part 4: Additional questions.** Two questions that are used for two different purposes. The first question regards the perception of the respondent regarding the disposal methods and is used as input for the recommendations (Chapter 12). The second one lets the respondent estimate their household's Plastic Waste Production (PW-Production), which is used as input for the PPF (Chapter 7).

6.2. QUESTIONNAIRE PART 1: SOCIO-DEMOGRAPHIC QUESTIONS

The first part of the questionnaire consists of questions on the socio-demographic situation. The socio-demographic variables that are asked in this part are: 'Gender', 'Birth Year', 'Place of residence', 'Education Level', 'Household Size', 'Number of children under the age of 13 in the household' and 'Income'. These questions are used to compare the sample with the socio-demographic situation in the six researched desas and kabupaten Gianyar and thus the representativeness of the sample group. Furthermore, this information might be directly linked towards their attitudes and practices towards waste management [34, 35]. This could be used to determine the utility curve of certain socio-demographic groups. The questions are asked in multiple choice form, to make responding more easily. For some questions, options like 'I don't know', or 'I prefer not to say' are given as well.

6.3. QUESTIONNAIRE PART 2: CURRENT WASTE MANAGEMENT QUESTIONS

The questions in part 2 asked about 'current disposal method', 'time spend daily on waste disposal per day' and 'monthly costs of the disposal method'. These questions are needed to understand the current waste management situation in every desa on a household level. The information obtained is used as input for the establishment of the PPF. Each question is offered in a multiple choice form, using the same options as of the attribute-levels of the stated choice experiment (Section 6.4).

6.4. QUESTIONNAIRE PART 3: STATED CHOICE EXPERIMENT QUESTIONS

The questions in part 3 form a stated choice experiment. This experiment is used as input for the utility curve. Stated choice experiments have an origin in behavioural sciences. Because simply asking people why they choose things, does often not represent their real choice behaviour, choice experiments were introduced. By asking the respondent to make a choice between pre-selected options, insight in the trade-offs people make and what preferences people have, is gained. With the information on these trade offs and preferences, future choices can be predicted, and thus future policies can be adjusted to this knowledge [82, 83]. This gained insight can ultimately be expressed as 'betas'. The betas contribute to the amount of 'utils' someone gives to a certain alternative; how probable it is that someone chooses that particular option. By estimating these 'betas' a model can be constructed, the model can make predictions about which alternative will be chosen [83]. The translation of the results of these questions to the 'betas' and the development of the utility model is done in Chapter 8.

In a stated choice experiment, respondents make a choice between alternatives (choice options). The choice is a *stated* preference, it represents the choice the respondent would make in a hypothetical situation e.g. when only the presented alternatives are available to choose from. The stated choice experiment is constructed by defining attributes, attribute levels and choice sets and fitting these in a choice set and questionnaire design as indicated in Figure 6.1 [84]. These different elements will be elaborated on in the following paragraphs.

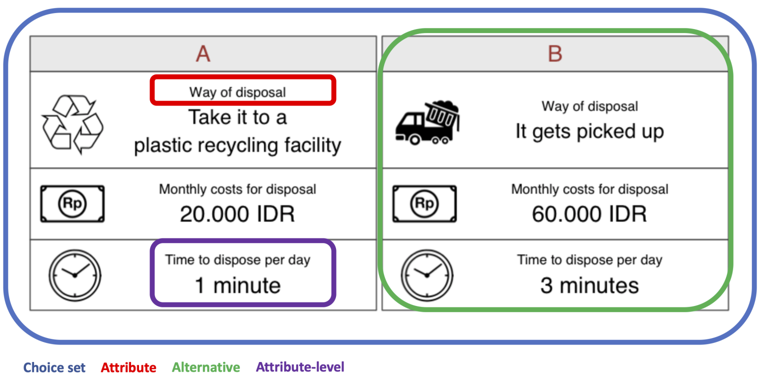

Figure 6.1: Defining Terms of a Choice Set [84]

6.4.1. Type of Experiment and Choice Sets

The form of choice experiment that was used for this experiment, was an unlabelled experiment. This means that the options (A or B) do not have an indicated 'name' (e.g. Figure 6.1). Besides that, all used attributes and attribute-levels are equal for both choices in the choice sets. The choice sets were constructed using the program Ngene. This program constructs choice sets in a 'orthogonal fractional factorial design'. This design minimizes the correlation between attribute levels within a choice set, which allows independent estimation of the influence of each design attribute on a choice [85]. Based on the number of attributes and their levels, Ngene produced the smallest possible fractional factorial design; in this case consisting of 16 questions. Because the number of choice sets, constructed by Ngene, is quite large (16), the choice sets were split up in two orthogonal blocks of eight questions (also generated by Ngene). Half of the respondents filled in block 1 and the other half filled in block 2 (for the full profiles generated by Ngene refer to Appendix G). To reduce the bias in the first and last question, three versions of each block were conducted (in total six versions). These two blocks could also be found in Appendix G.

6.4.2. Attributes and Attribute-Levels

In the stated choice experiment the two alternatives both have three attributes: 'disposal method', 'costs of plastic waste management' and 'consumed time for plastic waste management'. The disposal method indicates the way of disposing the plastic waste. The costs of plastic waste management indicate the costs a household makes to let the plastic be disposed, given the indicated disposal method. And, at last the consumed time for plastic waste management is a measurement of the amount of time that a household needs to let the plastic waste be disposed.

The attribute 'disposal method' needs four levels, in order to schematize the currently used waste handling methods (excluding informal waste handling services). These were introduced in Chapter 5 and can again be found in Table 6.1. It has been chosen to also create four attribute-levels for the other two attributes, as mixing of the amount of attribute-levels can result in more choice situations [85]. Hence, taking three attributes, each containing four attribute levels, results in a relatively easy-to-manage utility curve. Table 6.1 presents these attribute-levels. For each attribute, the coming paragraphs elaborate more on the levels.

Note that regarding the disposal method, the four levels stand for: 1) plastic waste dumping in water or on land, 2) open burning of plastic waste, 3) picking up of plastic waste (either at the house or at a collection point) or 4) bringing of the plastic waste to a recycling facility, respectively. These four methods are equal to the methods proposed in Chapter 5. Further, the costs of plastic waste management are expressed in monthly costs, since most households will pay their bills and fees on a monthly basis. The consumed time per household is on the other hand expressed on a daily scale, because this is more easy to measure for the respondents and therefore provides more reliable results.

Table 6.1: Attribute Levels Utility Curve

Attribute	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Disposal Method [-]	Dump	Burn	Pick Up	Self-Service
Costs [IDR/month]	20,000	60,000	100,000	140,000
Consumed Time [min/day]	1	3	5	7

Attribute-Levels of Disposal Method

The levels of the 'disposal method'-attribute consist of a simplified view of the disposal methods used in Bali. These disposal methods are introduced in Chapter 5: Dump, Burn, Pick Up and Self-Service. The description and substantiation of these definitions is provided in Chapter 5 as well.

ATTRIBUTE-LEVELS OF COSTS OF PLASTIC WASTE MANAGEMENT

The construction of the attribute-levels of the 'costs'-attribute is based on two separate methodologies: 1) following data of the World Bank, Rijkswaterstaat and the DLH (Ministery of Environment of Indonesia) and 2) using actual prices of waste management of several waste management organisations in Bali. These methodologies are combined to get useful values for the attribute-levels.

Following the Data of the World Bank, Rijkswaterstaat and the DLH The World Bank classifies the world's economies into four income groups: low, lower middle, upper middle and high [86]. The assessment of these classes is based on the Gross National Income (GNI) per Capita, calculated using the Atlas Method [87]. The GNI per Capita is the dollar value of a country's final income in a year, divided by its population. It therefore reflects a countries' income, before tax income of the citizens [88]. The thresholds of the World Bank's income classes, as of July 2019 [86] are provided in Table 6.2.

Table 6.2: Income Classes per Year According to the World Bank [86]

Income class	Lower bound	Upper bound
Low [$/year]	-	1026
Lower middle[$/year]	1026	3995
Upper middle [$/year]	3995	12,375
High [$/year]	12,375	-

The World Bank provides the GNI per Capita of each country specific as well. This amounts $3840 per year for Indonesia [89], which makes it a 'Lower middle income'-country. Furthermore, the World Bank provides data regarding the global waste management systems. Although this data is not very recent and precise, it could act as a sufficient basis to construct suitable levels of daily waste management costs. According to the World Bank (Figure 6.2) 'Lower middle income'-countries produce on average 0.29 tonnes waste per capita per year [90]. Other sources like Rijkswaterstaat and the DLH use a value of 0.25 tonnes waste per capita per year for Indonesia [91], which is equal to 0.68 kgs waste per capita per day. Seeing the data of the World Bank, Rijkswaterstaat and the DLH to be nearly equal, strengthens the reliability of these values. Since the information of the DLH is focused on Indonesia in particular, this value will be used in further calculations.

The World Bank does also provide data related to the 'Cost of Collection and Disposal (Figure 6.2) [90]. Given this figure, it seems reasonable to estimate the yearly average cost of collection at circa $ 60 per tonne [90] for a lower middle income country, which results in daily average collection cost of $ 0.164 per tonne. Since most waste management organisations are non-profit or governmental, it makes sense to assume the daily price of waste management per capita being equal to the costs. In that way, combining with the value of production of waste per capita, the daily, weekly and monthly costs and prices of waste management per capita in Indonesia can be estimated at $0.05, $0.35 and $1.45, respectively, which is equal to 800 IDR, 5600 IDR and 23,200 IDR. Note that above calculations were only used to construct the attribute-levels of the 'cost of waste management'-attribute of the questionnaire; they are not used as actual results.

	Low Income Countries	Lower Mid Inc Countries	Upper Mid Inc Countries	High Income Countries
Income (GNI/capita)	<$876	$876-3,465	$3,466-10,725	>$10,725
Waste Generation (tonnes/capita/yr)	0.22	0.29	0.42	0.78
Collection Efficiency (percent collected)	43%	68%	85%	98%
Cost of Collection and Disposal (US$/tonne)				
Collection[2]	20-50	30-75	40-90	85-250
Sanitary Landfill	10-30	15-40	25-65	40-100
Open Dumping	2-8	3-10	NA	NA
Composting[3]	5-30	10-40	20-75	35-90
Waste -to-Energy Incineration[4]	NA	40-100	60-150	70-200
Anaerobic Digestion[5]	NA	20-80	50-100	65-150

Figure 6.2: Estimated Solid Waste Management Costs by Disposal Methods, According to the World Bank in 2012 [90]

Following the Actual Prices of Waste Management Services in Bali Another way to get insight in the plastic waste management costs in Bali is to look at the actual collection and recycling organisations. There are multiple options for waste collection and/or recycling on the islad. It is possible to have a company come by to pick up all your garbage at once, and there are companies that will pick up your separated garbage. The latter will recycle the plastics as much as possible. To find a realistic value for this attribute, real prices from multiple companies have been observed. A widely known company in Bali is Eco-Bali, they offer a pickup and recycling service for a fee of 115,000 IDR (around €7) per month for an entire household [61]. It should be noted that Eco-Bali is a relatively expensive waste management company, meant to facilitate the touristic sector. Kono is another company that offers waste pickup services, the monthly cost of this service vary between 40,000 and 80,000 IDR (€2.50 and €5), depending on the types of waste the customer would like to have collected and the type of household the customer has [62].

Combination of the Data of the World Bank, Rijkswaterstaat and the DLH and the Data of the Actual Prices of Waste Management in Bali Both methodologies indicate cost of waste management, ranging between 20,000 IDR/month and 115,000 IDR/month. The attribute-levels are therefore set as follows: 20,000 IDR/month; 60,000 IDR/month; 100,000 IDR/month and 140,000 IDR/month, so it is expected that this range will fit the actual responses.

ATTRIBUTE-LEVELS OF CONSUMED TIME

'Consumed time' is defined as the average time per day it takes a respondent to dispose their garbage. This includes the time to separate the garbage and to bring it to the location of pick up (at home or at the facility). Studies by Bartelings [92], Bartelings and Sterner [93] estimated that on average 30 minutes per week is spent on household waste handling with a standard deviation of 30 minutes. This creates a range between 0 and 9 minutes per day. However, it was assumed that every disposal method requires at least some time investment. Hence, four attribute-levels should be chosen in a range from 1 to 9 minutes with equal distribution between them. As a result, the attribute-levels that were used for the stated choice sets are: 1, 3 ,5 and 7 minutes per day.

6.4.3. COHERENCE OF THE CHOSEN ATTRIBUTES WITH THE ECONOMIC-ENVIRONMENTAL MODEL

Although the attributes 'disposal method', 'costs of plastic waste management' and 'consumed time' have been chosen to include in the choice sets, the required outcome is to find the trade offs the population makes between the economic activity, expressed as the impact on the purchasing power of the households, and the environmental quality, expressed as plastic waste load. While it is very interesting to know what these trade offs exactly are, it is also important for the acquirement of the equilibrium between the utility curve and the PPF, since the PPF is represented by these variables as well. Now, probably the question arises why the presented choice experiments do not include exactly and only these two variables. While monthly costs, and thus the impact on the purchasing power of households, are actually included, there are reasons to not include plastic waste load directly, but instead use the variables 'disposal method' and 'consumed time'.

First of all, it is really important that respondents can make trade-offs between two alternatives without encountering too much complexity. Many studies have shown that the quality of the stated choice experiments decrease significantly when the respondents' task complexity is increased, which has shown to result in response errors [94–98]. In this case the risk of complexity was lying in the term 'plastic waste load' and its levels. Since there was a concern that including plastic waste load as an attribute and its levels in 'kilograms plastic waste load in the river' could make it too complex for the respondents to imagine how much plastic a hypothetical alternative represents. The population of the sample consists of people around different wealth and educational levels. It can therefore not be expected that they can estimate a specific amount of kilograms of a certain material (in this case plastic) correctly and equally.

In order to reduce this complexity, an alternative attribute is chosen to represent the environmental quality: 'disposal method'. The reason for representation of the environmental quality with this attribute is especially its relevance to the plastic waste load ending up in the rivers, while not being too complex to interpret since it is a day-to-day activity. The way people dispose plastic, either bringing it to a recycling facility, by letting it being picked up, burning it or dumping it, affects the amount of plastic that ends up in the river every day. These differences were already elaborated upon in Section 5.3, but in summary the amounts of plastic waste load per disposal methods increases respectively. Hereby it is assumed that respondents can imagine the environmental results of disposing plastic in a certain way, much better than imagining exact amount of kilograms of plastic that would end up in the environment.

A second argument for not including plastic waste load directly, but in the form of disposal methods, is its relevance to certain costs. This can be seen as another way of reducing complexity. It is assumed that it will be too hard for people to assign a price tag to plastic waste load in rivers. Attaching the disposal of a certain amount of kilograms of plastic in the river to certain (monthly) costs, does not sound natural and it even becomes more complicated when comparing this to an alternative with other attribute levels. In contrary, people already are used to pay a certain fee for different waste management services, or in the case of burning and dumping, they are used to the monthly costs of fuel or maybe even a penalty by the government.

Furthermore, it is intentionally not chosen to represent environmental quality in the form of photos of rivers or riverbeds which have different levels of plastic pollution shown. The reason for this, is the assumption that people do not intentionally pollute the rivers with their plastic waste. This happens indirectly, when they make use of the different disposal methods.

The reason for including 'consumed time' as an attribute is the expectation that people also consider the time they spend on disposing their plastic when comparing two different disposal alternatives. A study by Ando and Gosselin [99] has shown that the time constraint and the distance to a disposal bin, both matter when consumers choose for a certain way of disposal. Since distance to a disposal bin can be interpreted as 'consumed time' to bring waste to a disposal bin, it is actually a form of opportunity costs of time. According to another study by Halvorsen [100] that is conducted in Finland, increasing people's opportunity cost of time had a negative effect on their willingness to recycle. Furthermore, another stated preference analysis conducted in 2017 with US consumers, increasing the time has shown to have a negative influence on whether these consumers choose to recycle, even though the range of time in these choice sets was only 55 seconds per recycling round [101]. Although conducted with consumers with different nationalities than Balinese, these studies have shown that time is an important factor for consumers when disposing their waste in a certain way. Therefore, they have shown the relevance of involving time to the stated choice analysis of this study, since it is interested to know if this variable also effects Balinese people's choices.

6.5. Questionnaire Part 4: Additional Questions

The fourth and last part of the questionnaire contains two additional questions. One is about the perception on the environmental quality related to the four different disposal methods as proposed in Chapter 5. Respondents are asked to rank the four disposal methods on a scale of five levels, from totally not polluting (1) to very polluting (5). This question is used to validate experiences from the field about the perception of the inhabitants, and to write substantiated recommendations. In the last question of the questionnaire the respondents are asked to tell how much plastic waste his/her household produces in one day. Three pictures of three different sized garbage bags are shown. The respondent chooses the one most applicable to his/her household. The method of visualisation is chosen here, as it is expected that respondents know better what size of garbage bag they fill with plastic waste rather than the exact amount in kg of plastic they produced. The sizes of the garbage bags are afterwards translated to exact amount of kg by multiplying their volume in m^3 with 20, as household plastic waste has a density of 20 kg/m^3 [102]. This question is needed to determine the plastic waste production per household per day for constructing the PPF.

6.6. SAMPLE SIZE SURVEY

Before the survey could be conducted, the target sample size needed to be determined. The study areas have been chosen as stated in Chapter 2. The six desas where the surveys were conducted are: Mas, Kenderan, Pejeng Kawan, Batuan Kaler, Saba and Kemenuh. Chapter 2 provides the number of households in the desas as well: in total 10,642 households. However only 8335 of these households are located within the DAS Petanu, the catchment of the river, since the desas are not entirely located in the DAS; parts of the desas contribute to other catchments. The calculation of these values is done with the help of QGIS, following the same procedure as in Section 7.3.2. Briefly stated, it is assumed that the households are equally divided over the desa and by using the area of the desa that is located in the DAS, the number of households in the DAS can be calculated.

Above procedure leads to a target population (P), having a size of 8335. As the target population is known the sample size can be calculated with the help of Equation 6.1, proposed by Daniel and Cross [103]. The targeted confidence interval of the socio-demographic characteristics was chosen to be between 90 and 95%. The corresponding critical z-value [1]is between 1.645 and 1.96 respectively. Given a wanted margin of error (MOE) of 5 % and an assumed sample proportion (p) of 0.5, Equation 6.1 can be filled in. It can be concluded that a sample size (N) of 368 or 263 is needed for a confidence interval of 95% and 90% respectively.

$$N = \frac{P \cdot X}{X + P - 1} \quad \text{with,} \quad X = \frac{z^2 * p * (1-p)}{\text{MOE}^2} \tag{6.1}$$

Furthermore, a check is needed on the sample size of the stated preference. To make sure parameters are estimated at the level of statistical significance, the rule of thumb as proposed by Orme [104] is applied, which can be seen in Equation 6.2. In this equation L^{max} is the largest number of levels for any of the attributes, which is chosen to be four. J is the number of alternatives per choice set (2). S is the number of choice sets to be done by one respondent (8). Note that there are 16 different choice sets, but the choice experiment is divided in two blocks of eight, meaning that every respondent only encounters eight choice sets. Filling in Equation 6.2 leads to a required sample size of 125. This is smaller than the two required sample sizes for the socio-demographic characteristics.

$$N \geq 500 \cdot \frac{L^{max}}{J \cdot S} \tag{6.2}$$

Therefore, the sample size for the socio-demographic characteristics is decisive. It was chosen to set the target sample size (N) to be 300 respondents divided equally over the six research desas. In other words, in every desa approximately 50 respondents are needed. The corresponding z-value is 1.764, which means the confidence interval is equal to 92.23%.

6.7. OVERVIEW PROCEDURE FIELDWORK

After the structure of the questionnaire and the sample size were determined the fieldwork could be carried out. The followed methodology for the fieldwork is summarised below:

1. Delivery and writing of a permission letter (Appendix H) in Bahasa Indonesian for the Kantor Desa of the researched desas.

[1]The critical z-value is linked to the area under the standard normal distribution curve and is equal to the number of standard deviations from the mean. Note that standard deviations are directly linked to a confidence intervals.

2. Conduction of the surveys in the time period 24 February till 3 March 2020.

6.7.1. PERMISSION LETTER

A coordinated and planned approach appeared to be more effective than just walking around in a desa. This conclusion was made during the research of a previous Pantai Group [19]. Furthermore, Tony Manusama indicated that printed letters are a common means of communication within the government of Indonesia. Following the advise of the other Pantai Groups and mister Manusama, it was chosen to write a permission letter in Bahasa Indonesia. In the letter there was asked for permission and help to conduct the surveys in the desas. The goal of the letter was to to get in touch with banjar leaders (leaders of a certain neighborhood) and request to attend a banjar meeting. Banjars regularly organise banjar meetings, in which people (most of the time men) of a banjar attend. During such a meeting many people come together, which is a convenient moment to conduct the surveys. The letters were personally brought to the kantor desas in the morning of February 21st. The kantor desas are normally open from Monday to Friday from 8 am until 2 pm. In desa Saba, the first visited desa, the local officials were not able to speak English, so it was advised to bring a interpreter. In all the other desas the people were able to understand and speak (basic) English. The letter in Indonesian helped a lot to clarify the purpose of the visit and the employees of the kantor desa tried to help immediately. Support was given in many ways: e.g. a connection with the banjar leaders was established, or a phone number was provided to plan a date to conduct the survey. The permission letter turned out to be very effective and helped to conduct the survey in a relatively smooth manner.

6.7.2. CONDUCTION OF THE SURVEY

Between the 24th of February and 3rd of March the actual surveys were conducted. The questionnaires were online, so could either be filled in on the the provided tablets or on a respondent's own smartphone by scanning a QR code. The conduction took place in the morning, because in the afternoon temperatures were too high and rainfall events were more likely. In total the questionnaire was filled in by 300 respondents, about 50 in each of the research desas. To act as efficient as possible, the research group of six was split up in groups of two or three, who conducted the surveys in a designated part of the desa. However, the number of groups differed per desa, depending on the arrangements with the banjar leaders. To show gratitude for the cooperation of the people and create more awareness about plastic waste at the same time, respondents were given a bamboo straw. The chosen desas are relatively close to each other; from the most upstream desa of Kenderan it is a 45 minute drive to desa Saba most downstream. However, as it took the full morning (and sometimes even part of afternoon) to reach the target of 50, it was chosen to conduct the survey in every desa on a different day.

DESA MAS

A desa is subdivided into banjars. In desa Mas there was a lot of enthusiasm for the research in banjar Tarukan, which is located next to the Petanu river. Gus Bongkeng, who is the banjar's new leader since one year, is very keen to improve the waste management system in his banjar and wants to create more awareness about plastic pollution among the young people. He hopes that by creating more awareness among the younger generations, they could educate the older, more stubborn, generations. In this way, he tries to have less pollution in their waterways in the future. Furthermore, he released goldfish and carpers in the small canal in his village so people have a motivation to keep the waterways clean of waste. On Tuesday the 24th of February the leader organised a plastic walk, where the children were given plastic bags to pick up plastic garbage on the way. Many people of the village participated in this walk. After this, the people gathered in the village and did aerobics and participated in a lottery. Mister Bongkeng gave permission to conduct the survey during these festivities. With many people joining, it was convenient to conduct the surveys during these activities. Furthermore, it gave a great inside in the efforts that are given to improve the attitudes of the people towards waste management.

Desa Kenderan

On February 26th there was a banjar meeting to discuss the preparations for an upcoming ceremony in a central temple in the desa. Permission was given to attend this meeting by one of the banjar leaders. Note that in order to enter a temple a sarong and selendang, which are parts of the traditional Balinese clothing, were needed. Surprisingly, only men were attending the meeting. Most of them were older and had difficulty reading or did not understand the purpose of the research. Some of them only spoke Balinese and, since the questionnaire is drawn up in Bahasa Indonesian, could not understand the questions. As a result, only a few men filled in the questionnaire at the temple. Hence, afterwards surveys were also conducted at the stores, homes and public areas within the desa in groups of two. This approach took more time than conducting the surveys at large gatherings, like in desa Mas.

Desa Pejeng Kawan

In Pejeng Kawan there was unfortunately not a special meeting to which a permission to attend was given. Hence, the same strategy was used as in Kenderan. Hence, groups of two went to designated parts of the desa to carry out the survey. However, on that day, the 28th of February, the locals were very busy, because it was the day before a large Hindu ceremony. This meant that less people were on the streets and it took even longer time than in Kenderan to reach the target of 50 responses.

Desa Batuan Kaler

On February 25th a meeting was arranged with two persons of community TOL TOL, located in Batuan Kaler. This community has a close relation to Trash Hero, an international voluntary-driven initiative to educate, and clean the environment. During this meeting they shared information about their current waste management system and explained some of their future waste management plans. Ideas for improvement were exchanged as well. Furthermore, an invitation to the Kuningan ceremony on February 29th was given. On that day, a local guide introduced the questionnaire and the research to the local people outside an important temple. After the offering ceremony, they were asked to fill in the questionnaire. However, the people need to go to multiple temples during the Kuningan ceremony, therefore people were often quite in a rush. Nevertheless, due to the large amount of people attending the ceremony, it was possible to conduct the survey among 50 respondents.

Desa Saba

On the 2nd of March desa Saba was visited. The same strategy was used as in Kenderan and Pejeng Kawan, as there was no special meeting organised by a banjar leader. It appeared that the willingness of the people to fill in the questionnaire is much higher when a local important person, like a banjar leader, is supporting the research. As a result, quite some people did not want to fill in the questionnaire. This made it more difficult to reach the quote of 50 people in desa Saba, however it was achieved in the end.

Desa Kemenuh

The last surveys were taken in desa Kemenuh on the 3rd of March. Before going there, they had arranged a meeting on the 27th of February, with five of the in total eleven banjar leaders in desa Kemenuh as a response to the permission letter. After this meeting the phone numbers of five banjar leaders were exchanged. Those five banjars are located the closest to the Petanu river. Via WhatsApp, arrangements were made to attend three meetings on the 3rd of March. The first two meetings were on the same time. Four group members joined one large meeting and shared information with the banjar leaders and conducted many surveys. The other two group members went to another part in the desa to conduct the surveys with the help of another banjar leader. It appeared to be a very time-efficient way of conducting surveys, as banjar leaders have a big influence on local people, which makes them less sceptical towards our survey. After these meetings with the banjar leaders, some more people were interviewed at their homes with the help of a local guide, which was also arranged by another banjar leader. In total it was relatively easy to conduct the surveys in desa Kemenuh.

6.8. Answers to Questionnaire Part 1,2 and 4

In this section the answers of the questionnaire regarding to the socio-demographic (part 1), current waste management (part 2), and additional information (part 4) are given. These answers are used to help make the PPF and utility curve, as discussed in Chapter 7 and Chapter 8. Furthermore, parts of the discussion (Chapter 11) are based on the socio-demographic information. The answers to the stated choice questions (part 3) are not presented here as they can only be visualised with a utility curve, which will be done in Chapter 7. Before the answers will be given, an overview is shown of the respondents' desa and banjar of residence.

6.8.1. Distribution of Respondents' Location of Residence

Figure 6.3 visualises the number of respondents per desa and per banjar. As can be seen in Figure 6.3, in desa Batuan Kaler the least surveys were conducted with 40 respondents, in desa Saba the most surveys are conducted with 58 respondents. The banjar distribution in desa Mas and desa Batuan Kaler can be explained by the fact that a meeting of these banjars were visited and all the surveys were conducted there.

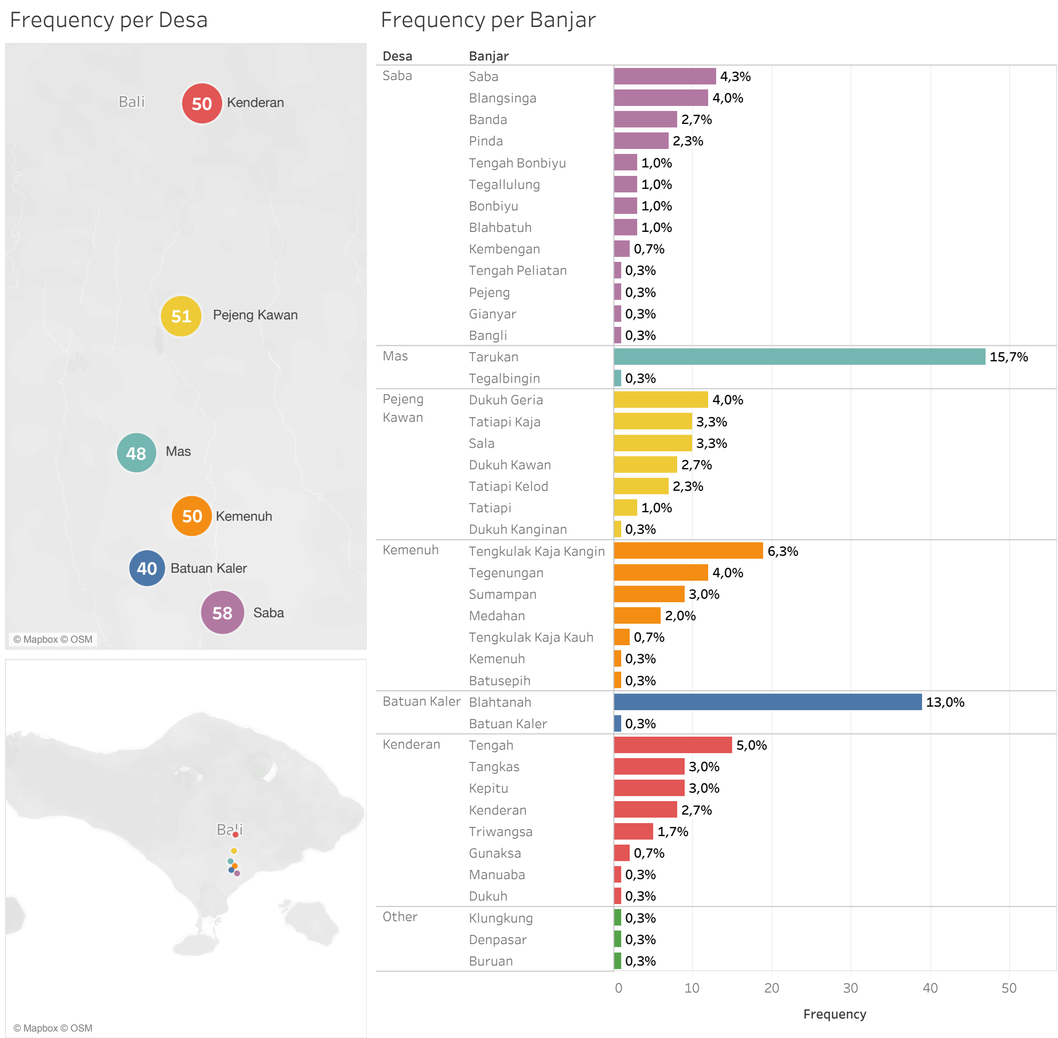

Figure 6.3: Distribution of Desas and Banjars of Residence (N=300)

6.8.2. Part 1: Socio-Demographic Information

The distribution of socio-demographic characteristics of the respondents include gender, age, educational level, income and household size. These are given in Table 6.3.

Table 6.3: Distribution of Socio-Demographic Characteristics (N=300)

Gender		**Net Income [Million IDR/month]**	
Male	65.7%	0 - 1,2	25.3%
Female	34.3%	1,2 - 4,6	26.3%
		4,6 - 14,2	2.3%
Age		>14,2	3.0%
13-17	3.7%	Does not know	21.7%
18-20	12.0%	Is not willing to tell	21.3%
21-30	32.3%		
31-40	21.7%	**Household Size**	
41-50	18.3%	1 - 3	9.3%
51-60	7.7%	4 - 6	60.0%
61-70	2.0%	7 - 10	19.0%
Missing	2.3%	11 - 20	10.3%
		21 - 42	1.3%
Education Level			
No Study	1.0%	**Household Size Without Children (Age <13)**	
Elementary School	4.7%	1 - 3	33.7%
Middle School	10.3%	4 - 6	46.0%
High School	49.7%	7 - 10	12.7%
College/University	31.7%	11 - 20	6.3%
Missing	2.7%	21 - 37	1.3%

Table 6.4 gives insight in the mean, median and mode of the numerical socio-demographic characteristics of the sample. Therefore, missing values are left out. Furthermore, 'income' is modified from ordinal data to ratio scaled values. This is done by taking the median of the ranges, while taking the lowest value of the highest income scale. The latter means that in this case the value 'more than 14.2 million IDR/month' is converted to 14.2 million IDR/month. Next, the mean, median and mode of the ratio scaled values are analysed, as can be seen below.

Table 6.4: Mean, Median and Mode of some Socio-Demographic Characteristics

	Age [years]	**Income [IDR/month]**	**Household Size**	**Household Size Without Children (Age<13)**
Mean	33.31	1,995,906	6.78	5.31
Median	31	1,700,000	6	4
Mode	21	1,700,000	6	4
N	293	171	300	300

6.8.3. PART 2: CURRENT WASTE MANAGEMENT INFORMATION

Information on the answers to the questions about the current used disposal method and corresponding costs and time can be found in Table 6.5.

Table 6.5: Distribution of Current Waste Management (N=300)

Plastic Disposal Method		**Disposal Time [min/day]**		**Plastic Disposal Costs [1000 IDR/month]**	
Self-Service	12.3%	0 - 1	29.7%	0 - 40	65.3%
Pick Up	71.0%	2 - 4	34.7%	40 - 80	10.7%
Burn	13.3%	4 - 6	14.0%	80 - 120	2.0%
Dump in River	0.0%	6 - 8	16.7%	120 - 160	0.3%
Dump on Land	2.3%	9 - 180	5.0%	Does not know/ prefers not to tell	21.7%
Public Garbage Can	1.0%				

Table 6.6 gives insight in the mean, median and mode of the numerical waste management char-

acteristics of the sample. Again, ordinal data is modified to ratio scaled parameter, using the same approach as in Table 6.4. Missing values are excluded from the analysis.

Table 6.6: Mean, Median and Mode of Disposal Time and Cost

	Disposal Time [min/day]	**Disposal Costs [IDR/month]**
Mean	5.37	28,000
Median	3	20,000
Mode	3	20,000
N	300	235

To create a PPF the results for used disposal method and costs are needed per desa. Therefore these results are also given per desa. Figure 6.4 shows the distribution of the current used disposal methods. Note that Table 6.3 and Figure 6.5 show six disposal methods, in contradiction to the four methods proposed in Chapter 5. To simplify the research model and further calculations, these six methods are merged to the four proposed methods: 'Dump in river' and 'Dump on land' are taken together as 'Dump', while 'Public garbage can' is assumed to be a part of 'Pick Up'. This results in the four proposed disposal methods: Self-Service, Pick Up, Burn and Dump.

What stands out from the charts is the vast amount of open burning in desa Kenderan. More on these remarkable results can be found in the discussion (Chapter 11). Figure 6.5 shows the distribution of disposal cost. Note that respondents who do not know or are not willing to tell their monthly costs, are excluded. As can be seen, most respondents have a monthly disposal cost of 0 - 40,000 IDR. Almost none of the respondents have a monthly disposal cost of more than 80,000 IDR. An explanation for this distribution is provided in the discussion (Section 11.4.1) as well.

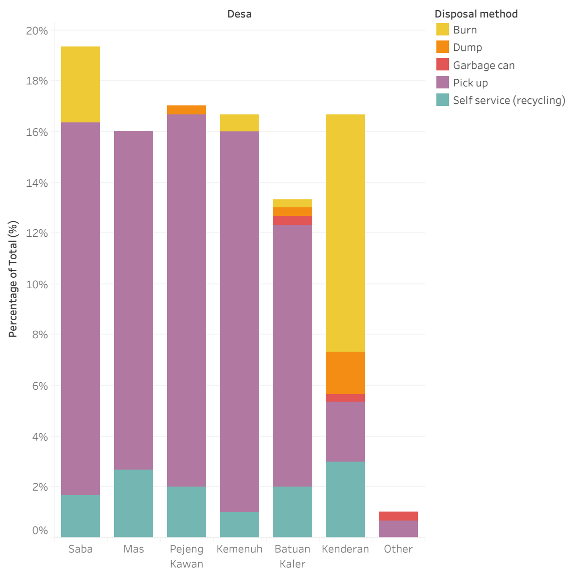

Figure 6.4: Distribution of Disposal Methods per Desa (N=300)

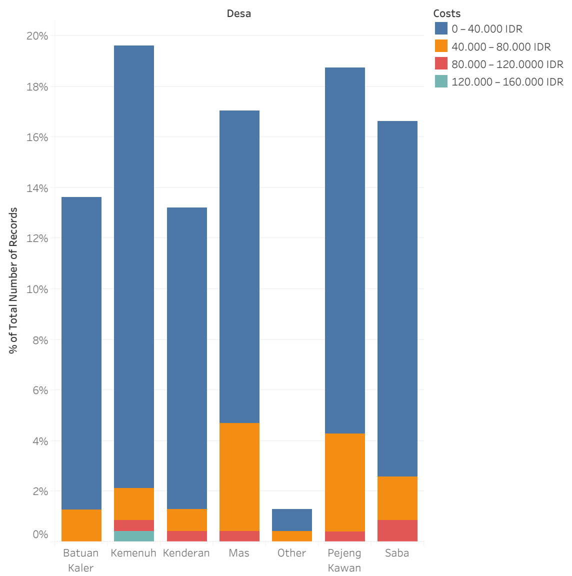

Figure 6.5: Distribution of Disposal Costs per Desa (N=300)

6.8.4. PART 4: ADDITIONAL INFORMATION

The responses to the first question of this part, about the associated environmental quality of the disposal methods, are visualised in the box plot in Figure 6.6. The green line resembles the median, the dots represent outlier observations and the upper and lower edge of the box represents the first and the third quartile of the responses respectively. The lines connected to the box represent a minimum or maximum observation, which is not considered a outlier.

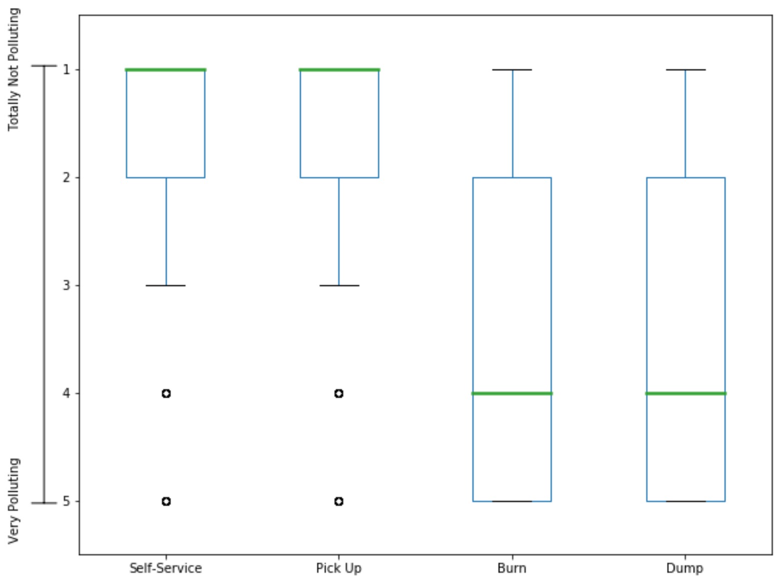

Figure 6.6: Boxplot of the Attitudes Regarding the Environmental Impact of the Disposal Methods.

As can be seen in Figure 6.6, most respondents consider Self-Service and Pick Up to be totally not polluting. Respondents that do consider these disposal methods as polluting or very polluting are considered as outlier observations. On the other hand, most respondents consider Burn and Dump to be polluting. Twenty-five percent of the respondents consider Burn and Dump as not polluting or totally not polluting.

The last question was on plastic waste production (PW-Production) per household. The distribution of the answers to this question is shown in Table 6.7. Responses are almost evenly divided over the three choice options.

Table 6.7: The Respondent's Perception of the Daily Plastic Waste Production of the Household

PW-Production per Household [g/d]	
~ 870 (Bag 1)	34%
~ 350 (Bag 2)	38%
~ 90 (Bag 3)	27%
< 90 (Less)	1%

Like the used disposal method and corresponding cost, the PW-production is also needed per desa for the establishment of the PPF. The option <90 g/d was only chosen by respondents living outside the six desas. Therefore, this option is not taken into consideration in Table 6.8. It can be seen that the distribution does differentiate between the desas.

Table 6.8: The Respondent's Perception of the Daily Plastic Waste Production of the Household per Desa

Desa	**870 g/d**	**350 g/d**	**90 g/d**
Saba	29%	37%	34%
Batuan Kaler	32%	41%	27%
Mas	40%	41%	19%
Kemenuh	35%	37%	28%
Pejeng Kawan	33%	35%	31%
Kenderan	35%	43%	22%

7

Part II: Production Possibility Frontier

A production possibility frontier (PPF) framework is developed. This PPF illustrates the trade-off between the current situation concerning the environmental quality and the economic activity: the plastic pollution in the Petanu river and the costs of waste management per household in the DAS Petanu, the catchment area of the Petanu river. These values are expressed in terms of Plastic Waste Load (PW-Load) and Impact on the Purchasing Power of a Household, respectively.

7.1. Overview Procedure PPF

To create a PPF, the following steps are performed:

1. **Calculate the PW-load (kg/day & g/s) in the Petanu river**: the PW-load in each river part of the Petanu river is calculated using a water quality model. The Plastic Waste Concentration (PW-Concentration) (g/m^3) is provided as well to gain more insight.
2. **Create scenarios:** Several scenarios are developed to construct the PPF. The baseline scenario, scenario 0, consists of the current plastic waste management situation. Four other scenarios are developed with either an improved system or no waste system.
3. **Create the PPF**: a curve is fitted through the five scenarios plotted on a graph with plastic waste load (environmental quality) on the x-axis and impact on purchasing power per household (economic activity) on the y-axis.

7.2. Plastic Waste Load in the Petanu River

In order to quantify the consequences of the waste management system on the Petanu river in Bali, a water quality model has been made. The objective of this model is to calculate the PW-load [1] in each part of the river. In this specific case the PW-Concentration in the Petanu river is provided as well. First the PW-load of each river part will be estimated and secondly this PW-load will be combined with the discharge to gain the PW-concentration. Since the development of scenarios makes use of the PW-load as parameter, an overview of both, the PW-Concentration and PW-load in each part of the river are presented as eventual result of this section: Figure 7.6 and Figure 7.7.

7.2.1. Fluxes Water Quality Model

A river is an incompletely mixed system, which can be simplified as a series of completely mixed systems, which implies that the quantity of interested is equally mixed over the volume. Seven so

[1] In the report, the PW-load will sometimes be provided in units of (kg/day), as well as (g/s). This intends to show the relationship between PW-load (kg/day) and PW-concentration (g/m^3). Furthermore, to improve readability, from now on the PW-load and PW-concentration will also possibly be presented without indication of the units.

called 'reactors' have been determined within the Petanu river. Within every reactor the specific PW-load and the discharge will be estimated based on the fieldwork and literature. A diagram of one single reactor is given in Figure 7.1. Δx Represents the length of the reactor along the direction of the river flow, while the flux $J_{Petanu,in}$ consists of the incoming discharge and incoming PW-load into the reactor from an upstream reactor or source. The flux $J_{Desa,in}$ represents the specific inflow of water and PW-load within the reactor reach. The flux $J_{Petanu,out}$ represents the discharge and PW-load out of the reactor. This will be the sum of flux $J_{Petanu,in}$ and $J_{Desa,in}$, since it has been assumed there is no decay in the amount of plastic possible, as plastic is assumed to be non-degradable in the short period of time it will be in a specific reactor. Therefore, the assumption of conservation of mass holds. To simplify the model even further, Step Loading of the plastic waste has been assumed. Step loading means that the loading rate changes from 0 to a constant value at a certain moment in time.

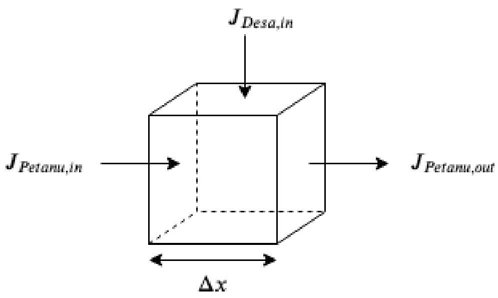

Figure 7.1: Diagram of One of the Simplified Reactors

7.2.2. DETERMINATION OF REACTORS

As can be seen in Figure 7.2 the proposed reactors have been based upon both: the researched desas and the river characteristics. First, the sources of the most upstream reactors have been numbered A till C. These sources represent the incoming plastic waste flux and incoming discharge from the areas upstream of those reactors. Second, the streams have been subdivided based upon the researched desa, e.g. in river reach 5 (Figure 7.2) the plastic waste input is coming from desa Mas [2]. The last division of reactors has been made on conjugation points in the river, i.e. location where the tributaries flow into the main channel. The corresponding sub-watersheds have been made based upon the digital elevation model of Bali (Figure 2.7). The considered reactors can be found below. The numbers and letters correspond to the numbers in Figure 7.2:

1. Reactor I: from A to 1. Focused around desa Kenderan.
2. Reactor II: from 1 to 2. Focused on approximately half of desa Pejeng Kawan.
3. Reactor III: from B to 2. Focused on the other half of desa Pejeng Kawan.
4. Reactor IV: from 2 to 4. Focused on desa Kemenuh.
5. Reactor V: from C to 3. Focused on desa Mas.
6. Reactor VI: from 3 to 4. Focused on desa Batuan Kaler.
7. Reactor VII: from 4 to 5. Focused on desa Saba.

Each reactor has a different length (Δx). These lengths have been determined with the help of QGIS and can be found in Table 7.1.

[2]Note that the incoming PW-load within a certain reactor is not solely originated from this single desa; more (non-researched) desas contribute to the load (Section 7.2.4)

Table 7.1: Length of Each Reactor

Reactor	Length [km]
Reactor I	6.24
Reactor II	4.38
Reactor III	6.19
Reactor IV	8.88
Reactor V	3.46
Reactor VI	3.59
Reactor VII	5.39

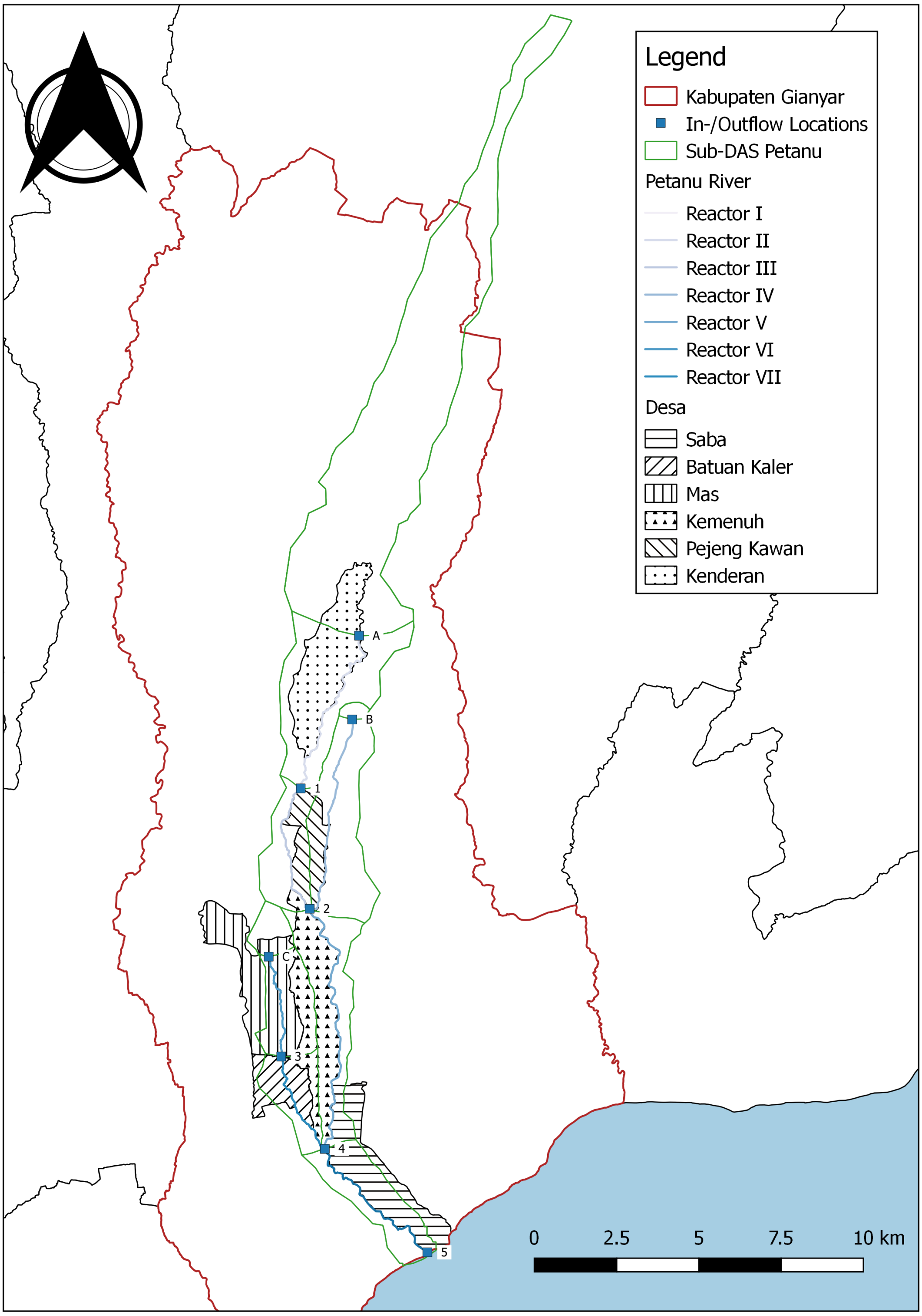

Figure 7.2: Division of the Petanu River in Reactors and Sub-Watersheds

7.2.3. DISCHARGE CALCULATION

Calculating the discharge of the several river reaches of the Petanu river is done by using the information of a single stream gauge in the Petanu river. This is the only available information source regarding the discharge in the system. The stream gauge is located at location 2 just after the confluence of the two river streams. The baseflow at this point is approximately 2 m^3/s, while the peakflow, as a result of heavy rainfall, is at most 10 m^3/s [33].

Moreover, Ocean Mimic organises beach clean-ups and based upon their records (Figure 7.3), it can be seen that most plastic is transported by the river at the start of the rainy season. A small sidenote should be placed upon this data as the amount of kilograms also depends on the amount of participants in the clean-up. However, the increase in collected plastic in December is a lot larger, so it can be concluded that rainfall plays an important roll in the amount of plastic in the river.

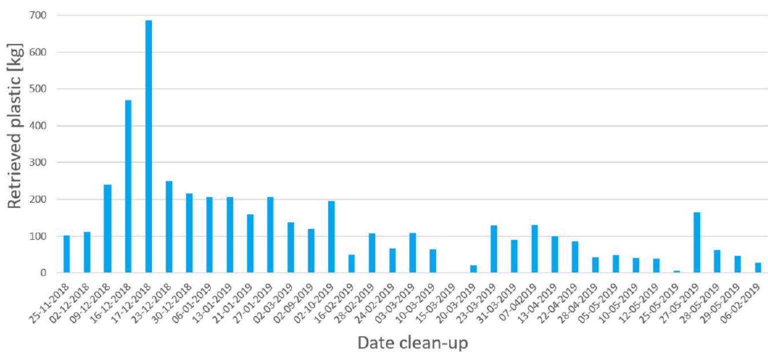

Figure 7.3: Data Beach Clean-Ups Ocean Mimic [105]

The large difference in the amount of plastic on the beaches between rainy and dry circumstances is also confirmed visually during the fieldwork. In Figure 7.4 it can be seen that the beach at desa Saba was relatively clean before the rainfall event (Figure 7.4), while the day after (Figure 7.5) the beach was completely loaded with waste. Moreover, Lebreton *et al.* [9] determined that the plastic input in oceans from Asia is the highest during the East Asian monsoon. Given these multiple corresponding observations, the discharge calculation at every inflow location will be based upon the peak flow of 10 m^3/s at location 2.

Figure 7.4: Beach at Desa Saba Before the Rain

Figure 7.5: Beach at Desa Saba After the Rain

The discharge within each separate reactor can be calculated using the relative catchment areas of each reactor and the discharge at location 2. The catchment areas have been calculated with the help of QGIS and are presented in Table 7.2. First the incoming and outgoing discharge of each river reach is calculated, without taking into account the subdivision based upon the researched desas. In other words, the flow in the main river reaches: A-2, B-2, 2-4, C-4 and 4-5 will be calculated. Afterwards the inflow at every location can be calculated, leading to the discharge in each reactor.

To simplify these calculations it has been assumed that there is no inflow from groundwater within the considered river reaches.

FLOW MAIN RIVER REACHES

Using the catchments given in Table 7.2 the area ratio of river reach A-2 compared to river reach B-2 is 53.537 : 9.502. Both together produce a discharge of 10 m^3/s. Applying the area ratio, this leads to a peakflow of 8.49 m^3/s at the end of river reach A-2 and a peakflow of 1.51 m^3/s at the end of river reach B-2. Since there has been assumed that there is no additional inflow from the groundwater, the peakflow at the beginning of river reach 2-4 is also 10 m^3/s. To calculate the peak flow at the end of river reach 2-4 the area of river reach 2-4 has to be compared to the catchment area of location 2, i.e. the catchment of the river upstream of location 2. This ratio is 63.039 : 8.321. This means the inflow from the catchment of the river reach 2-4 is equal to 1.32 m^3/s. Thus, the peak flow at the end of river reach 2-4 is equal to 11.32 m^3/s. This procedure is repeated for river reach C-4. The area ratio between river reach C-4 and the main channel is 10.056 : 71.360. This means that the peakflow in river reach C-4 equal is to 1.60 m^3/s. Hence, the peakflow at the beginning of river reach 4-5 is equal to 12.92 m^3/s.

Table 7.2: Needed Catchment Areas for Calculation Baseflow

Location	**Catchment [km^2]**
River reach A-2 and upstream of A	53.537
River reach B-2 and upstream of B	9.502
River reach 2-4	8.321
River reach A-2,B-2 and upstream of A and B	63.039
River reach A-2, B-2, 2-4 and upstream of A and B	71.360
River reach C-4 and upstream of C	10.056

DISCHARGE AT EVERY IN- AND OUTFLOW LOCATION

The above procedure was repeated for every distinct sub-catchment. The results and all needed information can be found in Table 7.3. The numbers and letters correspond to the fluxes $J_{Petanu,in}$ and $J_{Petanu,out}$ and the reactors correspond with the flux $J_{desa,in}$. In other words, the numbers and letters correspond to a (sub-)catchment, and the reactors to a runoff area, which is defined as the area from which the runoff (surface flow) ends up in that particular part of the river.

Table 7.3: All Discharges Needed for the Water Quality Model

Location/Reactor	**Catchment/Runoff Area[km^2]**	**Discharge [m^3/s]**
Location A	37.684	5.97
Reactor I	11.016	1.75
Location 1	48.700	7.72
Reactor II	4.837	0.77
End River Reach A-2	53.537	8.49
Location B	0.377	0.06
Reactor III	9.125	1.45
End River Reach B-2	9.502	1.51
Location 2	63.039	10.00
Reactor IV	8.321	1.32
End River Reach 2-4	71.360	11.32
Location C	1.597	0.25
Reactor V	4.616	0.73
Location 3	6.213	0.98
Reactor VI	3.843	0.61
End River Reach C-4	10.056	1.59
Location 4	81.416	12.91
Reactor VII	5.750	0.91
Location 5	87.166	13.82

7.2.4. PLASTIC WASTE LOAD CALCULATION

The PW-loads per reactor and per source location (A, B and C) are calculated. First, each contributing desa in the total catchment area of the Petanu river is determined. Secondly, the PW-load per desa is calculated, after which a PW-load per reactor or source location can ultimately be estimated [3]. The final results could be found in Table 7.6.

CONTRIBUTING DESAS

The desas that are researched in the survey (Saba, Batuan Kaler, Mas, Kemenuh, Pejeng Kawan and Kenderan) do not solely contribute to the PW-load in the Petanu river, since there are more desas located in the catchment area. These 'non-researched' desas add to the PW-load in the river as well. They should therefore be included, however the calculation of the PW-load per desa is done differently for these non-researched desas compared to the six researched desas. An overview of all contributing desas can be found in Table 7.5.

RESEARCHED DESAS

To calculate the PW-load of the six researched desas the following steps are performed:

1. The PW-production per desa is estimated. This is done by multiplying the average PW-production per household in a certain desa by the total number of households in that desa in 2016 [36–38, 41, 42]. The average PW-production per household is provided by the results of the survey.

2. The percentage of the PW-production that is disposed in a certain way is determined. These fractions are also obtained from the survey results.

3. Each of the four disposal methods is characterised by a certain percentage of the PW-production that ends up in the river as PW-load. These percentages can be found in Table 5.1 and are 4.6%, 6.5%, 25% and 100% for Self-Service, Pick Up, Burn and Dump, respectively.

4. Combining the percentages of step 2 and step 3, the resulting PW-load per desa is calculated. For example: in desa Saba 18 % of the PW-production is burned according to the survey results. Table 5.1 shows that 25 % of the burned plastic ends up as PW-load in the river. Meaning that 25 % of 18 % of the PW-production in Saba ends up in the river as a result of plastic waste burning in the desa. Repeating this calculation for the other disposal methods results in an accumulated PW-load per desa.

5. The percentage of the desa that is located within the DAS Petanu river is determined. This is called the Area Correction Factor (ACF) and differs per desa. This value is combined with with step 4 to determine the resulting PW-load entering the Petanu river.

The results of these steps can be found in Table 7.4. Specifically the results of step 1 (PW-production), Step 4 (percentages of a certain disposal method and step 5 (total PW-load) are showed. Note that the PW-load indicates the PW-load in the DAS Petanu river, due to the desa.

Table 7.4: Plastic Waste Production (PW-Production) [kg/day] and Total Plastic Waste Load (Total PW-Load) in the DAS Petanu [kg/day] per Researched Desa.

Desa	**PW-Production**	*Self-Service*	*Pick Up*	*Burn*	*Dump*	**Total PW-Load**
Saba	834.8 kg/day	10 %	70 %	18 %	2 %	64.0 kg/day
Batuan Kaler	370.3 kg/day	16 %	78 %	3 %	3 %	28.0 kg/day
Mas	1517.8 kg/day	6 %	90 %	0 %	4 %	79.0 kg/day
Kemenuh	1072.7 kg/day	6 %	90 %	4 %	0%	76.4 kg/day
Pejeng Kawan	321.8 kg/day	6 %	93 %	0 %	1 %	23.6 kg/day
Kenderan	800.5 kg/day	20 %	14 %	57 %	9 %	200.7 kg/day

[3] Note that the PW-load does not necessarily have to be equal to the (later mentioned) Plastic Waste Production (PW-Production), since probably not all produced plastic waste will end up in the river due to managing of waste and because some desas are not fully located in the DAS Petanu.

'NON-RESEARCHED' DESAS

Since the survey does not provide data regarding the other, 'non-researched', desas in the catchment area, another approach to calculate their associated PW-load is needed. According to a report on the management of kabupaten Gianyar, an average person in the region produces 0.38 kg waste per day, from which 17.08 wt. % is plastic waste [27]. Given the population per desa [36–38, 41, 42], the PW-production per desa can be calculated. Furthermore, the Bali Partnership provides information about the average percentage of the PW-production in Bali that ends up in the river system (33%) or is burned (19%) [11]. Since there will always be a residue of plastic waste after burning, it is assumed that 25% of the burned plastic waste still ends up in the river [57], meaning that on average in Bali 37.8% (= 25% * 19% + 33%) of the produced plastic waste will get into the river as PW-load. Following this procedure, the PW-load of each separate 'non-researched' desa can be estimated. Lastly, the percentage of the PW-load that ends up in the Petanu river was determined by looking at the percentage of the desa that is located in the DAS Petanu. The results of these calculations, together with the PW-load in the Petanu river of the researched desas, are provided in Table 7.5. The table shows the PW-load in units of [g/s] as well. The underlying assumption of this value is an equal division of PW-load over a day (24 hours).

Table 7.5: Overview of the Plastic Waste Production (PW-Production) [kg/day] and the Plastic Waste Load Entering the Petanu River (PW-Load) [kg/day & g/s] per Desa, Separated in Researched Desas and 'Non-Researched' Desas

Desa	**PW-Production [kg/day]**	**PW-Load [kg/day]**	**PW-Load [g/s]**
Researched Desas			
Saba	834.8	64.0	0.74
Batuan Kaler	370.3	28.0	0.32
Mas	1516.8	79.0	0.91
Kemenuh	1072.7	76.4	0.88
Pejeng Kawan	321.8	23.6	0.27
Kenderan	800.5	200.7	2.32
'Non-Researched' Desas			
Pupuan	430.6	162.5	1.88
Sebatu	549.5	107.5	1.24
Kedisan	351.2	128.1	1.48
Tegallalan	593.7	81.1	0.94
Batuan	741.2	65.3	0.76
Sukawati	961.2	119.3	1.38
Tampaksiring	630.2	131.9	1.53
Sanding	203.0	62.2	0.72
Pejeng Kaja	334.2	126.2	1.46
Pejeng	397.6	145.9	1.69
Pejeng Kangin	319.4	32.7	0.38
Manukaya	721.5	45.3	0.52
Bedulu	609.8	118.6	1.37
Peliatan	584.5	161.0	1.86
Pengotan	233.7	5.6	0.06
Tiga	430.4	7.9	0.09
Sekaan	108.0	29.4	0.34
Bayung Gede	125.7	8.6	0.10
Batur Tengah	178.2	4.5	0.05

PLASTIC WASTE LOAD PER REACTOR AND PER UPSTREAM AREA

The PW-load per desa is used to calculate the PW-load into the reactors (reactors as proposed in Section 7.2.2) and at the locations A, B and C, which could be found in Table 7.3. Both the reactors and locations are shown in Figure 7.2. The PW-load at locations A, B and C is the accumulation of all PW-load into the upstream catchment areas of those locations. For the sake of clarity: the PW-load into a reactor is represented by $J_{Desa,in}$ in Section 7.2.1 and the PW-load at locations A, B and C by $J_{Petanu,in}$ of the most upstream reactors.

The specific PW-load of each desa could contribute to the PW-load of one or more reactors or upstream catchment areas, since a single desa can be located in several runoff areas or catchments. Therefore, three steps are needed to estimate the PW-load per reactor/location. First, the percentages of each desa located in the runoff area/catchment of a certain river reach are determined. This is done by using QGIS. Secondly the PW-load of each desa is divided over the runoff areas/catchments, correspondingly to the percentage of the desa that is located in the particular area. At last, the accumulation of these plastic waste loads per runoff area/catchment results in the PW-load per reactor/location. Note that in all these steps is assumed that the population density is equal in the whole area of one desa. Table 7.6 shows the results of these calculations. The PW-load at the outflow of the Petanu river, which is in fact the accumulation of the plastic waste flows at each reactor and location, is presented as well. In Appendix I the detailed elaborations of above steps could be found.

Table 7.6: Plastic Waste Load (PW-Load) per Reactor and per Location (A, B and C) and the PW-Load at the Outflow of the Petanu River

Reactor/Location	**PW-Load [kg/day]**	**PW-Load [g/s]**
Reactor I	338.74	3.92
Reactor II	117.76	1.36
Reactor III	325.21	3.76
Reactor IV	140.45	1.63
Reactor V	84.46	0.97
Reactor VI	91.43	1.06
Reactor VII	180.98	2.09
Location A	655.28	7.58
Location B	12.64	0.15
Location C	68.59	0.79
Outflow Petanu River	**2015.53**	**23.33**

7.2.5. MODELLED PLASTIC WASTE CONCENTRATION AND PLASTIC WASTE LOAD

Finally, as the step loading and the discharge in every reactor and at every location are known, the PW-concentration in the Petanu river can be modeled. To do so, the law of conservation of mass [4] is needed. The mass balance corresponding to Figure 7.1 can be seen in Equation 7.1.

$$V\frac{\delta c}{\delta t} = J_{Petanu,in} \cdot A_c - J_{Petanu,out} \cdot A_c + W_{Desa,in} \tag{7.1}$$

The mass fluxes in the case of a diffusive sytem, like a river, are given by Fick's first law: $J = -D\frac{\delta c}{\delta x}$, which means that the concentration of plastic changes both in time and in space. However, the transport of plastic in the river only consists of advective transport, which in this case means that the transport of plastic is only due to the displacement of water. Therefore, Equation 7.1 can be simplified to Equation 7.2.

$$Q_{Petanu_i,in} \cdot W_{Petanu_i,in} - Q_{Petanu_i,out} \cdot W_{Petanu_i,out} + Q_{Desa_i,runoff} \cdot W_{Desa_i,dumped} = 0 \tag{7.2}$$

In Equation 7.2, Q stands for the water flux (m^3/s) and W for the Pw-load entering the river, which from now on is expressed in (g/s). This means that the concentration within every reactor can be calculated with Equation 7.3. Note that step loading is assumed, hence the concentration within the whole reactor is constant.

$$C_{Reactor_i} = Q_{Petanu_i,in} \cdot W_{Petanu_i,in} + Q_{Desa_i,runoff} \cdot W_{Desa_i,dumped} \tag{7.3}$$

[4] The law of conservation of mass states that for any closed system, the mass of the system must remain constant over time

In Figure 7.6 the result of modelling the Petanu river with the above equation is given. Due to the absence of measurements of the PW-concentration in the whole Petanu river, it is not possible to validate this model. Nevertheless, the model gives a good indication of the locations where improvement of the waste management system could result in the largest improvement of the environmental quality. It can be seen that at the downstream end of the Petanu river, the PW-concentration is as high as 64 g/m^3.

Figure 7.7 presents the PW-loads per river reach, which are equal to the values provided in Table 7.6. The PW-load at the downstream river end is 2015.5 kg/day.

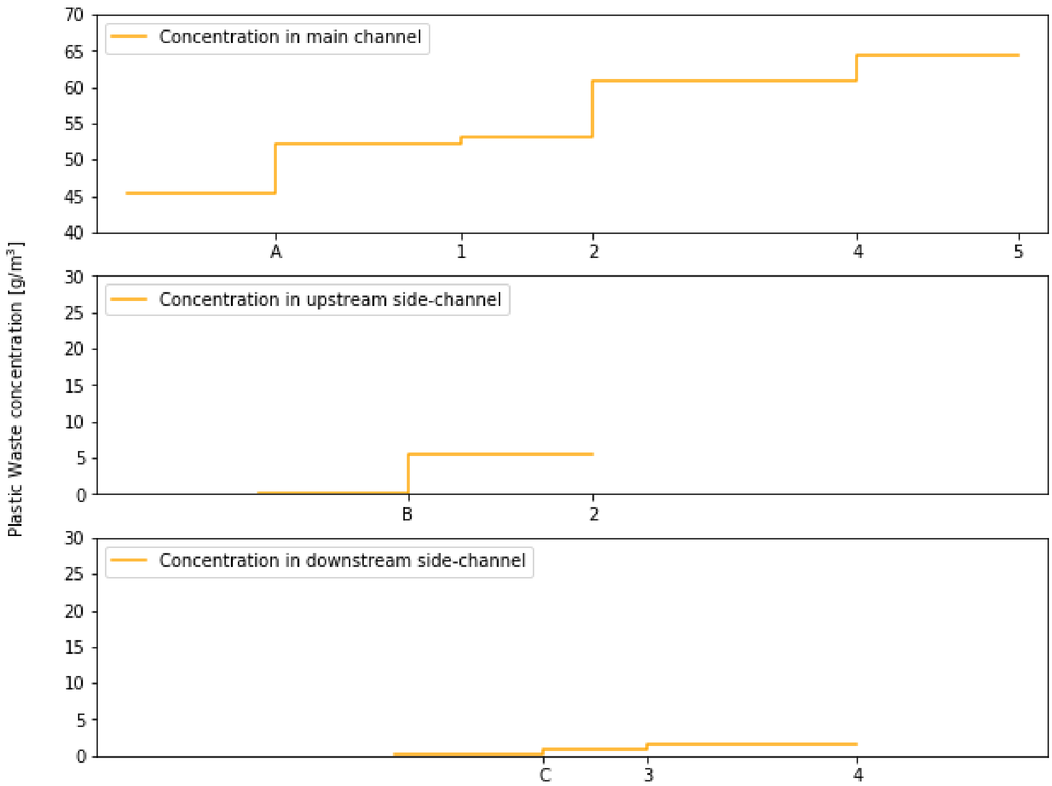

Figure 7.6: Modelled Plastic Waste Concentration in the Petanu River

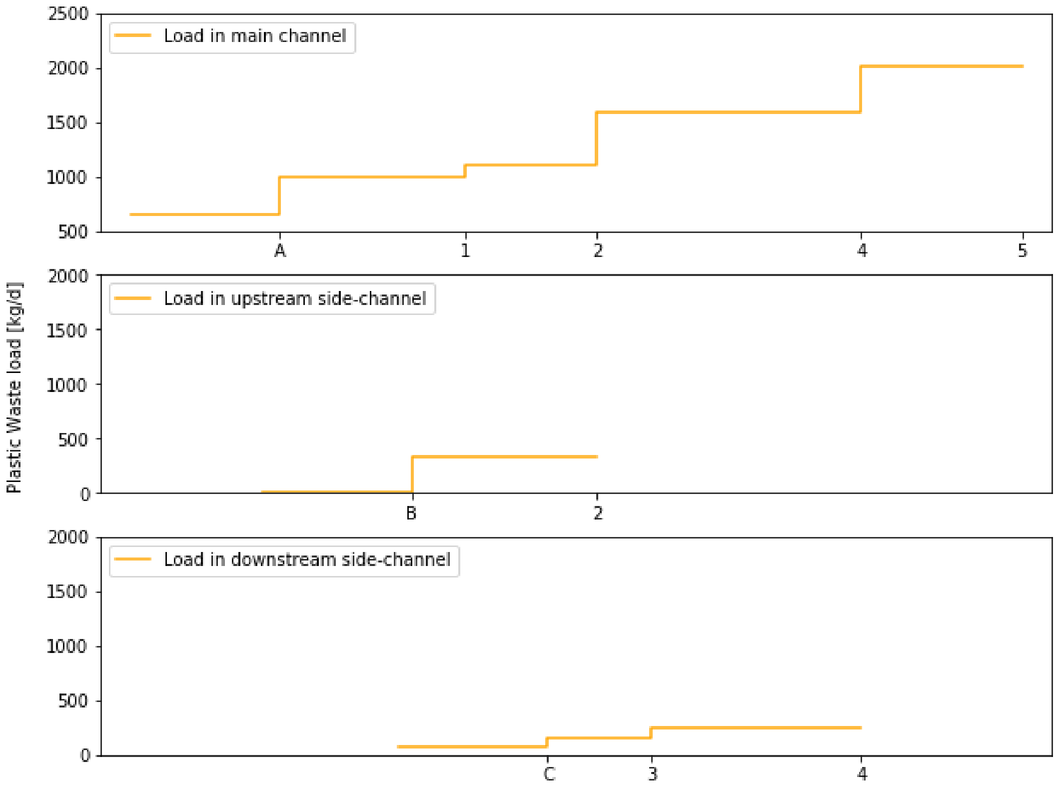

Figure 7.7: Modelled Plastic Waste Load in the Petanu River

7.3. SCENARIOS

As said before, this research focuses on the impact of the improvement of the current waste management system on the PW-concentration/PW-load solely. To determine the associated environmental quality of increasing the collection of (plastic) waste and/or the establishment of more recycling facilities, i.e. the reduction of plastic pollution, and the corresponding cost for the households, multiple scenarios will be established. These scenarios will be used to create the PPF. Literature provides in general two efficient ways to improve the waste management system; 1) ease and increase the collection of plastic waste, i.e. increase the amount of garbage trucks and pick up the waste at the doorstep of local people and 2) create value from plastic waste like what is done with a recycling facility [10, 106]. The creation of the scenarios will therefore be based on these types of improvements.

For the set-up of the scenarios the current situation, scenario 0, will be the baseline and by adding or subtracting waste management elements, four other scenarios are created. The scenarios are constructed in such a way that a clear distinction between efficient and inefficient scenarios will arise: scenario 1 represents the situation without waste management, scenario 2 presents an efficient situation using some more bank sampahs (recycling facilities), scenario 3 provides an efficient way of adding garbage trucks to the system and scenario 4 provides a very inefficient way to do so. The difference in efficiency between the scenarios is needed to plot a useful PPF.

First, the elements used to build-up the scenarios are introduced, after which scenario 0 will be elaborated. Finally the four other scenarios will be described. Note that during the build-up and interpretation of the following scenarios, the plastic waste in the river will be expressed in terms of PW-load [kg/day] instead of PW-concentration [g/m^3].

7.3.1. ELEMENTS SCENARIOS

The scenarios, which are the foundation of the PPF curve, are created using elements. These elements are elements of the waste management system which could lead to an increase or decrease of plastic pollution. All introduced elements are already existing in the current waste management system of kabupaten Gianyar and will only be increased or decreased in numbers to create scenarios. As a result, all of the information used in this paragraph is introduced in Chapter 3 and 4. The associated costs and environmental quality (reduction in plastic) of the elements are summarised in Table 7.7. The elaboration of the numbers is done in the following subsections.

'Operational Costs' are defined here as the costs that need to be covered by the payment of the users of the service and/or to run the operation of the element. The 'Investment Costs' on the other hand are normally paid by the government and are meant to install the element, however within the presented scenarios it is assumed that all additional costs (operational and investment costs) of added elements will be fully paid by the households either directly or indirectly via taxes.

The scenarios are based upon the decentralised waste management system in Bali [21]. Decentralisation means that every desa needs to organise their own waste management services and thus, in the case with these elements, the system is not as efficient as possible. This is because the elements often have a higher maximum capacity than which is needed in a desa. This leads to trucks or facilities not being in use every day. It also results in general in relatively less efficiency when using more elements. This effect can be seen in the elaboration of the different scenarios.

Table 7.7: Overview Costs and Reduction Plastic Pollution per Element.

Disposal Method	**Elements**	**Investment Costs [Million IDR/month]**	**Operational Costs [Million IDR/month]**	**Plastic Reduction [kg/d]**
Pick Up	Truck	2.92	31.731*	462 **
	TPS3R***	0.33	10.5	-
Self-Service	Bank Sampah	0.2	3.0	12.7

* These operational cost are in case the garbage truck operates every day of the month.
** 6.5 % of the load is illegally dumped in the environment.
*** Note that for every two trucks a new TPS3R is needed.

GARBAGE TRUCKS

An option to increase the percentage managed waste is to increase the solid waste collection capacity by increasing the number of garbage trucks. It is known from the interview with I Wayan Subawa (Appendix E) that one truck has on average a cargo box of 6 m^3, although most of the time the trucks are filled up more than the official maximum load of the cargo box (Figure 4.12). Therefore, it is assumed that 9 m^3 waste per trip is collected. This equals approximately 1350 kg of waste per trip [27]. 17.08% of the weight of the average household waste is plastic in kabupaten Gianyar [27]. Since only 8% of the people in kabupaten Gianyar is sorting their waste, it can be assumed that the material ratio for the collected waste is the same as the produced waste and, thus, also 17.08% of the waste in a truck consists of plastic [27]. Hence, it is assumed that approximately 231 kg of plastic is transported in one garbage truck.

According to I Wayan Subawa (Appendix E) every truck can carry out two trips a day. In other words: 462 kg of plastic waste can potentially be collected every day. However, in Bali the waste management service is decentralised, which means that every desa has its own waste management service and associated truck. As a result, the average collection per day can in practice deviate significantly from the 462 kg/day. Furthermore, a truck would collect the waste in a whole desa at once, however not the whole area of a desa is necessarily located within the DAS Petanu. Therefore, the PW-load reduction of one additional truck is not equal to the average daily plastic weight that is collected by that truck. Lastly, part of the collected waste is illegally dumped. Research of Widyarsana *et al.* [16] showed that 6.5% of the waste that is collected by a truck ends up in the environment. The above information provides some challenges during calculation of the scenarios, which will be elaborated upon in the corresponding sections.

The acquisition costs of a single truck are 350 million IDR, i.e. approximately 23,000 euro (Appendix E). It is assumed that a truck has an operational lifetime of 10 years [60]. This means that the monthly investment costs would be 2.92 million IDR. A single trip needs at least 20 liters of petrol and 1 liter petrol costs at this moment in time 8820 IDR [107]. Hence, 352,800 IDR is needed to pay for the petrol every day a truck operates (2 trips is equal to 40 liter). This means that the monthly petrol costs are on average 10,731,000 IDR, if the truck operates every day. Furthermore, the driver and the two workers of the truck earn approximately 2 million IDR per month if they operate twice a week (Appendix E). This means that if they would operate full-time their monthly salary would be 7 million IDR per person. In other words: the monthly full-time wage of the three employees is 21 million IDR. In total the monthly operational costs are 31,731,000 IDR, exclusive maintenance. It is assumed that maintenance is not covered by the income of the prices the users of the service pay, but by governmental support and therefore it is not of interest in the model.

TPS3R

Dinas Lingkungan Hidup Kabupaten Gianyar [27] identified that not only garbage trucks are limited but also transportation facilities. One of those facilities, which are preferred by the DLHK of kabupaten Gianyar, is the TPS3R. At this moment, there is only one TPS3R facility in the Gianyar regency, which means that as soon as there are more trucks in place, new TPS3R facilities need to be build.

The calculation of associated costs and waste processing capacity of the TPS3R is based upon the existing TPS3R in desa Sanur Kauh (Appendix C). At this moment 3.4 tonnes of waste is processed every day while making profit. There are two desas connected to this TPS3R, meaning that it will be assumed that for every two trucks one TPS3R is needed. The users of the TPS3R pay approximately 30,000 IDR per month to make use of its service. In total 350 households are connected to the TPS3R which means the TPS3R receives 10.5 million IDR per month from its users. Therefore, the assumption has been made that a TPS3R needs 10.5 million IDR per month from its users in order to operate; the operational costs.The acquisition costs of a TPS3R are 100 million IDR [58, 59] and its lifespan is assumed to be 25 years. This means the monthly investments costs are equal to 0.33 million IDR.

BANK SAMPAH

Besides the pick up of waste by a garbage truck, it is possible to bring recyclable plastic to a waste bank, i.e. bank sampah. Furthermore, as stated in chapter 4, bank sampahs only accept PET plastic, besides other recyclables like paper and glass. Hence, the other types of plastic in the household waste can not be brought to a bank sampah. Approximately 30% of the plastic waste of Balinese people is PET [19]. Moreover, of the 0.38 kg waste production per person per day, 0.065 kg is plastic (17.08%) [27]. This means that 0.019 kg PET plastic waste is produced per person per day in Gianyar. Looking at data from Denpasar on average 130 households are connected to one bank sampah [65]. As on average a household in Gianyar consists of five people [27], a bank sampah connected to 130 households collects 12.7 kg PET plastic every day. This will be assumed as the plastic waste processing capacity of a bank sampah.

Bank sampahs are often sponsored by external companies or NGOs, however without the help of an external sponsor they are estimated to have an investment requirement of 60 million IDR [66]. A bank sampah has an installment of 25 years approximately, resulting in a monthly investment costs of 0.2 million IDR. Besides these costs, there is often one person working at a bank sampah, who earns on average approximately 3 million IDR (Appendix C). It has been assumed that this person is paid with money retrieved from tax that is paid by local inhabitants. Besides that, bank sampahs are profitable on itselves and consumers get money from the bank if they use the service. As a result the operational costs are limited to 3 million IDR per month.

7.3.2. SCENARIO 0: CURRENT SITUATION

Scenario 0 is based on the current situation and is therefore considered to be the baseline scenario. Furthermore, some parameters within the current situation are used to build-up the other scenarios: 1, 2, 3 and 4. The PW-load in the river in the current situation is 2015.5 kg/day, as stated in Table 7.6. This flux is the result of each disposal method, including dumping, the residue of burning and illegal dumping by the garbage trucks. For the help of making each scenario, the following parameters about the current situation are determined:

1. The current amount of plastic which is dumped or burned by the households contributing to the DAS Petanu, i.e. Mismanaged Plastic Waste at Household level (MPWH).

2. The current PW-load in the river because of dumping and burning by the households, i.e. Mismanaged Plastic Waste Load at Household level ending up in the Petanu ($MPWLH_{Petanu}$). *Note: this value is not equal to the PW-load, since illegal dumping by garbage trucks is excluded.*

3. The factor which represents the ratio between the PW-load in the river due to dumping and burning ($MPWLH_{Petanu}$) and the total amount of plastic waste due to dumping and burning (MPWH), i.e. the Reduction Factor of the MPWH (RF_{MPWH}).

4. The number of households within the DAS Petanu.

5. The average costs per household of the current waste management system.

6. The total PW-production within the DAS Petanu.

MPWH The total MPWH is determined for all the desas which are located in the DAS Petanu. MPWH is defined as the amount of plastic waste that is either burned or dumped at household level. The MPWH is required to determine the quantity of plastic waste which could in theory be picked up in the current situation and differs from the PW-load, since the latter includes illegal dumping by the trucks. Of the 25 desas which are (partially) within DAS Petanu, only for six desas the burning and dumping ratios are known from the survey. For the other desas the percentages of 19% burning and 33% dumping are used (Figure 4.1). The ratio between these values tells us that it can be assumed that on average 37 % of the MPWH is burned and 63% of the MPWH is dumped within these desas. For each of the desas, the area located within the DAS Petanu is determined individually using the area correction factor (ACF). It is assumed that the population density distribution within the desas is constant. For each of the desas the number of households within the DAS Petanu can be determined, and thus the total number of households within the DAS. In this way, the MPWH per desa conributing to the DAS Petanu is determined, resulting in a total MPWH of 2861.1 kg/day within the DAS Petanu for all desas combined. 4.8% of the MPWH is PET, which is 137.3 kg/day.

$MPWLH_{Petanu}$ The current PW-load in the DAS is 2015.5 kg/day, which includes illegal dumping by the trucks. To calculate how much of the PW-load is due to the mismanagement (i.e. dumping or burning) of plastic by the households, the $MPWLH_{Petanu}$ for each of the desas is determined. Per desa the MPWH is known. The fraction of burnt plastic which does not end up in the river is 75%. For each of the desas the amount of burned plastic is then multiplied by 0.25, because 25% of the burned plastic will end up in the river. The amount of dumped plastic is added to this and by multiplying with the ACF per desa, the plastic which is dumped or burned by the households per desa is determined. The accumulation of these values leads to the total $MPWLH_{Petanu}$, which is 1822.3 kg/day, and is equal to the PW-load excluding illegal dumping by trucks. Moreover, note that the difference between MPWH and $MPWLH_{Petanu}$ is explained by the percentage of the burnt plastic waste that does not ends up in the river. In this way it can also be shown that the illegal dumping by trucks in scenario 0, the current situation, amounts 193.2 kg/day.

RF_{MPWH} Since now the MPWH and $MPWLH_{Petanu}$ are known, the RF_{MPWH} can be calculated with the help of Equation 7.4. This factor represents the ratio between $MPWLH_{Petanu}$ and MPWH and is an important factor to calculate the effect of adding or removing waste management elements in upcoming scenarios.

$$RF_{MPWH} = 1822.3/2861.1 = 0.6369 \tag{7.4}$$

Households To calculate the number of households within the DAS Petanu, the ACF per desa is used, under the assumption that the population density is constant in all desas. The sum is taken of the number of households within the DAS Petanu for each desa. This results in a total number of households of 21,968 within the DAS.

Average Current Cost per Household In the survey the respondents were asked what they pay on a monthly basis for waste disposal. For each of the six desas the average costs are determined. In Table 7.8 an overview is given of the waste disposal costs per household within the six desas. Taking the weighted average of these costs (accounting for the number of households in a desa), the average waste management costs per household for the DAS Petanu can be determined: 29,101 IDR/month. In this estimation of the weighted average, it is assumed that the six desas are representative for the total area, which is quite justified given the small variation in costs between the desas.

Table 7.8: Determination of Waste Management Costs

Desa	Respondents* [#]	Average Cost per Household [IDR/month]	Households [#]	Total Cost [IDR/month]
Saba	43	27,441	2031	$557 \cdot 10^5$
Batuan Kaler	30	24,000	830	$199 \cdot 10^5$
Mas	40	35,000	3001	$105 \cdot 10^6$
Kemenuh	45	27,111	2355	$668 \cdot 10^5$
Pejeng Kawan	44	30,000	731	$219 \cdot 10^5$
Kenderan	29	25,517	1694	$432 \cdot 10^5$

* The number of respondents that filled in 'I do not know' or 'I don't want to say' are excluded.

Total PW-Production The total plastic waste production within the DAS is calculated by using the total plastic waste production in the desas and applying the ACF per desa. This results in the plastic waste production in the DAS per desa. Taking the sum of the plastic waste production per desa within the DAS gives a value of 7915.3 kg of plastic waste per day.

Scenario 0 in the PPF From the above information scenario 0 can be constructed. This scenario is characterised by a PW-load of 2015.5 kg/day and average costs of waste management per household of 29,101 IDR/month. To compare the scenarios with each other, a new parameter is introduced: the Plastic Waste Load Reduction (PWLR). It represents the difference in PW-load between scenario 0 and the situation of interest. Since scenario 0 is baseline, the PWLR amounts currently 0 kg/day.

7.3.3. SCENARIO 1: NO WASTE MANAGEMENT SERVICES

Scenario 1 presents the virtual situation of no waste management service. In this case, the total waste management in kabupaten Gianyar is ceased. It is assumed that this will lead to zero costs of waste management per household.

The total PW-production in the DAS and the factor RF_{MPWH}, both obtained in Section 7.3.2, are used to calculate the corresponding PW-load. When there is no waste management, it assumed that MPWH is equal to the total PW-production in the DAS; all of the waste is either burned or dumped. Assuming that the ratio between the fraction burned plastic waste and fraction dumped plastic waste stays constant, the factor RF_{MPWH} stays constant as well. This results in the PW-load being equal to the 'new' $MPWLH_{Petanu}$, so multiplying the PW-production of 7915.3 kg/day by the factor RF_{MPWH} results in the PW-load: 5041.4 kg/day.

In this way the total PW-load associated to scenario 1 is 5041.4 kg/day, the PWLR is -3025.9 kg/day and the waste management costs per household are zero.

7.3.4. SCENARIO 2: ADDITIONAL BANK SAMPAHS

In scenario 2, the consequences of adding a certain amount of bank sampahs to scenario 0 are investigated. Since bank sampahs only process PET, the maximum amount of bank sampahs that virtually can be added to the system is obtained by looking at the amount of PET in the composition of the current MPWH. This value is already calculated in Section 7.3.2 and amounts 137.3 kg/day. Since a bank sampah can process 12.7 kg PET per day, a maximum of 10 bank sampahs can effectively be added to the facilities in the DAS.

When 10 bank sampahs are added to the system, there will be an amount of 130.2 kg PET per day which is additionally managed by these facilities. This is consequently equal to the reduction of the MPWH, which means that the 'new' MPWH amounts 2730.9 kg/day. The new PW-load in the river can be computed by multiplying this MPWH by the RF_{MPWH} and adding this value to the amount of illegally dumped plastic waste, which is the same as in scenario 0: 193.3 kg/day, since there are no more trucks in action. Ultimately, a new PW-load of 1934.6 kg/day is obtained, which is equal to a PWLR of 80.9 kg/day. This value slightly differs from the 130.2 kg/day that is processed by the bank sampahs, since the fraction of plastic within the 130.2 kg/day that was considered to be burned in scenario 0, is taken into account as well. Moreover, these calculations only make sense when the same assumption as in scenario 0 is honoured: a constant factor RF_{MPWH}.

The additional costs of this scenario could be evaluated by calculating the total costs per month needed to run a bank sampah, which can be obtained from Table 7.7: a total of 3.2 million IDR/month. Accounting for 10 additional bank sampahs, the total waste management costs per household of this scenario sums up to 30,558 IDR/month.

7.3.5. SCENARIO 3: TWO ADDITIONAL TRUCKS

Another method to increase the waste management capacity is to apply more garbage trucks to the system. This will lead to a reduction of PW-load. To make sure that the trucks are applied in the most efficient way, only two trucks are added. Since the waste management system in Bali is decentralised, new virtual garbage trucks will be exploited by the government of a single desa. To compute the efficiency of the specific trucks it is needed to decide which desa purchases these. The magnitude of the MPWH per Desa, calculated as in scenario 0, can be used to do so. It appears that the magnitude of MPWH is the largest in desas Sukawati and Kenderan; 499.8 kg/day and 528.3 kg/day, respectively. These desas are therefore assumed to be the desas of choice.

In Table 7.7 it is stated that the plastic reduction of a single truck is 462 kg/d. These trucks will therefore be fully efficient, however their waste processing capacity will not fully contribute to a reduction of the MPWH. The fact is that the desa Sukawati is not entirely located in the DAS of interest; some plastic waste of this desa will end up in another river than the Petanu river. It is assumed that the part of the area of the desa located in the DAS is linearly related to the contribution to the MPWH. Moreover, it is assumed that the garbage truck in the desa processes plastic waste equally distributed over the area. In that way, it can be estimated that the reduction of MPWH due to desa Sukawati is reduced by 164.3 kg/day. On the other hand, desa Kenderan is 100 % located in the DAS and therefore the associated truck fully contributes to the reduction of MPWH: 462 kg/day. The total reduction of MPWH associated to this scenario then sums up to 613.8 kg/day, which is equal to an amount of MPWH of 2247.3 kg/day.

The new MPWH can be used to compute the PW-load associated to scenario 3. The first step is to multiply the MPWH by RF_{MPWH}, leading to a first estimate of the PWLR. However, this calculation is not entirely complete. A small fraction of PW-load has to be added: the amount of illegally dumped plastic waste by the two virtual trucks and by the already existing trucks. As stated in Table 5.1 on average 6.5% of the plastic waste in a garbage truck is illegally dumped in the environment. For the two proposed trucks, this will lead to an additional PW-load of 39.9 kg/day. As seen in scenario 0, the amount of illegally dumped plastic waste in the baseline scenario is 193.3 kg/day. The eventual PW-load will then be 1664.5 kg/day. That is equal to a total PWLR of 351.0 kg/day.

The additional costs of this scenario can be computed by looking at the costs of the trucks and the needed TPS3R. As explained in Section 7.3.1 garbage trucks can not function on their own; one recycling facility, a TPS3R, is needed per two trucks. Therefore the total additional waste management costs are equal to the total costs (investment and operational) of two trucks and one TPS3R. These costs sum up to 45.5 million IDR/month. Regarding the amount of households, scenario 3 is therefore characterised by a PW-load of 1664.5 kg/day, a PWLR of 351.0 kg/day and total costs of waste management per household of 31,170 IDR/month.

7.3.6. SCENARIO 4: AN ADDITIONAL TRUCK IN EVERY DESA

The last proposed scenario investigates a very inefficient situation: the addition of one single garbage truck per desa in the decentralised system of Bali. Since nearly none of the desas produces enough waste to fully load a truck per day, the purchase of that many trucks will definitely result in partly unproductive use of them. The scenario will therefore result in relatively high additional costs, compared to the PWLR.

To calculate the PWLR, at first the reduction of MPWH is estimated. The way to do so, is calculating the MPWH per desa per day. When a desa produces less MPWH per day than the plastic waste processing capacity of a single truck (460 kg/day), it is assumed that all of the MPWH is processed by the truck. When a desa produces more MPWH (Kenderan and Sukawati), the garbage truck only processes the amount equal to the full capacity. Knowing these values, the total reduction of MPWH can be calculated, which amounts 2782.4 kg/day. Note that the effect on the reduction of MPWH of desa Kenderan and desa Sukawati is calculated in the same way as in Section 7.3.5.

A MPWH reduction of 2782.4 kg means a 'new' MPWH of 87.7 kg/day. Multiplying this value by RF_{MPWH}, adding the illegal dumping of scenario 0 (193.3 kg/day) and adding the illegal dumping of the virtual trucks ($0.065 \cdot$ MPWH reduction), results in a new PW-load: 424.3 kg/day. The PWLR will then amount 1591.2 kg/day.

The next step is to compute the effectiveness of each truck per particular desa. The ratio between the produced MPWH per desa and the plastic waste processing capacity of a truck is used for this estimate. This ratio decides the amount of days that a truck is used per month per single desa, e.g. when the ratio is 0.33, the truck is used 10 days per month; the truck is only needed 10 days per month to process the plastic waste in the desa. Within these calculations it is assumed that a single month consists of 30 days and, moreover the days of use per month per truck are rounded up.

Now the effectiveness of the trucks is known, it can be used to calculate the total costs of the trucks, since the used days per month determine the operational costs. Accounting for these operational costs and the investment costs, the total costs for waste management per household are 55,311 IDR/month. Note that the inefficiency of this scenario is largely determined by the investment costs per truck, which do not change regardless of the usage per month. In the end, scenario 4 is characterised by waste management costs per household of 55,311 IDR/month, a PW-load of 424.3 kg/day and a PWLR of 1591.2 kg/day.

7.4. ESTABLISHMENT PRODUCTION POSSIBILITY FRONTIER

Table 7.9 summarises the PW-load and the corresponding costs of the scenarios. The final step in creating the PPF is plotting all these data points on a graph and fitting a line trough those data points.

Table 7.9: Overview Plastic Waste Load (PW-Load) and Average Costs per Scenario

Scenarios	PW-Load [kg/d]	Average Costs per Household [IDR/month]
Scenario 0	2015.5	29101
Scenario 1	5041.4	0
Scenario 2	1934.6	30558
Scenario 3	1664.5	31170
Scenario 4	424.3	55311

For the establishment of a PPF it is important that the quantity on the x-axis (the environmental quality) increases as the quantity on the y-axis (the economic activity) decreases, however in this particular case the PW-load (possible x-axis) decreases as the costs per household (possible y-axis) increases. To achieve an environmental-economic model, the x-axis therefore had to be mirrored, since a low PW-load corresponds to a high environmental quality. As a result, the y-axis had to be mirrored as well. Therefore, the costs have been modified to 'impact on purchasing power of a household' by multiplying the costs with minus one. In other words, the costs reduce the purchasing power. The Python code that is used to execute all calculations and the above described modification of the graph can be found in Appendix J. The graph is showed in Figure 7.8.

After modification a line should be fitted. In this case a quadratic function is the most suitable option. The standard form of a quadratic function is given in Equation 7.5.

$$y = a \cdot x^2 + b \cdot x + c \tag{7.5}$$

This fit, a quadratic one, is most suitable as it is estimated that the reduction of the first 100 kg plastic waste in the river is relatively cheaper than the reduction of the last 100 kg plastic waste in the river, due to inefficiencies in the system. One of the inefficiencies is for example the fact that one truck is bound to a certain desa, causing a truck having a certain impact on the PW-load depending on the PW-production in a specific desa. This inefficiency cause is elaborately explained upon in Section 7.3. Another inefficiency is the illegal dumping of the waste haulers, the garbage trucks. In this model it has been assumed that the percentage of waste illegally dumped by waste haulers stays equal to the current situation (6.5%), however to decrease the last kilograms of plastic waste load the illegal dumping has to be stopped, which costs a considerable amount of money [10]. As reduction of illegal dumping by waste haulers and other leakages within the system are not taken into account in the model, a PW-load of zero is impossible to achieve [10]. Therefore, the curve ends at scenario 4, which is the scenario in which in every desa an extra truck is driving.

Moreover, the line does not go exactly through the data points. This is due to fitting. The reason for not fitting a line straight through all data points is the amount of estimates needed to create the data points. As a result, it has been assumed that a mathematical fit is more appropriate than an exact fit in this case. The values for the a,b and c variables of the fit are given in Table 7.10.

Table 7.10: Values for Variables a, b and c in the Quadratic Equation of the Production Possibility Frontier

a	b	c
$-1.54 \cdot 10^{-3}$	20.36	$-6.35 \cdot 10^{4}$

Note: the graph of the PPF has a mirrored x-axis. As a result, filling in the values for a,b,c in a graph with a non-modified x-axis will result in a different graph than the graph depicted in Figure 7.8

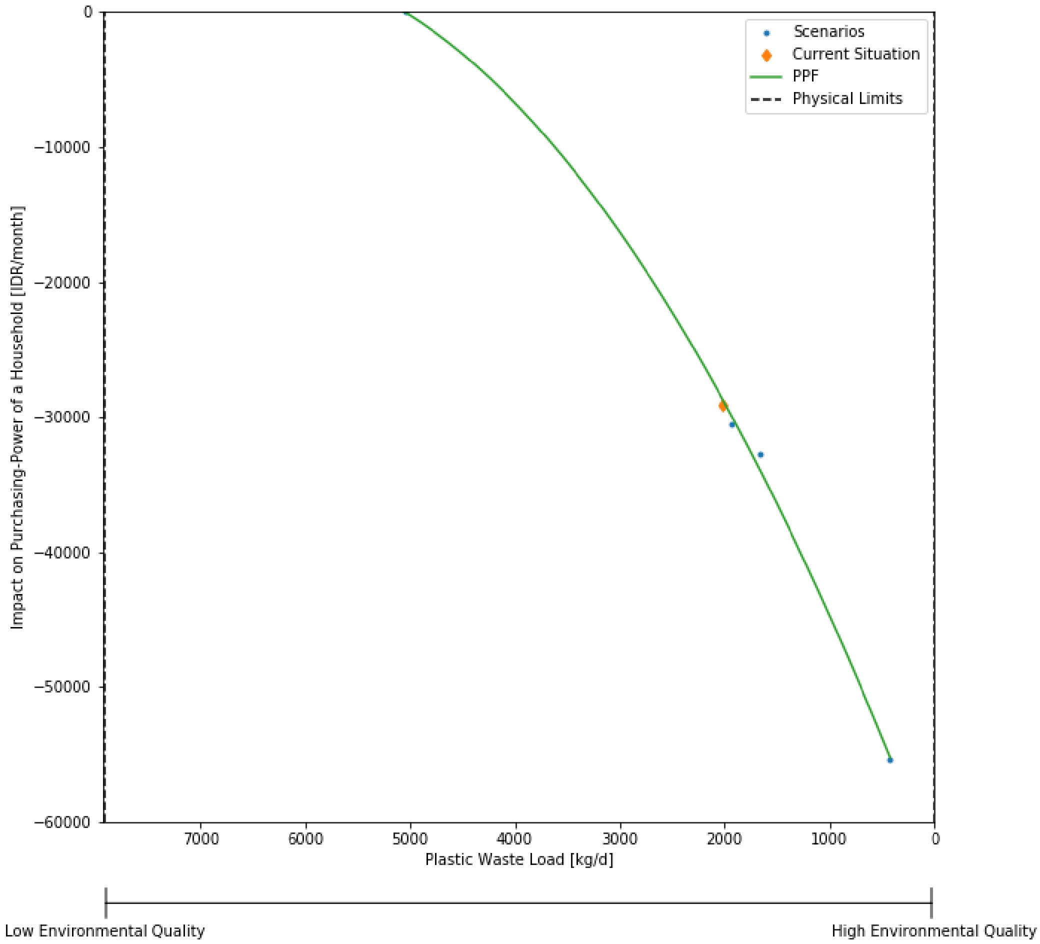

Figure 7.8: Production Possibility Frontier of Impact on Purchasing Power of a Household Versus Plastic Waste Load

7.5. SENSITIVITY ANALYSIS PPF

A sensitivity analysis is a mean to apportion the uncertainty in outputs of the model to different sources of uncertainty in the inputs. It is important to determine the most significant uncertainties for further research. It is possible to perform a local and a global sensitivity analysis [108]. In a local sensitivity analysis the influence of a change in a single input parameter on the model output is determined [109]. In a global sensitivity analysis on the other hand all input parameters are varied simultaneously [108]. This makes it possible to evaluate the relative impact on the output variance corresponding to each input parameter as well as the interactions between the multiple parameters [108]. In other words a global sensitivity analysis is a more in depth analysis and has therefore the preference.

The global sensitivity analysis of the PPF has been performed with the help of the open source library SALib in Python [110]. SALib contains multiple sensitivity analysis methods. It has been chosen to use the Sobol's method, which determines the contribution to the variability in the model of each parameter individually and their interactions [108]. The model outputs in this specific case are the variables a, b, c that are used for quadratic fitting (Equation 7.5). In this model there are many uncertain input parameters. First of all, for the non-researched desas, the fraction of waste that is either dumped or burned is an assumption based upon the average value in Bali [11]. Secondly, the values in Table 5.1 are assumptions, i.e. $\%\text{Dump}_{\text{river}}$, $\%\text{Burn}_{\text{river}}$, $\%\text{PickUp}_{\text{river}}$ and the percentage of PET in the household plastic waste ($\%\text{PET}_{\text{waste}}$), that is used to calculate the percentage for Self-

Service. Thirdly, the percentage of PET that ends up in the river ($\%PET_{mismanaged}$) is an assumption as well as the cost per household of the current waste system. Lastly, a very large assumption is the cost and capacity of all waste management elements (e.g. trucks and bank sampahs). All input parameters are independent of each other.

Let x = $(x_1, x_2, x_3...)$ be the input parameters. To determine the influence of these parameters on the variables of the standard quadratic equation, the sensitivity has been modeled with a change of 10% of all input parameters. In other words, the parameters are modelled with bounds of 10% larger than estimated and 10% smaller than estimated. This interval is rescaled to an interval of [1,0], with a normal distribution [108].The output variables are a function of the input parameters ($f(x)$), which has a mean (f_0) (Equation 7.6 and a variance (D) (Equation 7.7).

$$f_0 = f(x)dx \tag{7.6}$$

$$D = f(x)^2 dx - f_0^2 \tag{7.7}$$

Sobol's method is based upon the decomposition of D into effects of a single input parameter and combinations of the input parameters [108]. An in depth explanation of the Sobol's method is beyond the scope of this research and is left out here. In summary the Sobol's method enables to determine the first order sensitivity indices as well as the total order sensitivity indices. The first order indices is the fractional contribution of a single parameter to the output variance. The total order takes also the influence of parameter combinations into account [108].

In Figure 7.9 these total order sensitivity indices of the input parameters are given with respect to the individual variables (a,b,c). In general the cut-off value of 0.05 is used to distinguish between important and irrelevant parameters [108]. It can clearly be seen in Figure 7.9 that fraction burned, $\%Burn_{river}$, $\%PickUp_{river}$, $\%PET_{waste}$ and $\%PET_{mismanaged}$ are irrelevant parameters. The fraction of waste that is dumped at household level and $\%Dump_{river}$ are however important and have a significant influence on variables a and b. Lastly, both the current costs as well as the costs of specific element are very important parameters. Especially, the costs of a specific waste management element has a significant influence of at least 40% on the variability of the PPF.

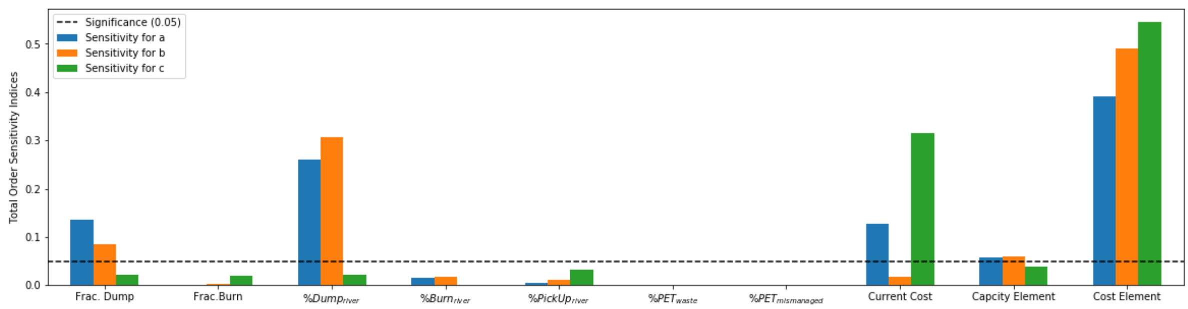

Figure 7.9: Sobol's Sensitivity Indices of the Input Parameters used for the Establishment of the Production Possibility Frontier

8

Part III: Utility Curve

The utility curve represents the population's preferences and trade-offs between the economic activity and the environmental quality of plastic waste in the river. Many times people can not simultaneously maximize (or minimize) multiple items. An example of this is maximizing purchased items to infinity, while minimizing the corresponding costs to zero. Since bought items definitely have a price tag, buying more will also increase the costs. Therefore it is interesting to know at what price tag people are willing to buy an item. So, in this case, how much people are willing to pay to improve their waste management system. To do a research on this, a discrete choice model has been conducted.

The utility curve is created by the utility function that consists of the objects that are being traded off and their weights. Not every object has the same weight, since people tend to attach more value to a certain object above the other(s). In order to get insights in these trade-offs, a stated choice experiment has been conducted. In this stated choice experiment respondents from the researched desas are asked to make choices between hypothetical choice situations, in which specific characteristics differ, as was earlier explained in Section 6.4. This stated choice experiment provided data, of which the analyses are shown in this chapter.

First, some background information is given and the estimation of the utility function with the corresponding parameters is elaborated upon. Secondly, two utility models are explained and their estimates are amplified. Hereafter the general utility curve is established and shown. Lastly the preferences among groups (or 'segments') with different socio-demographic characteristics are examined.

8.1. Discrete choice model

The discrete choice model based on Random Utility Maximization was the basis for this research [111]. The utility of an alternative is obtained using the results on which alternatives have been chosen by the respondents. The total utility can be split up in two parts, the systematic utility (U_i) and the error term (ε_i). The formula for the utility of an alternative i can be seen below:

$$U = V_i + \varepsilon_i$$

The systematic utility captures all that can be related to observed factors, such as age, gender, travel time, cost etc. The error term captures all that cannot be captured in the systematic utility, ie. everything that was not directly asked in the choice sets. This error term, therefore, could exist of unobserved factors, heterogeneity in tastes, and randomness in choices [83]. Chorus quotes the following about the total utility: "Randomly sampled individuals choose the alternative whose total utility is the highest.". However, if the systematic utility is the highest for one alternative, that one still might not be chosen (due to the unobserved utility). The higher the systematic part of the utility, the bigger the *probability* is of it being chosen. In this research, only the systematic part of the utility is considered.

The systematic part of the utility is the weighted sum of the attributes m, as can be seen in the equation below. The attributes have certain values, or 'levels', x_{im}. Each attribute value has a 'beta' β_m that represents the 'weight' of that attribute. This beta is also called the 'attribute parameter'.

$$U = V_i + \varepsilon_i = \sum_m \beta_m \cdot x_{im} + \varepsilon_i$$

The reason for conducting a discrete choice analysis, is to find the mean beta of the population. This gives insight of what weight people give to a certain attribute in order to maximize their own utility. To find this mean beta, a sample from the population is drawn and the sample mean of beta is obtained based on the observed choices of the sample. The mean beta tells how many 'utils' increases in the total utility, when changing the corresponding attribute one stepsize (one euro, or one minute for example).

8.2. ESTIMATING PARAMETERS

One line of the data from the choice experiments contains both, the two alternatives, with their corresponding attribute levels (Table 6.1) and the choice that is made by the respondent. Each respondent has a personal ID, which can be used to track back its (socio-demographic) characteristics. This data is analysed using 'Biogeme', an open source Python package. Biogeme is designed for the maximum likelihood estimation of parametric models in general, with a special emphasis on discrete choice models" [112]. The main aim of Maximum Likelihood Estimation (MLE) is based on the Maximum Likelihood-principle; under the assumed statistical model (iteratively) finding the set of parameters that make the observed data the most likely [83, 113]. Because of numerical reasons, the computer looks for the betas that maximize the negatively valued *log* likelihood (LL(β)) of the function.

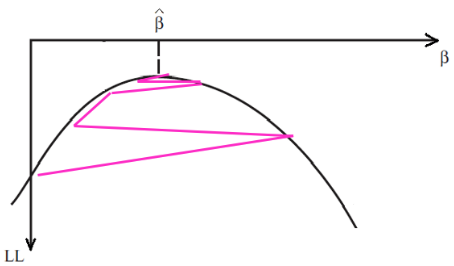

Figure 8.1: $\hat{\beta}$ maximizes the Log Likelihood Function.
The Model makes the Data most Probable ('Likely') [114].

The log-likelihood is used to asses the model's fit in the McFadden's R-squared (ρ^2) parameter, which has a value between 0 and 1 [115]. The McFadden's R-square compares the estimated model LL(β) to a completely random (or *no*) model LL(0). The estimated model shows the estimated parameters that fit the data the best, while the *no* model (LL(0)) does not have any estimated parameter, thus the betas are contained at 0. Equation 8.1 indicates the formula of McFadden's R-square.

$$\rho^2 = 1 - \frac{LL(\beta)}{LL(0)} \tag{8.1}$$

The R-squared thus portrays to what extent the estimated model fits the observed data. The higher the ρ^2, the better the model fits the data.

8.3. TWO UTILITY FUNCTIONS: DUMMY VARIABLES VS. CONVERTED RATIO SCALED VARIABLES

The data is analysed in two manners: the first approach describes the utility function with dummy variables, while the second approach describes the utility function after the conversion to ratio scaled variables. The reason for using both methods is the need for analysis in two ways.

The first approach analyses the data straight forward: the disposal methods are taken as nominal variables using dummy coding. Dummy variables are independent variables that either take the value 0 or 1 [116]. Dummy coding is being used for categorical data, which in this case is the attribute 'disposal methods' existing of four categories. Dummy coding, together with "effects coding", is widely used for the analysis of discrete choice experiments with independent nominal variables [117].

This first method is important to analyse, in order to have insight in the results without the assumptions about the resemblance of the attribute 'disposal method' with the environmental quality, expressed in plastic waste load, as discussed in Chapter 6. Since this model is very straight forward and probably has less bias because of the lack of assumptions, it will also be a right tool to validate the results of the second model.

For the second approach the 'disposal method' attribute is converted to a ratio scaled variable: the plastic waste load (PW-Load) that corresponds to that certain method. In Section 6.4.3 it was already elaborated upon that the attribute 'disposal method' represents the environmental quality, since it is corresponding to a certain amount of PW-Load that ends up in the river. Since it is assumed that respondents have knowledge about the environmental quality associated to the different disposal methods, it is interesting to know what the utility function looks like when taking the PW-Load into account.

The second method is also important for the final result of this study: the real-world coupled economic-environmental model, where the PPF is coupled to the utility curve. In order to couple these two curves, both need to have the same units on the axes of the graph: the monthly impact on purchasing power in IDR per month, and the plastic waste load in kg plastic per day. While the first variable is explicitly present between the researched attributes, the second is 'hidden' in the attribute 'disposal methods'. In order to to attain the PW-Load in kg per day, the respondents' preferences of the choice data are analysed using PW-Load in kg per day per household, after which this is aggregated to the entire DAS Petanu to obtain the economic-environmental model.

8.3.1. UTILITY FUNCTION - ANALYSIS WITH DUMMY VARIABLES

When categorical nominal variables, like 'disposal methods', are present in a discrete choice experiment, these are frequently analysed using dummy coding [117]. Converting a categorical variable requires L-1 dummy variables [1], that either have the value 0 ('no') or 1 ('yes'). 0 is the so called 'control group' and the 1 is the 'treatment group'. This means that the utility that will be estimated for the treatment group is relative to the control group [84].

This first utility model distinguishes itself by the usage of dummy coding for the variable 'disposal methods'. The four categories of this variable are coded into L-1, so three dummy variables. In this, the category Pick Up is taken as the control group, since it is the most common disposal method in the researched area. All other categories are treatment groups, where Self-Service, Burn, and Dump are respectively represented in the dummy variables $D1$, $D2$ and $D3$ (and take the value 1 for their corresponding dummy). The estimated parameters of these treatment groups are relative to the Pick Up option. Table 8.1 gives the coding scheme of the dummy variables used for the disposal methods categories. As can be seen, Pick Up has the value 0 for all dummy variables.

[1] L being the number of attribute levels

Table 8.1: The Coding Scheme that is Used to Convert the Categorical Variable 'Disposal Methods' into Dummy Variables.

Attribute level	D1	D2	D3
Self-Service	1	0	0
Burn	0	1	0
Dump	0	0	1
Pick Up	0	0	0

Equation 8.2 shows the linear utility function that is estimated. While $D1$ to $D3$ represent the dummy variables of the variable 'disposal methods'. C and T represent the monthly disposal costs (in 1000 IDR/month) and the daily disposal time (in minutes per day) respectively. The betas $\beta_{disposal1}$ until β_{time} represent the to be estimated parameters using Maximum Likelihood Estimation (MLE) on the observed data. It is expected that the estimated cost an time parameters will be negative, since an increase of the consumption of capital and time are predicted to lead to a decrease in the overall utility. An expectation is however not present for the dummy variables of the disposal costs, since these are independent nominal variables.

$$U = \beta_{disposal1} \cdot D1 + \beta_{disposal2} \cdot D2 + \beta_{disposal3} \cdot D3 + \beta_{cost} \cdot C + \beta_{time} \cdot T \tag{8.2}$$

Table 8.2 shows the MLE estimates of the first model. The values of the parameters are shown under 'coefficients' and can be interpreted as the utils that are gained (if value is positive) or lost (if negative) by one unit increase of the attribute [83]. Their standard errors (SE), t-statistics and p-values ('probability value'), which are all used in order to test whether the parameter is significant, are also given. All estimated parameters appear to be significant on a 1% level (all p-values are below 0.01), except for the time-parameter β_{time}, which turns out to have a t-statistic of -1.49 and p-value of 0.14. [2]

Table 8.2: Results of the MLE estimates: Utility Function with Dummy Variables

Indicator	Coefficient	SE	t-stat	p-value
$\beta_{disposal1}$	0.656	0.0539	12.18	0.00
$\beta_{disposal2}$	-0.809	0.0545	-14.84	0.00
$\beta_{disposal3}$	-0.746	0.0523	-14.25	0.00
β_{cost}	-0.00661	0.000922	-7.17	0.00
β_{time}	-0.0237	0.0159	-1.49	0.14

Table 8.3 displays the part-worth utilities of the attributes and its levels, which show in what extent they contribute to the overall utility. The part-worth utility of an attribute level is calculated by taking the beta of the corresponding attribute and multiplying it by that level. Since the attribute 'disposal methods' consists of three independent dummy variables, the t- and p-values are depicted three times. Since Pick Up is the control group, the utility is set to zero. The fourth column gives an indication of the relative attribute importance with regard to the overall utility. This is obtained by calculating the range per attribute by extracting the lowest part-worth utility value from the highest and taking its absolute value. The range of an attribute is subsequently divided by the sum of all ranges and is given in percentages in the table.

[2] In this study it is decided to conclude that the null hypothesis can only be rejected if it falls outside of the 95% confidence interval. This corresponds to a t-statistic of at least ± 1.96 and a p-value of 0.05 or lower. The t-statistic and the p-value are widely known and used values for the analysis of statistical test. The null hypothesis is in this case that all betas are zero and there is no significant difference between the estimated parameters and a beta that is contained at 0.

Table 8.3: Attractiveness Stated Preference Model for All Respondents – With the Usage of Dummy Variables for the Attribute 'Disposal Method'

Attribute	**Part-Worth Utility**	**t-value**	**p-value**	**Relative Attribute Importance [%]**
Disposal method				57.8%
Self-Service	0.66	12.18	0.00	
Burn	-0.81	-14.84	0.00	
Dump	-0.75	-14.25	0.00	
Pick Up	0.00			
Costs (per month)		-7.17	0.00	36.5%
20.000 IDR	-0.13			
60.000 IDR	-0.40			
120.000 IDR	-0.79			
160.000 IDR	-1.06			
Time (per day)		-1.49	0.14*	5.6%
1 minute	-0.02			
3 minutes	-0.07			
5 minutes	-0.12			
7 minutes	-0.17			

*Insignificant on a 0.05 level

It is clear that the attribute 'disposal methods' has, with almost 60%, the highest attribute importance. Dump and Burn give a dis-utility relative to the level of Pick Up, while Self-Service gives a positive utility. Interestingly enough, the values for Burn and Dump seem to be very close to each other, where burning has a slightly lower part-worth when compared to dumping. Hence, it may be concluded that Self-Service is seen as the best option, while burning and dumping are both seen as the worst options.

The second most important attribute appears the be the monthly 'disposal costs', when comparing the attribute importance of the variables. It is important to know that the parameters are given in units *1000* IDR per month. The attribute is face valid: the decreasing tendency of the levels are in line with the expectations. With an increase in costs, the part-worth utility values become more negative, which means that people's preference is according to lower costs.

Although the attribute 'time' appears to be insignificant and has a relatively small importance, face validity is present. An increase in disposal time per day, decreases the contribution to the total utility. Hence time is a relatively unimportant variable, but it leads to some increase in dis-utility, therefore this variable shouldn't be ignored.

Table 8.4 gives insight in values that are important for the interpretation of the model fit. The R-squared (ρ^2) value indicates to what extent the estimated model fits the observed data. The null log likelihood gives the value for the log likelihood when all parameters (betas) are constraint to zero. The final log likelihood gives the value of the log likelihood after the most 'likely' betas are estimated. The R-square is 0.241 which indicates a reasonable fit of the data. The convergence is reached, which means that there are no identification problems.

Table 8.4: Model fit of the Dummy Coded Model

ρ^2	**0.241**
Null log likelihood - LL(0)	-1663.553
Final log likelihood - LL(β)	-1262.288
Diagnostic	Convergence reached

WILLINGNESS TO PAY

The parameter values (coefficients), that can be seen in Table 8.2, are easily translatable to how valuable an improvement for the consumer is. In other words, what is the people's Willingness To Pay (WTP) in order to change? To attain the WTP for an attribute, the parameter of that attribute is divided by the cost parameter. For time this is done easily by dividing β_{time} by β_{cost}, which gives the value of 3.6. Since the cost attribute is however in 1000 IDR per month, this comes down to 3,600 IDR per month. Considering that time has the unit minute per day, this value is interpreted as: "People are willing to pay 3,600 IDR per month to reduce 1 minute in their daily disposal time ."[3]

To apply this for the dummy variables, Pick Up is used as the control group. To obtain the WTP from one disposal method to another, the range between the corresponding betas is used. This range is calculated by subtracting the coefficient of the disposal method the transition leads to, from the coefficient of the disposal method at the start of this transition. For example, the transition from Burn to Self-Service would give the following range:

$$R_{Burn \rightarrow Self-Service} = \beta_{Burn} - \beta_{Self-Service} = \beta_{disposal2} - \beta_{disposal1} = -0.809 - 0.656 = -1.465 \quad (8.3)$$

This range is then divided by the parameter of cost β_{cost}, and gives the value: 221.6. Again, since the 'cost' attribute is in 1000 IDR/month, the WTP is equal to 221,600 IDR per month. The interpretation of this WTP value is as follows: "People are willing to pay 221,600 IDR per month (more) to make the transition from Burn to Self-Service." Table 8.5 shows the willingness to pay per transition, with respect to the third variable. The WTPs appear to be remarkably high for the transitions of disposal methods, with in particular the transitions from Burn or Dump to Self-Service.

Table 8.5: Willingness to Pay: First Utility Model

Transition	**WTP [IDR/month]***
Pick Up ⟶ Self-Service	99,200
Burn ⟶ Dump	9400
Burn ⟶ Pick Up	122,400
Burn ⟶ Self-Service	221,600
Dump ⟶ Pick Up	113,000
Dump ⟶ Self-Service	212,300
Decrease of 1 minute in daily disposal time	3600**

*All amounts are rounded op to 100 IDR
**Insignificant on a 0.05 level

8.3.2. UTILITY FUNCTION - ANALYSIS WITH CONVERTED RATIO SCALED VARIABLES

The second utility model distinguishes itself by the conversion of the attribute 'disposal methods' to the environmental quality that is expressed in plastic waste load (PW-Load). This leads to the attribute, that was previously analysed as an independent nominal variable, to be expressed in a ratio scaled variable. For the economic-environmental model a two dimensional utility curve is required, with the variables PW-Load and impact on monthly purchasing power. In order to obtain this two dimensional utility function, first the different levels of disposal methods have been converted to their corresponding PW-Load per household. Second, the time variable is kept constant, which leads to a *new* utility function containing the two required variables with respect to the time. This utility function can then be aggregated by taking the total number of households, so it depicts the total PW-Load in the Petanu River. Lastly, differences in preferences among socio-demographic groups have been examined.

PLASTIC WASTE LOAD VARIABLE

Each disposal method category is associated with a certain environmental quality. This environmental quality is expressed in the percentage of plastic that ends up in the environment by means

[3] This value gives an indication of the WTP for time. However, since the parameter for time has proven to be insignificant, drawing conclusions from this value should be done with care.

of the specific disposal method (Table 5.1 in Section 5.3). For Self-Service this percentage is 4.6%, for Pick Up 6.5%, for Burn 25% and for Dump 100%. The assumption is made that respondents interpreted the disposal method while keeping the amount of plastic that ends up in the environment in mind. These percentages are multiplied with the average amount of plastic one household produces, which is 0.3638 grams per household per day.[4] The result is the amount of plastic that ends up in the environment on average for a household per disposal method. Table 8.6 displays the amount of plastic per disposal method that ends up in the river. Thereby, the assumption is made that only pieces of plastic are taken into consideration, and not for instance toxic gasses that will be created by open burning of plastic.

Table 8.6: Plastic Waste load (PW-Load) per Household per Disposal Method

Disposal Method	**PW-load per Household [kg/hh/day]**
Self-Service	0.0166
Pick Up	0.0236
Burn	0.0909
Dump	0.3638

As can be seen in Table 8.6, the values of Burn and Dump for their PW-Load are relatively different, with burning being on the less polluting side. What is however remarkable is that according to the previous findings in the first utility model (Table 8.3), the part-worth utilities of these two categories were nearly the same, with burning having even a slightly lower part-worth utility.

New Parameter Estimation Using Plastic Waste Load

Equation 8.4 shows the linear utility function that is estimated. Since the disposal methods are converted to a PW-Load variable, the utility function consists of three variables: PW-load (in kg per household per day), cost (in 1000 IDR per household per month), and time (in minutes per household per day). These variables are respectively represented by P, C and T in Equation 8.4. The betas β_{pwload}, β_{cost}, and β_{time} represent the to be estimated parameters using Maximum Likelihood Estimation (MLE) on the data. All betas are expected to be negative, since an increase in the pollution of the environment and the consumption of capital and time, are predicted to lead to a decrease of the overall utility.

$$U = \beta_{pwload} \cdot P + \beta_{cost} \cdot C + \beta_{time} \cdot T \tag{8.4}$$

Table 8.7 shows the MLE estimates of the second model. The estimated values of the betas are shown in the first column. They all appear to be negative, which is according to the expectations and indicates the presence of face validity. All three p-values of the parameters are smaller than 1%, which implies that the null hypothesis can be rejected and the estimated parameters are significant. What is remarkable, is that the time variable seems to be significant now, in contrary to previous findings in the utility model with dummy variables (Table 8.2).

Table 8.7: Results of the General MLE estimates: Utility Function with Ratio Scaled Variables

Indicator	**Coefficient**	**SE**	**t-stat**	**p**
β_{pwload}	-3.84	0.232	-16.55	0.00
β_{cost}	-0.00810	0.000816	-9.93	0.00
β_{time}	-0.0818	0.0143	-5.72	0.00

Filling in the values of the betas in Equation 8.4 gives the estimated utility function. This function is displayed below in Equation 8.5:

$$U = -3.84 \cdot P - 0.00810 \cdot C - 0.0818 \cdot T \tag{8.5}$$

[4]This amount of plastic production per day is calculated by taking the average plastic waste production per household in all desas within the DAS Petanu. So both researched and non-researched desas are taken into account.

Table 8.8 displays the part-worth utilities of the attributes and its levels, which show in what extent they contribute to the overall utility. Like in the first utility model, the relative importance per attribute has been calculated by dividing its range by the sum of all attribute ranges.

Even though the relative importance of 45% of the attribute 'disposal method' is still the highest when compared to the other attributes, it is obvious that it is still lower than the relative importance that we have seen in the first utility model with the dummy variables (58%). The relative attribute importance of 'time' also occurs to have changed and now has a value that is almost thrice as much as the previously obtained percentage of 5.6%. It seems like it has taken a part of the importance of the attribute 'disposal method'. On the other hand, the 'cost' attribute seems to have stayed relatively the same, with only an increase of 2% when compared to its relative importance in the utility function with the dummy variables.

Table 8.8: Attractiveness Stated Preference Model for All Respondents – With the Usage of the Corresponding 'PW-Load' for the Attribute 'Disposal Method' (N=2400)

Attribute	**Part-Worth Utility**	**t-value**	**p-value**	**Relative Attribute Importance (in %)**
Disposal method		-16.55	0.00	45.1%
Self-Service	-0.06			
Pick Up	-0.09			
Burn	-0.35			
Dump	-1.40			
Costs (per month)		-9.93	0.00	38.3%
20,000 IDR	-0.16			
60,000 IDR	-0.49			
120,000 IDR	-0.97			
160,000 IDR	-1.30			
Time (per day)		-5.72	0.00	16.6%
1 minute	-0.08			
3 minutes	-0.25			
5 minutes	-0.41			
7 minutes	-0.57			

Table 8.9 displays the model fit of the MLE estimate. The final log likelihood is somewhat lower than the log likelihood of the previous estimated model with dummy variables. This also explains why McFadden's R-square (0.141) is slightly lower, but still indicates a reasonable estimation of the observed data. The convergence is reached, which means that there are no identification problems.

Table 8.9: Model fit of the Ratio Scaled Model

ρ^2	**0.141**
Null log likelihood - LL(0)	-1663.553
Final log likelihood - LL(β)	-1429.404
Diagnostic	Convergence reached

WILLINGNESS TO PAY

The willingness to pay for the second model is calculated in the same manner as the first model: the estimated parameters (Table 8.7) are used for the calculation. The resulting WTPs are shown in Table 8.10.

The WTP for reducing the daily disposal time is done in the same way and has this time the value of 10,100 IDR/month. The interpretation is that people are willing to pay 10,100 IDR per month in order to reduce one minute of their daily disposal time.

The WTP for the reduction of the PW-Load by one unit is done by dividing its parameter by the parameter of cost, i.e. β_{pwload} is divided by β_{cost} and gives the value 474.1. Since the cost variable is however in 1000 IDR per month, the WTP comes down to 474,100 IDR/month. Its interpretation is that people are willing to pay 474,100 IDR per month (more) to reduce 1 kg of their plastic waste load that ends up in the environment per day. Since 1 kg is however a high amount and is unlikely to be daily produced by a household, it could also be said that people are willing to pay 47,400 IDR per month in order to reduce 100 grams of their plastic waste load.

Table 8.10: Willingness to Pay: Second Utility Model

Transition	**WTP [IDR/month]***
Decrease of 100 grams in daily PW-Load	47,400
Decrease of 1 minute in daily disposal time	10,100

*All amounts are rounded op to 100 IDR

The WTP of PW-Load can then be calculated into transitions from one disposal method to another. This is being done by taking their corresponding PW-Load (Table 8.6) into account. The disposal methods now have a ratio scale and have an order, from Self-Service being the least polluting to dumping being the most. Considering the negative sign of the PW-Load parameter, which indicates a decreasing tendency, an improvement from one disposal method to the other can only be made if a shift is being made to a less polluting way of disposal.

The WTP for the transition of one disposal method to another is done by taking the difference between their part-worth utilities (Table 8.8) and dividing this by the parameter for costs. This difference is calculated by subtracting the part-worth of the disposal method the transition leads to, from the part-worth of the disposal method at the start of this transition. For example, the transition from Burn to Self-Service would give the following difference:

$$R_{Burn \rightarrow Self-Service} = PW_{Burn} - PW_{Self-Service} = -0.35 - 0.06 = -0.29 \tag{8.6}$$

This difference is then divided by the parameter of cost β_{cost}, and gives the value 35.2. Again, since the cost attribute is in 1000 IDR/month, the WTP is equal to 35,200 IDR per month. The interpretation of this WTP value is as follows: "People are willing to pay 35,200 IDR per month (more) to make the transition from burning to Self-Service."

Table 8.11 shows the willingness to pay per transition of the disposal methods, with respect to the time variable. The WTPs appear to be substantially smaller than similar WTPs that were observed in the previous method (Table 8.5). There the range of WTPs were between 9400 to 221,300 IDR/month, while here this range is considerably smaller. Another noticeable outcome is that the WTP for the transition from some disposal methods to others are substantially lower than resulted from the first method. For instance, the transition from Burn to Self-Service is shifted from 221,600 to 35,200 IDR/month, which comes down to a decrease of 84%.

Table 8.11: Willingness to Pay for the Transition of Disposal Methods Using their PW-Load

Transition	**WTP [IDR/month]***
Pick Up ⟶ Self-Service	3300
Burn ⟶ Pick Up	31,900
Burn ⟶ Self-Service	35,200
Dump ⟶ Burn	129,400
Dump ⟶ Pick Up	161,300
Dump ⟶ Self-Service	164,600

*All amounts are rounded op to 100 IDR

TIME VARIABLE

Even though it is interesting and sufficient to know that the time variable plays a role in peoples preferences about how to dispose their plastic waste, the variation of time will further not be analysed. In order to obtain the desired two dimensional utility function for the definite economic-environmental model, the time dimension will be hold on one value.

This constant value has chosen to be the median/mode value of the time. In the questionnaire, respondents have been asked to fill in their daily plastic waste disposal time. The results are shown in Section 6.8.3 and are summarised in Table 8.12 below. The table shows the values of the mean, median and mode of the total of the respondents' disposal time per day. The mean (5.17 minutes) is relatively higher than the median and mode, which are have both the same value (3.00 minutes). This difference can be explained by the fact that a small number of really high outliers (varying from 30 to 180 minutes) have been detected among the answers. These small number of outliers seem to have such an influence, that the average takes a much higher value than the median and mode. This has led to the decision to use the median (or mode) in order to keep the time variable constant.

Table 8.12: Mean, Median, Mode of the Time Variable

	Time [min/day]
Mean	5.173
Median	3.000
Mode	3.000

REWRITING THE UTILITY FUNCTION

By holding the variable time constant at its median/mode value, one dimension is 'eliminated', which leads to a two dimensional utility function. The utility function with its estimated betas is rewritten by filling in 3.000 minutes for T(ime). This process can be seen below: Equation 8.5 becomes Equation 8.7 , which is equal to Equation 8.8.

$$U = -3.84 \cdot P - 0.00810 \cdot C - 0.0818 \cdot 3.000 \tag{8.7}$$

$$\Longleftrightarrow$$

$$U = -3.84 \cdot P - 0.00810 \cdot C - 0.2454 \tag{8.8}$$

As can be seen, the utility function now contains the variables P (PW-Load) and C (costs), their parameters, and a constant -0.2454. This utility function is a linear two dimensional function, with respect to time. The variables and the constant have a decreasing tendency: they are all negative, which means that with an increase of one of the variables, the overall utility decreased. This is reasonable, since a higher pollution and higher costs are likely to give consumers more dis-utility.

However, when speaking in economic-environmental model terms, only the terms *saving of* costs, *saving of* pollution, and *saving of* time are considered. In this context the loss of a unit of a certain attribute is not playing a role, while the gain that is being obtained by saving a unit of that attribute, is. For costs, this would for instance be the utility that has been *gained* when one unit of costs (1000 IDR/month) is not spend or *saved*.

This approach results in absolute value of the estimated parameters for the variables, which consequently means that also the constant becomes positive, since the absolute value for β_{time} is taken. Therefore the final utility function that is being used for the economic-environmental model is shown below in Equation 8.9. Thereby U represents 'Utility', P represents 'plastic waste load' in kg plastic per day per household and C represents 'the monthly impact on purchasing power' in 1000 IDR per month per household.

$$U = 3.84 \cdot P + 0.00810 \cdot C + 0.2454 \tag{8.9}$$

8.4. ESTABLISHMENT OF THE GENERAL UTILITY CURVE

In order to establish the general utility curve that is adjacent to the PPF (Figure 7.8), the utility function shown in Equation 8.9 is modified is some extent. First, the utility function is rewritten as a 'PW-Load function'. This function is given below in Equation 8.10[5] and as can be seen, the utility value and the cost value are now a function of the PW-Load.

$$P = \frac{U - 0.2454 - 0.00810 \cdot C}{3.84} \tag{8.10}$$

Second, the PW-Load, that is one of the variables in the function, is aggregated to the whole DAS Petanu. Since the PW-Load in the utility function was given per household, the aggregation is done by the multiplication with the total number of households in the area, which is equal to 21,968. This could be done because Equation 8.10 gives the plastic waste load of an *average* household in the DAS Petanu. The result is that PW-Load is expressed as the *total* amount of kilograms plastic per day (for the whole area). This unit is in line with the unit used for the PPF.

Next, the the utility *value* is manually and iteratively adjusted in order to obtain the equilibrium. This equilibrium is equal to the point of tangency amidst the PPF and the utility curve. In other words, the utility value is adjusted in such manner that the utility curve (which is in fact linear) 'touches' the PPF and thus becomes its tangent line. The iterative process consists of filling in multiple values for U until it converges to be the tangent line of the PPF. This helps in creating a two dimensional space for the utility curve, where the x- and y-axis are equal to the axes of the PPF. By filling in a numeric value, the 'utility variable' is kept constant at one value and its dimension is 'eliminated'.

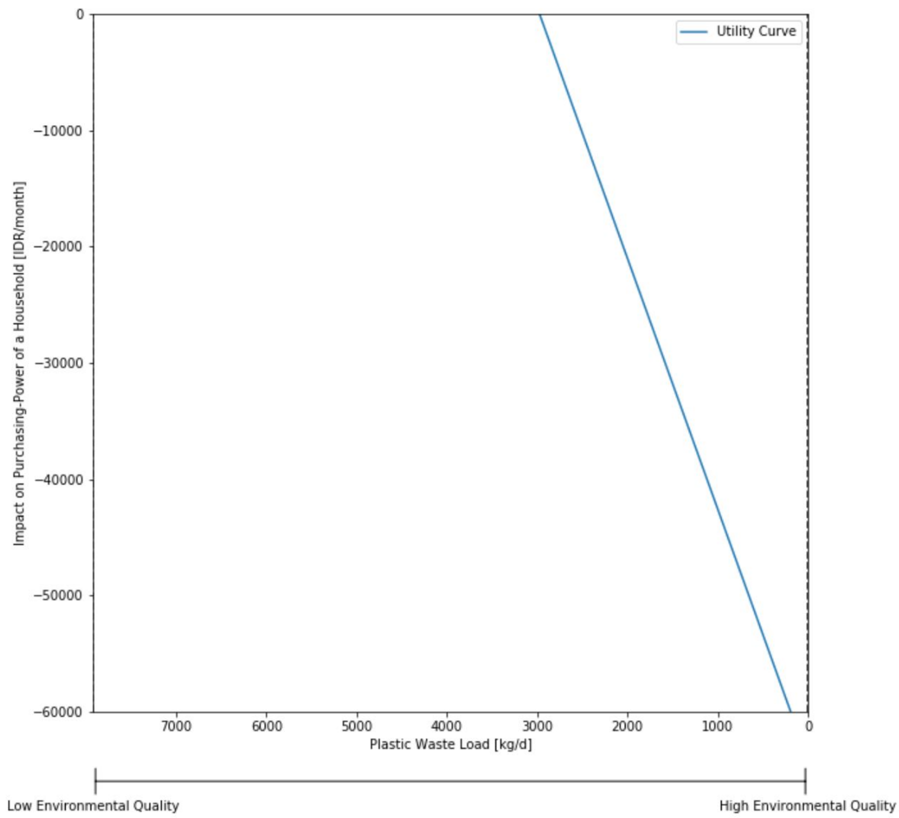

Figure 8.2: General Utility Curve, U=0.765

[5]In abstract form:

$$P = \frac{U - Const_{time} - \beta_{cost} \cdot C}{\beta_{pwload}}$$

As a result of the previous steps the utility 'curve' as shown in Figure 8.2 is achieved. The iteratively found value of the utility is thereby 0.765 [6]. An exact equilibrium point could however not be achieved as there are too many uncertainties for low plastic waste load values of the PPF. Therefore, the given utility curve is here the value that comes closest to the PPF. Nevertheless, this function does provide insight in the trade off respondents make regarding the cost for the waste management and the environmental quality. The cost for the waste management system expressed in the impact on their purchasing power and the environmental quality expressed in the plastic waste load in the Petanu River.

8.5. COMPARING PREFERENCES AMONG SEGMENTS

In this section, differences around preferences between various groups of interest, the so called 'segments', are analysed. These segments are created by categorizations based on socio-demographic characteristics.

The preference differences between segments can be analysed by dividing the total dataset into groups by adding the so called group variables. These group variables are effect coded indicator variables that either take the value 1, 0 or -1. The codes divine to which group that line in the dataset corresponds. Since each line in the dataset corresponds to a respondent with certain characteristics, it can easily be traced down what the value of the indicator variable will be.

As said, the indicator variables are effect coded, which works similarly to dummy coding, but is usually used when there is no specific control group [118]. In other words, the preference of a specific group is compared to the whole set of group instead of being compared to the control group. Here, effect coding is concluded to be more compatible, since in the comparison of preference among groups, it is best to avoid choosing one group as the reference. Using effect coding, S-1 indicator variables[7] are being created. The first S-1 groups correspond to only one indicator variable and take the value 1 for that particular variable. The last group takes the value -1 for all indicator variables. In Table 8.13 an effect coding scheme for three variables is shown. When there are only two group segments, only one indicator variable is used that either takes the value 1 for one group and -1 for the other.

Table 8.13: Effect Coding Scheme

Group segments	**G1**	**G2**
Group1	1	0
Group2	0	1
Group3	-1	-1

The effect coded group variables are used in order to divide the dataset in to smaller sections and computing separate models per group segment. The betas of a certain group are estimated by choosing only the lines that correspond to the indicator value of that group. Next, the log likelihoods of the estimated segmented models (LL(β)) are used to calculate whether the parameters of these groups differ significantly. This process is called the Likelihood Ratio Test and makes use of the value of the Likelihood Ratio Statistic (LRS) [83]. Thereby the log likelihoods of the separate groups are subtracted from the the log likelihood of the overall model, where the betas of all respondents are examined. This is then multiplied by -2. Equation 8.11 shows an example of how the LRS is calculated.[8] Thereby LL(β_{total}) represents the log likelihood of the overall model.

$$LRS = -2 \cdot \left[LL(\beta_{total}) - LL(\beta_{group1}) - LL(\beta_{group2}) - LL(\beta_{group3}) \right] \tag{8.11}$$

[6] Utility is expressed in the unit 'utils'.

[7] S being the number of segments

[8] This is just an example for three group segments. When there are only two group segments, LL(β_{group3}) is left out. When there are more groups, the log likelihoods of those groups are also subtracted from LL(β_{total}).

The LRS is then used to compare it with the chi-square (χ^2) threshold value. This threshold value depends on the degrees of freedom (df), which is calculated by multiplying the number of parameters by the number of segments, minus one (S-1). Since the number of parameters is 3, for example for three groups the df is equal to 6. When the LRS value is higher than the chi-square threshold value, it can be concluded that there is a significant difference between the preferences of the examined groups.

Table 8.14 shows the estimated parameters of the groups for which the Likelihood Ratio test showed that there is a significant difference. The test has been conducted for segments of Age, Education Level, Disposal Method, Gender, Income, and Desa of Residence. Only the first three segments have proven to have significant preference differences. The parameters of the groups that have been found to have insignificant differences among the segments, are not presented in the table.

In the creation of groups, coherent separations and decently sized segments have been a focal point. The segments for Age have been separated from the median on, which created two similarly sized segments. Education has three levels, of which 'low' contains people who have had no study or only went to elementary or middle school, 'medium' contains people that went to high school, and 'high' consist of people that went to university. For disposal method, the category Pick Up also contains people that indicated to throw their plastic waste in a public garbage can, while the disposal methods Burn and Dump are conjoined together. This is mainly done, because small segments are hard to analyse statistically. Furthermore, the created cohesive groups made sense, based on their degree of pollution.

Table 8.14: Preference Differences Between Groups With Different Socio-Demographic Characteristics

		Age		Education			Disposal method		
Indicator	**All respondents**	**≤ 31 years**	**>31 years**	**Low**	**Medium**	**High**	**Self-Service**	**Pick Up**	**Burn & Dump**
PW-load	-3.84	-4.26	-3.40	-3.06	-3.53	-4.89	-3.27	-4.08	-3.43
Cost	-0.00810	-0.00636	-0.01020	-0.00464	-0.00819	-0.00976	-0.00472	-0.00955	-0.00454
Time	-0.0818	-0.0896	-0.0772	-0.0256*	-0.0903	-0.0949	-0.112	-0.114	0.0793**
ρ^2	0.141	0.149	0.138	0.0840	0.125	0.209	0.0960	0.166	0.120
LL(β)	-1429.404	-726.633	-664.599	-243.695	-723.241	-416.929	-185.522	-998.584	-229.354
n	2400	1232	1112	384	1192	760	296	1728	376

*Insignificant on a 0.05 level
**no face validity

After analyzing differences among the groups, it is interesting to know which attributes the groups differ in their preferences among. The fact that the models of the groups differ significantly does not substantially mean that all examined attribute parameters differ significantly. It is possible that the segments have different parameters for 'cost', but are indifferent for the other attributes. Moreover, it is also interesting to know what the utility function would look like when the segments (or household characteristics) are taken into account. For both analyses, so called 'interaction variables' are used.

Interaction variables are variables that depict the influence of a group (e.g. 'Age') to a certain attribute (e.g. 'cost'). The interaction variable is in fact the multiplication of the attribute with the group variable, which is an effect coded indicator variable. It is examined whether the interaction variable is significant. If that is the case, it can be stated that the groups differs in their preferences on the examined attribute. For example, to estimate whether the beta for 'cost' differs between the two groups of Ages, a new beta is estimated for the interaction variable of Age and 'cost'. When this beta is significant on a 0.05 level, it can be concluded that the examined segments have different parameters for that attribute.

To test whether there is a significant interaction of the group variable with multiple attributes, the Likelihood Ratio test is conducted repeatedly after modifying the model by adding an extra interaction variable. In this case, every added interaction variable adds an extra degree of freedom (df) for the examination of the LRS. After finding the significant interaction variables per segmentation (e.g. age or education), all these interaction variables are added to the overall model.

For the analysis, it appeared that the interactions between age and cost, education and PW-Load, and disposal methods and time were significant. All these interaction variables are added to the overall model, for which the utility function is as follows:

$$\begin{aligned} U = \left(\beta_{pwload} + \beta_{pe1} \cdot E1 + \beta_{pe2} \cdot E2\right) \cdot P \\ +\left(\beta_{cost} + \beta_{ca} \cdot A\right) \cdot C \\ +\left(\beta_{time} + \beta_{td1} \cdot D1 + \beta_{td2} \cdot D2\right) \cdot T \end{aligned} \tag{8.12}$$

For Equation 8.12 the following holds. P, C and T are the variables for PW-Load, cost, and time, while β_{pwload}, β_{cost} and β_{time} are their parameters respectively. $E1$ and $E2$, A, and $D1$ and $D2$ are the effect coded indicator variables for education, age, and disposal method. β_{pe1} and β_{pe2} are the parameters of the interaction variables of PW-Load and education. β_{ca} is the parameter of the interaction variable of cost and age. Lastly, β_{td1} and β_{td2} are the parameters of the interaction variables of time and disposal method. Table 8.15 shows how the groups segments are coded into effect coded indicator variables.

Table 8.15: Distribution of Current Waste Management (N=300)

Age		**Education**			**Disposal method**		
	A		**E1**	**E2**		**D1**	**D2**
>31 years	1	Low	1	0	Self-Service	1	0
≤ 31 years	-1	High	0	1	Burn & Dump	0	1
		Medium	-1	-1	Pick up	-1	-1

Table 8.16 shows the MLE estimates of the model with the integrated significant interaction variables. The value of the betas are shown in the first column under 'coefficient'. All betas appear to be statistically significant on a 0.05 level. The betas of the interaction between the attributes and indicator variables can be interpreted as differences in parameters between the groups.

Table 8.16: Results of the MLE Estimates: Utility Function with Dummy Variables

Indicator	**Coefficient**	**SE**	**t-stat**	**p**
β_{pwload}	-3.84	0.267	-14.42	0.00
β_{cost}	-0.00830	0.000849	-9.78	0.00
β_{time}	-0.0594	0.0196	-3.03	0.00
β_{pe1}	0.896	0.417	2.15	0.03
β_{pe2}	-1.18	0.377	-3.13	0.00
β_{ca}	-0.00214	0.000794	-2.69	0.01
β_{td1}	-0.0855	0.0306	-2.80	0.01
β_{td2}	0.134	0.0276	4.8	0.00

Table 8.17 gives the values of the betas per segment. In the first column the overall MLE estimates are given for all respondents, except for the ones that have a value missing for one of the three group variables. In this overall model, there is no interactions added. On the right, the MLE estimates of the model with the interaction variables are given. As can be seen, the beta of 'costs' differs for both age groups, the beta of 'PW-Load' differs per education group, and the beta of 'time' differs per disposal method group. Based on the Likelihood Ratio Test, it can be concluded that the model with the interactions has significantly better estimates, than the one without interactions.

Table 8.17: Significant Differences Among Groups, When Modelled Together

	Basic model	**Model with interaction variables**							
		Age		**Education**			**Disposal method**		
Indicator	**All respondents***	**⩽ 31 years**	**>31 years**	**Low**	**Medium**	**High**	**Self-Service**	**Pick up**	**Burn & Dump**
PW-load	-3.83	–		-2.944	-3.556	-5.02		–	
Cost	-0.00810	-0.00616	-0.01044		–			–	
Time	-0.0814	–			–		-0.1449	-0.1079	0.0746**
ρ^2	0.141					0.154			
LL	-1358.267					-1336.955			
n	2280					2280			

*Respondents who have a missing value for one of the grouping variables above, are excluded.

**no face validity

9

Results

In this chapter the results of the real-world coupled economic-environmental model are presented. These are in fact the ultimate results of the research. First, the general model will be presented, after which different utility curves of specific segments of the research group are shown. In the final section, the population segments associated with the highest and lowest environmental quality are given. These segments are formed by combining multiple characteristics of the population and hence corresponding preferences.

9.1. General Coupled Economic-Environmental Model

To start of, the general utility curve is coupled with the production possibility frontier (PPF). This is shown in Figure 9.1. As said before, the equilibrium point is the point on the PPF of which the tangent is equal to the utility curve. In Figure 9.2 it can be seen that the established general utility curve has a steeper slope than the tangent of the point on the PPF that represents the current situation (status quo). The status quo point is defined here as the location on the PPF where the plastic waste load (PW-load) is equal to 2015.5 kg/d and the corresponding impact on purchasing power (28,731 IDR/month). Note that the impact on purchasing power does not exactly correspond to the impact on purchasing power of Scenario 0, i.e. the current situation, (Section 7.3.2), which is 29,101 IDR/month. This is because the PPF is created by mathematical fitting of the created data points, rather than plotting a line exactly through the data points. The steeper slope compared to the status quo indicates that households are willing to pay more for their waste management services than they currently do in order to reduce the plastic waste load in the Petanu river.

Figure 9.3 shows the tangent of the endpoint of the PPF. It illustrates that this line is not equal to the general utility curve; the PPF does not reach a tangent equal to the utility curve. In other words, an equilibrium point can not be found here. This is because, the PPF cannot be extended as more uncertainties arise after the current endpoint. Nevertheless, the global location of the utility curve acts as a good indication that an average household is willing to pay for the improvement of the waste handling in the DAS Petanu and hence decrease of PW-load in the Petanu river.

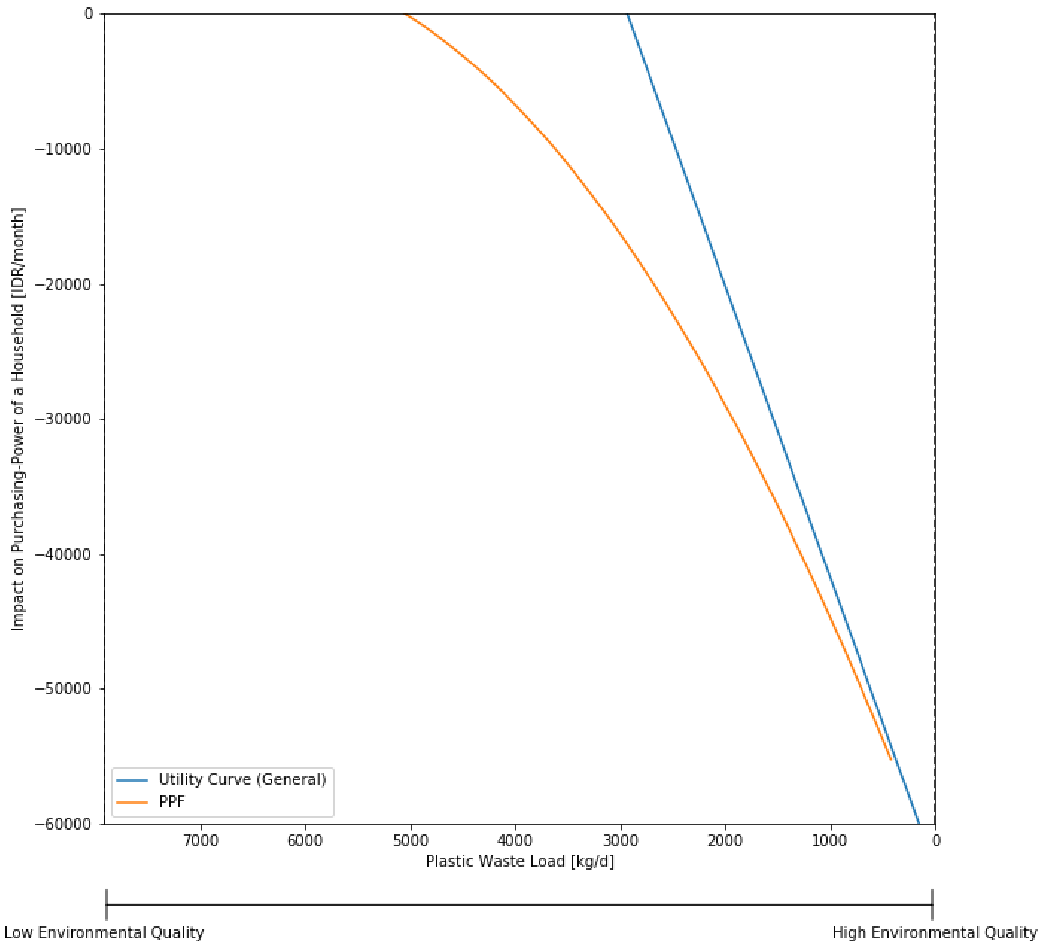

Figure 9.1: Coupling of the General Utility Curve with the Production Possibility Frontier

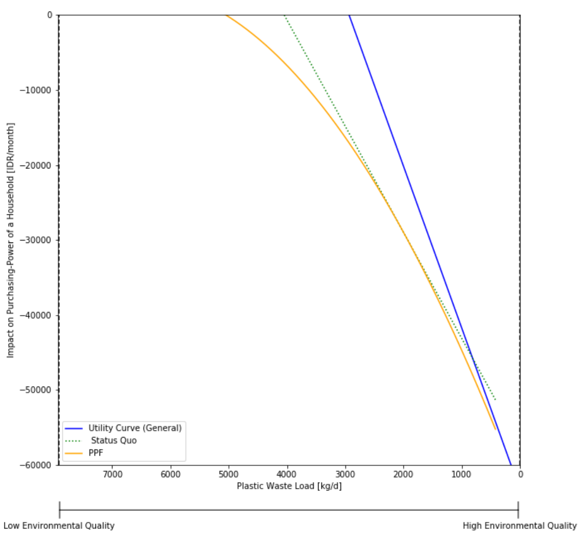

Figure 9.2: Coupling of General Utility Curve with the Production Possibility Frontier (PPF) and Depiction of the Tangent at Status Quo

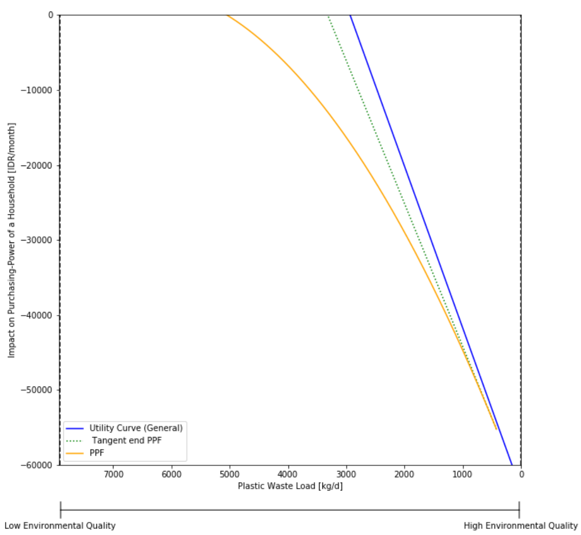

Figure 9.3: Coupling of General Utility Curve with the Production Possibility Frontier (PPF) and Depiction of the Tangent of Endpoint PPF

9.2. SEGMENTED ECONOMIC-ENVIRONMENTAL MODEL

The PPF is also coupled to the utility curves of different segments of the population. This is done according to Table 8.14. The segments in which the research group is divided are 'Age', 'Education' and currently used 'Disposal method'. The 'Age' segment is divided between groups above and below 31 years of age. 'Education' is divided between low, medium and high levels of education. The segments of 'Disposal methods' are divided into people that chose 'Pick Up', 'Burn' & 'Dump' and 'Self-Service'. Hence, the segments of 'Burn' and 'Dump' are taken together, because separately these segments were too small to analyse statistically. It should be noted that each of these segments are made in such a way that the other two attributes are kept at the level corresponding to the general utility curve, so within a segment only that particular attribute matters to the made differentiation.

Figure 9.4 shows the different utility curves for the age groups above and below 31 years of age. The points of tangency with the PPF indicate that the group with the age below 31 years are willing to pay more for the waste management system, which results in a lower PW-load. Figure 9.5 gives the utility curves for the three different education levels: low, medium and high education levels. The point of tangency with the PPF for the higher level education shows that the group with a higher education level are willing to pay more for the waste management system. Figure 9.6 shows the utility curves for the different methods of disposal, either 'Pick-Up', 'Burn' & 'Dump' or 'Self-Service'. The disposal method 'Pick-Up' has the lowest PW-load at the point of tangency with the PPF.

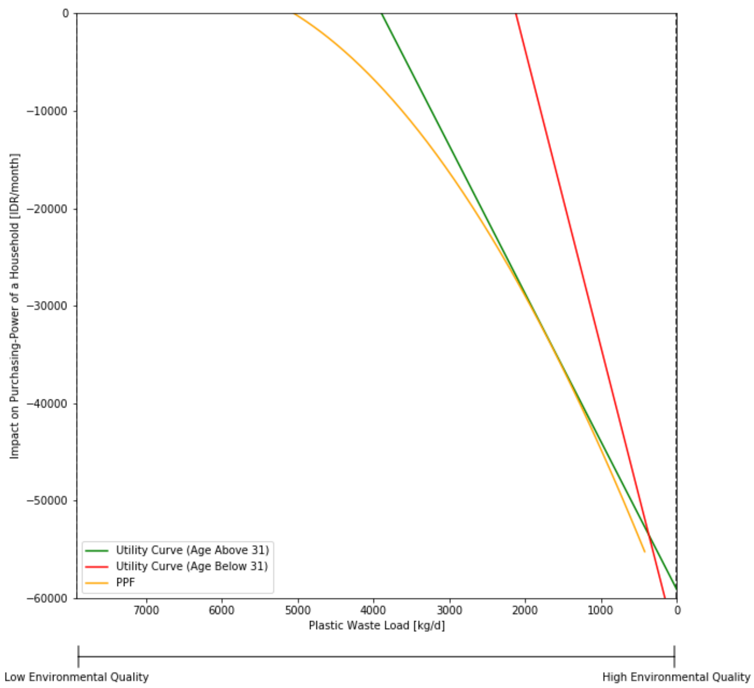

Figure 9.4: Coupling of the Utility Curves of two Varying Age-Groups and the Production Possibility Frontier (PPF)

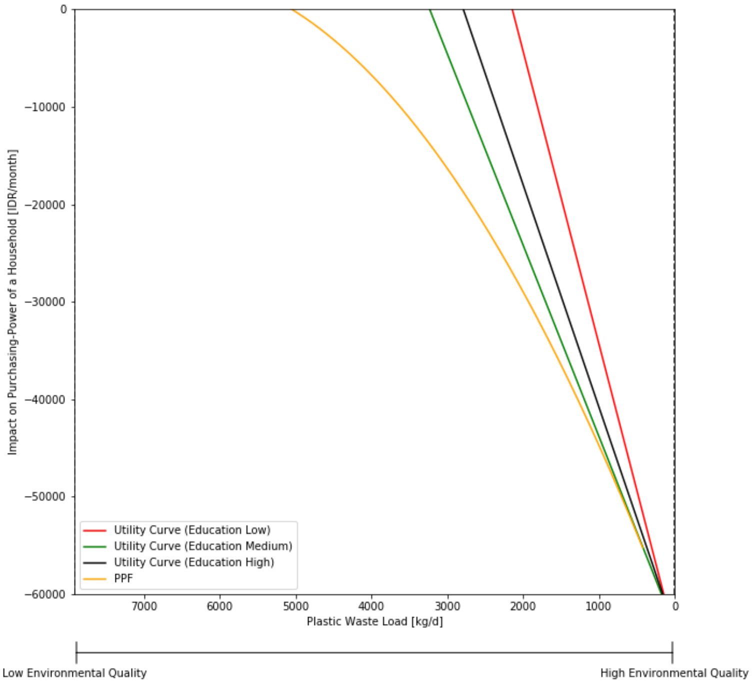

Figure 9.5: Coupling of the Utility Curves of three Groups with varying Education Levels and the Production Possibility Frontier (PPF)

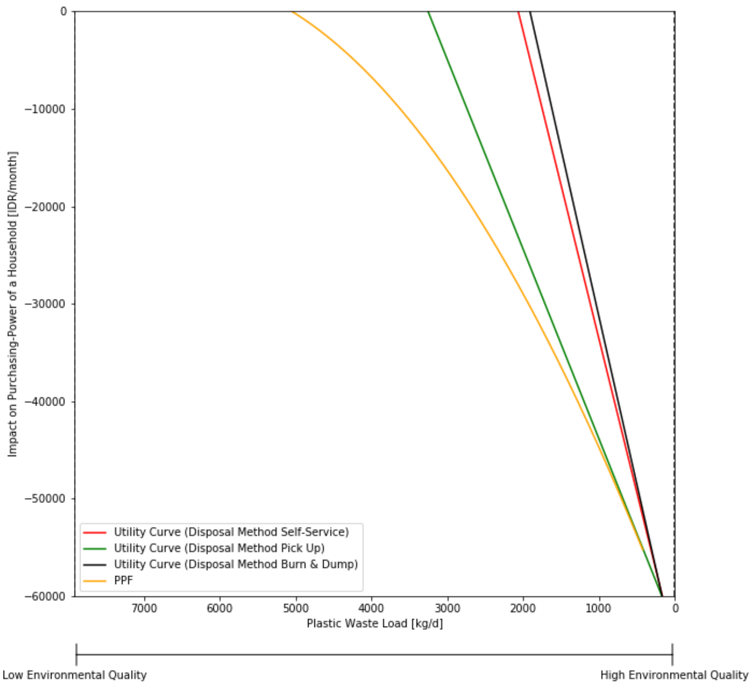

Figure 9.6: Coupling of the Utility Curves of three Groups with Varying Disposal Methods and the Production Possibility Frontier (PPF)

9.3. MODEL OF COMBINATIONS OF CHARACTERISTICS

Lastly, the PPF is coupled with utility curves that are created by combining multiple characteristics of the population, instead of solely looking at one particular characteristic as in Section 9.2. It is chosen to create the specific utility curves that have either a point of tangency associated with the highest environmental quality or with the lowest environmental quality, since those are most relevant for the research conclusions. The curves are based on the information in Table 8.17.

In Figures 9.7, 9.9 and 9.11 the utility curve is given for the population groups with a low educational level, age above 31 years and with varying disposal methods, plotted in such a way that it has a point of tangency with the PPF. This results in minimum associated environmental qualities. Figures 9.8, 9.10 and 9.12 show the utility curve for the group with a high educational level, age below 31 years and with varying disposal methods. These utility curves are also plotted in such a way that they have a point of tangency with the PPF. The combination of segments in this group result in a maximum environmental quality. Note that every combination of segments of the population (as in Section 9.2) is investigated, however only the combinations with associated minimum and maximum environmental quality are presented. Furthermore, note that the figures in which the varying disposal methods are the only variance, do not show much deviation from each other.

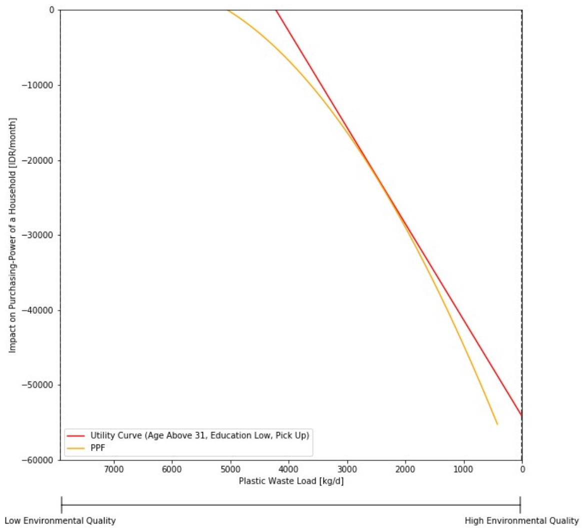

Figure 9.7: The Utility Curve of a Group with low Education Level, Age Above 31 Years and Disposal Method: Pick Up, Coupled to the PPF

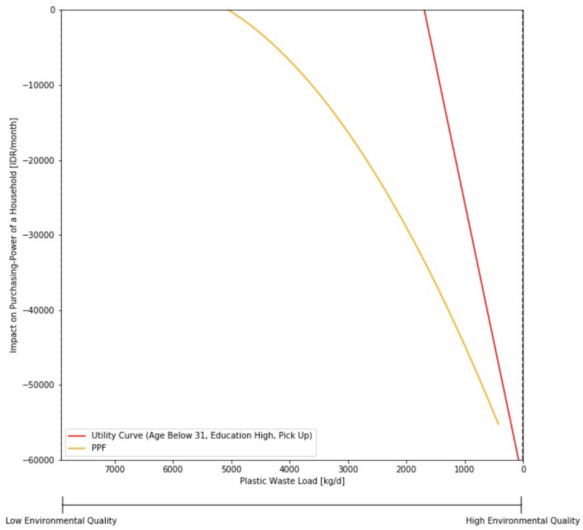

Figure 9.8: The Utility Curve of a Group with high Education Level, Age Below 31 Years and Disposal Method: Pick Up, Coupled to the PPF

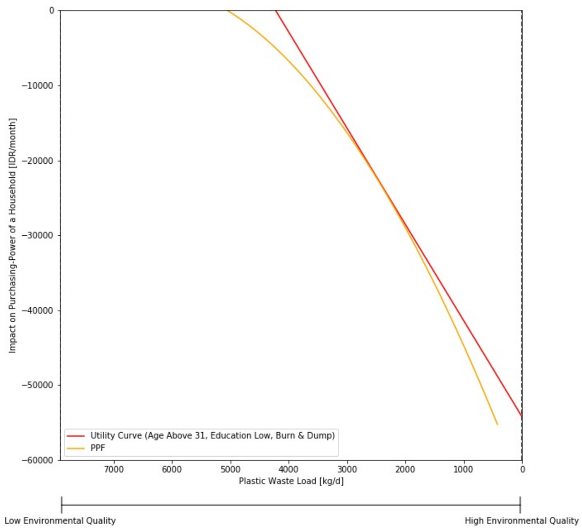

Figure 9.9: The Utility Curve of a Group with low Education Level, Age Above 31 Years and Disposal Methods: Burn & Dump, Coupled to the PPF

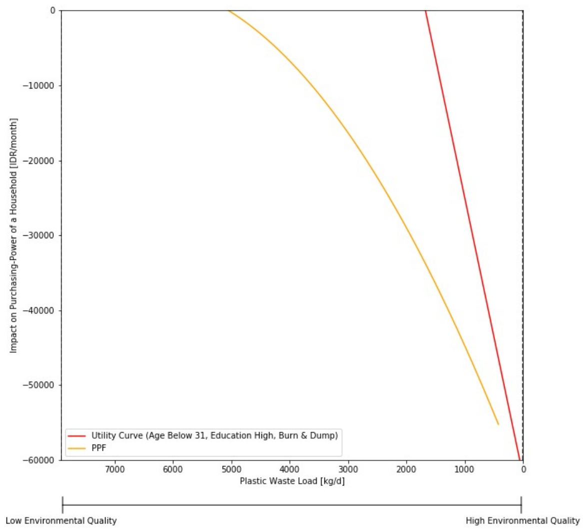

Figure 9.10: The Utility Curve of a Group with high Education Level, Age Below 31 Years and Disposal Method: Burn & Dump, Coupled to the PPF

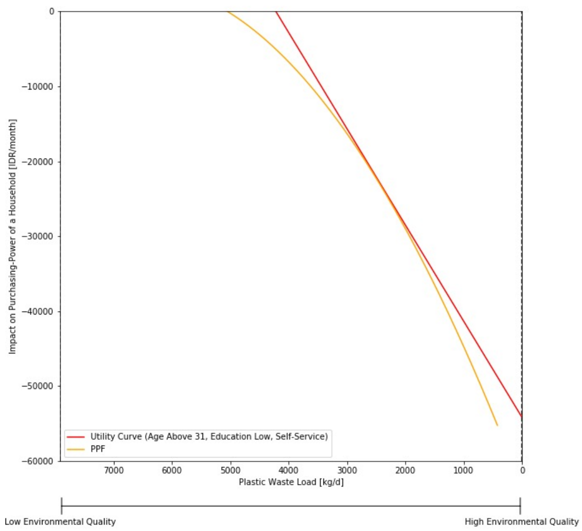

Figure 9.11: The Utility Curve of a Group with low Education Level, Age Above 31 years and Disposal Method: Self-Service, Coupled to the PPF

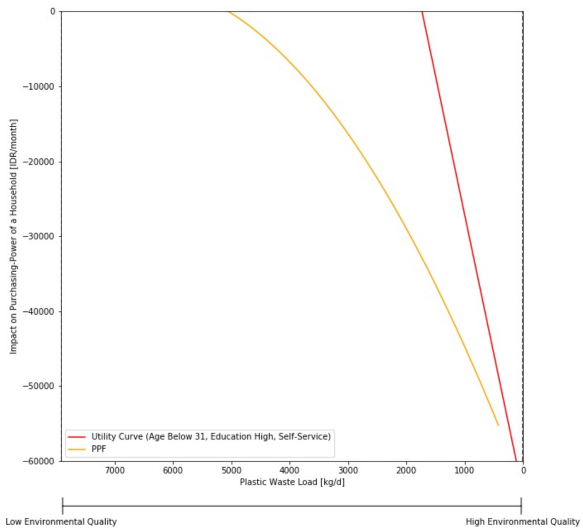

Figure 9.12: The Utility Curve of a Group with high Education Level, Age Below 31 Years and Disposal Method: Self-Service, Coupled to the PPF

10

CONCLUSION

Only little is known about the attitude of the Balinese people towards a solid waste management system. However, this knowledge is needed to improve the current inadequate waste management system, since the decentralised system relies largely on public participation. This is of importance since many Balinese rivers are polluted with plastic waste. To fill this knowledge gap, a real-world coupled economic-environmental model has been build that visualises the trade-off between plastic waste load in a river and the corresponding average monthly costs of the waste management system per household, expressed as impact on purchasing power of household. This model is used to answer the main research question:

What are the trade-offs between the environmental quality regarding the prevention of plastic pollution versus the economic activity of the local people in a specific watershed in Bali?

This research is a case study on the attitudes of the households in the watershed of the Petanu river, located mainly in the Gianyar regency in the south-east of Bali. The watershed of the Petanu river is flowing through five sub-districts, which are all indicated as critical. Critical implies in this case that improvement of the waste management system in these areas is high on the agenda of the Balinese Government. It has been concluded that other highly polluted rivers are only flowing through one or two critical areas and are a less good representation of the island of Bali as a whole. Therefore, an intervention-strategy for the waste management system in the Petanu's watershed, which are the recommendations following from this research, has the most impact and relevance.

The need for improvement of the waste management system in the watershed of the Petanu river is emphasised in this study. It has been determined that per day in total 7915 kg plastic waste is generated by the households within the watershed alone, which results in a plastic waste load of 2015.5 kg/d in the Petanu river during heavy rainfall. The high percentage of plastic waste entering the river is primarily a result of mismanagement of plastic waste at the household level, i.e. open burning and dumping of waste. The choice for disposing the waste by burning or dumping is fuelled by an inadequate waste management system. The waste management system of the Gianyar regency and Bali is decentralised with both, formal and informal waste collecting services. It is decentralised in the sense that garbage trucks, which collect waste from households, are either operating only within a certain village or sometimes even only within a neighbourhood. The availability of other services, like sorting facilities and collection points also differs per village. Waste collection of public spaces and buildings, like markets, is regency operated and hence less decentralised. Moreover, other formal services are privately operated and are too expensive for an average household. The last formal services are collection points for recyclables (bank sampahs), where PET plastic can be exchanged for money. These are however too sparely distributed, which is a missed opportunity as 30% of the generated plastic waste by households was estimated to be PET. Beside formal services, there is a informal waste collection service by individual collectors (pemelung). This is often the only service option when there is no garbage truck. However, collection by pemelung is limited and variable over time. Consequently, households are left with limited options for disposing their waste and, hence, burn or dump their waste themselves. Choosing these disposal methods is enhanced by the lack of knowledge on the environmental impact of open burning and dumping respectively. Part of the households in the watershed of the Petanu river even evaluate the mismanagement of plastic waste as not polluting.

The formal waste management system has thus to be extended, however to what extent depends on the willingness of local people to invest in the system. This is because users of a waste management system have to pay for this system themselves. Therefore, improvement of the waste management system implies greater costs for households and leads to a lower purchasing power. At the same time, improvement of the waste management system also leads to a lower plastic waste load in the river. The relation between invested money and plastic waste load reduction is non-linear, as for a higher plastic waste load reduction, the efficiency of the waste management system drops. This is shown with a production possibility frontier (PPF). The PPF is combined with a utility curve, that is a result of a stated-preference research among 300 households within the watershed. The utility curve visualises the average trade-off of the households regarding costs versus plastic waste load. Besides a general utility curve for the whole population in the watershed of the Petanu, also utility curves have been established for different segments of the population.

It was concluded that an average household in the watershed of the Petanu river is willing to pay more than they currently do in order to decrease the plastic waste load. To be precise, an average household is willing to invest 47,400 IDR per month in order to reduce their contribution to plastic waste load by 100 grams per day. Without further research, this trade-off could not be matched to the PPF to create an exact equilibrium point. Nonetheless, it does indicate that the formal waste management system can be extended with approval of the people. Furthermore, it was found that age and education level have a negative and positive correlation with the willingness to pay for an improved waste management system respectively. In other words, the trade-off of people that are younger or have higher education level, is more in favour of the reduction of plastic waste load. This is enhanced by the fact that combining the characteristics of a low age and a high education level leads to the population segment associated with the highest willingness to pay for an improved waste management system, and vice versa. Gender and income level appeared to have no significant relation with willingness to pay. Lastly, it was concluded that time is a significant determinant for the choice of disposal method corresponding to a certain plastic waste load. People that already use a collection service, want to be as time-efficient as possible.

11

Discussion

In this chapter the results are discussed and put in perspective of other literature. This is followed by an elaboration on all delimitations, assumptions and limitations of the research as a whole.

11.1. Results in Perspective

In order to answer what the trade-off of a household looks like between plastic pollution of the Petanu river and the costs corresponding the waste management system, a real world coupled economic-environmental model has been established. The production possibility frontier (PPF) visualises the most efficient waste management systems with corresponding cost and plastic waste load (PW-load) in the river. It can be seen that reduction in PW-load is possible, although to reduce the PW-load even further, illegal dumping by waste haulers should be tackled. This is in line with research of Ocean Conservancy and McKinsey Center for Business and Environment [10], who stated that besides increasing the collection rate also leakage of waste within the collection system should be reduced in order to improve the PW-load. Furthermore, it should be noted that the corresponding plastic waste load reduction (PWLR) of a single truck or bank sampah decreases as the total number of trucks and bank sampahs increases due to competition. As a result, the PPF is an arced curve.

The utility curve, on the other hand, provides information about the trade-off households make between cost for a waste management service and the PW-load that originates from a certain service. It can be seen that utility curve is not equal to the tangent of a point on the PPF. Therefore, no equilibrium point could be found. At this moment, the utility curve is steeper than the tangent of the last point on the PPF and definitely steeper than the status quo. This is a first indication that in general households are willing to pay more for the usage of the waste management services if they are available. To find the perfect equilibrium point more research on the assumptions underlying the PPF is needed. At the same time, the segmentation of the utility curve show some very interesting results.

First of all, it has been shown that younger people ($\leq$ 31 years old) are prepared to pay higher amounts for waste management services than older people with the same corresponding waste load reduction. As a result, the equilibrium point of both utility curves with the PPF is significantly different. This negative correlation between age and willingness to pay (WTP) for environmental quality is in line with studies from e.g. Tanrıvermiş [119], Ali *et al.* [120], Han *et al.* [121]. An explanation for this difference might be the awareness on the polluting effects of mismanaging of waste. Part of the children in kabupaten Gianyar has been educated at school about the damaging effects of plastic waste mismanagement, which created higher awareness also among their parents [122–125]. Another reason, also suggested by Ali *et al.* [120], is that older people are more sceptical towards waste management improvements and are therefore less likely willing to pay for the service.

Secondly, education leads to a higher WTP, as shown by the results. Hence, there is a positive correlation found between education level and WTP for waste management services. This is in line with other research on the the WTP for improved waste management services in developing countries (not specifically PWLR). For example: research by Awunyo-Vitor *et al.* [126] and Nkansah *et al.* [127] showed that the WTP increases with a higher education in Ghana, Rahji and Oloruntoba [128] achieved the same results in Nigeria. Furthermore, also Tanrıvermiş [119] and Han *et al.* [121] determined a positive correlation between educational level and WTP.

Moreover, gender and income level had no significant influence on the WTP. This is not in line with the results from the study of Han *et al.* [121], who found that men have a higher WTP than women and a positive relation between WTP and income. On the other hand, there are also studies that determined that women have a higher WTP compared to men [93] or found that there is no relation between WTP and gender [129, 130]. Additionally, most studies find a positive relation between WTP and income (e.g. [120, 130]). Hence, it is remarkable that there is no significant relation found between income level and WTP in this research.

Lastly, time has been determined to be a significant determinant for the choice of disposal method corresponding to a certain PW-load. Tucker and Speirs [131] showed that time is a big contributor for the people's attitude towards a disposal method. Moreover, a study by Ando and Gosselin [99] showed that the time needed for recycling has a significant influence on the recycling rates in multifamily dwellings, which could be compared to the compound housing in Bali. This is enhance by a study of Aprilia *et al.* [132] in which was found that on average a household in Jakarta is willing to pay others 16,500 IDR/month for sorting their waste if the government requires sorting at household level. This means that the stimulated disposal method by a government should be as time-efficient as possible for the households in order for them to choose that particular disposal method and corresponding PW-load.

11.2. DELIMITATIONS

This research was conducted in the limiting time-span of twelve weeks. Therefore, delimitations were needed to be able to finish the research in the given time.

11.2.1. STUDY AREA

The DAS Petanu has an area of 9.791 km^2 and is home to approximately 21,968 households [26]. In a maximum fieldwork period of two weeks it is however impossible to conduct one survey in every household. Consequently, it has been chosen to conduct the survey only in six desas in the DAS, in the downstream end. These six desas have been chosen as the social-demographic situation in all of them is different, creating a diverse target group. Hence, these six desas are assumed to represent kabupaten Gianyar as a whole. In the six desas approximately 50 households conducted the survey (Figure 6.3). To have results with a confidence interval between 90 and 95%, 300 respondents is a large enough sample size (Section 6.6).

11.2.2. PLASTIC WASTE LOAD AND DISCHARGE

It is known, that the PW-load in rivers is the highest at the beginning of the rainy season [9, 105]. The monsoon season begins approximately in October, however the extremely heavy rainfall occurs mostly in December [27, 31]. This indicates that the PW-load and discharge is the highest in December. However, the fieldwork was conducted from the end of February till the beginning of March. Hence, measurements of the peak PW-load and discharge were not possible. Moreover, it was chosen to focus the research more upon to attitudes of the local people rather than on the river characteristics and observed PW-load. Therefore, no measurements on PW-load and discharge were performed. This implies that the plastic waste concentration model of the Petanu river could not be validated and is purely theoretical.

11.3. ASSUMPTIONS

Besides time constrains, the research is subjected to assumptions. These assumptions were necessary as some information was not available or only partly.

11.3.1. REPRESENTATIVENESS

The capability of the respondents from the six researched desas to represent the complete kabupaten Gianyar is a strong assumption. To test for a representative sample a statistic test (chi-square) should be performed. The target group of the survey are the persons within a household that makes the decisions regarding the household's waste management (i.e. not the total population), however, socio-demographic characteristics of kabupaten Gianyar and/or the researched desas are only available for the total population. Therefore, the inputs of the test are too different to compare them statistically. It is however possible to compare the results visually with literature data from the six desas and kabupaten Gianyar.

First of all, it is clearly visible that among the respondents there are relatively more men (65%) than women (35%). In kabupaten Gianyar and the researched desas there are approximately the same amount of women compared to men [27, 30, 36–38, 41, 42]. This can be explained by the fact the only men are allowed to visit the banjar meetings, which were in some desas used as location to conduct the surveys (Chapter 6). However, women are mostly in charge of household waste management in Indonesia, as most of them have housekeeping as their primary activity [133]. The 'hiding' of women in houses makes it harder to conduct surveys among them and as a result they are under-represented in this research. Another reason for the under-representation is that the illiteracy percentage of women is higher than of men in the region [134]. This makes it harder for them to fill in the survey without the help of an interpreter.

Furthermore, because of the set target group the percentage of the respondents with an age between 21 and 40 is 54%. This is much larger than in the whole researched desas, where on average only 30% of the people has an age between 21 and 40 [36–38, 41, 42]. This, however, is not a problem as the six desas have an average age composition of the population comparable with kabupaten Gianyar [36–38, 41, 42, 135]. This means that the age composition of the target group in different parts of kabupaten Gianyar would be similar to the age composition of the respondent's in this research.

Thirdly, the education level of the respondents is relatively high with only 4.7% having elementary school as highest education level and 1.0% that never went to school. In comparison, 26% of the total population of the six desas never went to school and 37% only finished elementary school or is still in elementary school [36–38, 41, 42]. Especially the 26% of the people that never went to school is of importance as those are all people of the older generations and thus possibly part of the target group [36–38, 41, 42]. This group is hard to interview with the help of a written survey as lack of education results in illiteracy. Furthermore, people that never attend school appeared to be more likely to speak only Balinese rather than also Bahasa Indonesia, which is the language that is used for the survey. However, in kabupaten Gianyar this percentage is lower as 8.24% of the people has never attended school [134]. Meaning an under-representation of the uneducated people in the six desas is less important.

Moreover, the household size of the respondents is comparable to the average household size of five people in Gianyar and the six desas [36–38, 41, 42, 135] as 60% of the respondents answered to have a household of 4-6 people. The larger household sizes of the respondents could be due to misinterpretation of the question, more on this can be found in Section 11.4.1.

Lastly, most respondents, that knew and were willing to tell, earn less then 4.6 million IDR per month. In the Bali province the minimum wage is 2.5 million IDR per month (in 2020) for a 40hr workweek [136]. At least 25% of the respondents earn less than the minimum wage. This can not be compared with data of kabupaten Gianyar since this data is not available.

11.3.2. Mismanaged Plastic Waste at Household Level

The percentages of waste being either burned or dumped at household level for all desas are based upon a study of The Bali Partnership Assembly [11], which presents an average of Bali. This could lead to an deviation of the real situation in the DAS Petanu. Furthermore, these percentages deviated from the average percentages found in the results of the questionnaire (Table 6.3). This can be explained by two reasons. First of all, The Bali Partnership Assembly [11] determined the percentages based upon measurements of PW-load in waterways and the environment. Yet, in this research the percentages have been determined based upon the question 'How do you dispose your plastic waste most of the time?'. This question is subjected to social desirability [137, 138]. In other words, people could answer that they do not dump their waste as they feel ashamed about it, although in real life they do dump their waste. This means that the percentages determined by the questionnaire are subjected to bias and therefore, also deviate from the real world situation. Secondly, the results from the questionnaire have a large standard deviation, especially for burning. This is a consequence of a decentralised waste management system and different social desirable attitudes to the disposal methods. In a decentralised system the waste management services deviate from desa to desa. Furthermore, due to different education levels, attitudes to the individual disposal methods could be different. This implies that percentages of burned and dumped plastic waste are sensitive to the chosen desas in this case. Both reasons were taken into account when choosing 19 and 33% for burning and dumping respectively. The sensitivity analysis of the PPF showed, however, that the percentage of dumping has a significant influence, although limited, on the PPF (Figure 7.9).

11.3.3. Dumped Plastic Waste

Both, for the establishment of the PPF and the utility curve it has been assumed that all plastic waste dumped in the environment ends up eventually in the river. However, the build-up of the amount dumped (plastic) waste in the environment during dry periods has been neglected. This build-up does take place as (plastic) waste is mostly re-mobilised due to rainfall [9]. There are however cleanups, organised by organisations like Ocean Mimic and Trash Hero, that reduce this build-up by picking up plastic waste in nature. Although, most cleanups are currently taking place on beaches instead of in the inland areas. Hence, the effect of clean-ups on the build-up of plastic waste in the environment during the dry season might be limited. This means that, despite the assumption that all plastic waste that gets dumped ends up in the river, the estimated PW-load in the river is probably lower than the real load. To check the theoretical PW-load it is wise to measure the PW-load in the Petanu river at the peak of the monsoon season in December. If the percentage of dumped waste that ends up in the river is known, it will reduce the variability of the PPF significantly (Figure 7.9).

11.3.4. Burned Plastic Waste

Plastic waste is often burned together with other waste material. It is assumed that 19 % of the waste generated in the DAS is burned [11]. 17.08 % of the waste generated consist of plastics [27], therefore it is also assumed that 17.08 % of the burned waste is plastic. This assumption is permissible because it is assumed that all generated waste is burned when this disposal method is chosen by households. After open burning 20-30 % of the burned materials are left as residuals, the average of this is assumed as 25 % of the burned plastic is left as residual. The residuals are assumed to get retained in the environment. Because of rainfall the residuals are assumed to eventually get washed into the Petanu river. The burned fraction of waste has a insignificant sensibility for the PPF curve and thus the uncertainties are insignificant.

11.3.5. Illegal Dumping by Waste Haulers

Leakage of plastic waste by illegal dumping done by waste haulers is a large contributor of the total marine plastic soup [10]. However, this research is focused solely on the impact of increasing the waste-collection waste by expanding the waste collection system. Therefore, the percentage of collected waste (6.5%) that is leaked into the environment due to illegal dumping is kept constant in all scenarios. The percentage that is used is based upon a research of Widyarsana *et al.* [16]. This study defined the exact percentage of waste that is illegally dumped after transporting the waste to a TPS3R [16]. This percentages is determined for solid waste and not for plastic waste in particular. However, it has been determined that of the mixed waste that enters the TPS3R, 65% is of low-residual-value of which 10% is illegally dumped. Approximately, the same percentage of plastic waste is of low-residual-value, as only 30% is PET [19]. Therefore, it is assumable that also 6.5% of the total plastic waste entering the TPS3R is illegally dumped. Moreover, from the sensitivity analysis can be concluded that a deviation of 10% of the 6.5% has negligible influence on the PPF.

11.3.6. PET Plastic

The average percentage of PET over plastic on three beaches in Bali, at which a river outflows, is determined by the Pantai group 1 to be 4.8% [17]. It is assumed that this percentage is representative for the Petanu river. In the research of group 1 the spread in the PET percentage of the total plastic waste at those beaches was significant. Thus the assumption that 4.8% of the plastic in the Petanu river is PET is uncertain. Pantai group 3 found that 30% of the plastic consumption consist of PET. This data is based om multiple households in three areas outside of kabupaten Gianyar. It is assumed that the PET consumption in the DAS Petanu is the average of the three other regions, which may result in a bias. Nevertheless, the sensitivity of the percentage of PET over the total plastic waste quantity in the Petanu river is negligible. The uncertainty of the percentage of PET plastic in the Petanu river is therefore less important.

11.3.7. Costs of the Current Waste Management System

The average costs of the current waste management system for a household are estimated based upon the questionnaire. As a result more than 60% of the respondents have a monthly disposal cost of 0 - 40,000 IDR. Almost none of the respondents have a monthly disposal cost of more than 80,000 IDR. There is, however, a big difference between paying nothing for the service or paying 40,000. At this moment, the average of 20,000 has been used in the calculation of the costs of the current waste management system. In total this brings the average monthly paid fee in the six desas to 29,101 IDR/month/household. However, during the fieldwork often people told that they only need to pay 10,000 or 15,000 IDR per month. Operational costs or investments costs that are paid by the government with tax money, is in this number not taken into count. Nevertheless, it is an indication that there could be a difference between the estimated costs of the current waste management system and the real costs. The costs of the current waste management system in the six desas could be scaled-up to the whole DAS Petanu, because 1) the six desas are representable for the whole DAS Petanu, 2) the standard deviation of the monthly costs is small and 3) the answer is not subjected to social desirability. However, the current cost is an important parameter with significant influence on the variability of the PPF (Figure 7.9).

11.3.8. Costs and Capacity Waste Management Elements

The cost of a truck consists of the operational costs and the investment costs. The operational costs consist of the wages for the garbage collectors, wages for the truck drivers and the petrol costs. These costs are given by the Dinas Lingkungan Hidup Kabupaten Gianyar [27] and are given for the current situation. In the current situation the trucks are not operating every day, the costs are calculated assuming that the trucks are operating every day of the week. It is assumed that the workers are payed as much for the additional days of work. The petrol costs are proportional with the operational days. The investment costs of 350 million IDR are spread out over 10 years. The lifetime of the truck is assumed to be 10 years, but this could be shorter of longer and this influences the investment costs per month. The loading space of a garbage truck has a volume of 6 m^3 (Appendix E), however this is not taken as the capacity of the truck. The trucks are overloaded, therefore it is assumed that the trucks are loaded 1.5 times the loading space on average.

For every two trucks one TPS3R facility is assumed to be needed, in the present situation this is not the case. From the data of the TPS3R in desa Sanur Kauh, it is known that households pay approximately 30,000 IDR per month for the TPS3R services. It is assumed that 10.5 million IDR is needed for the TPS3R facility to break even. The acquisition cost of a TPS3R facility is 100 million IDR, the life span of the facility is assumed to be 25 years. This life span could also vary and thus the monthly investment costs of 330,000 IDR per month is assumed. For the TPS3R facility the processing capacity of the facility in Sanur Kauh is assumed to be normative.

The investment costs of a bank sampah are estimated to be 60 million IDR and the life span of a bank sampah is approximately 25 years. The monthly investment costs are thus also variable. The operational costs of a bank sampah consist of one worker. The assumed wage for one worker is assumed to be 3 million IDR per month. The bank sampah itself is assumed to be profitable by buying a reselling PET. The capacity of a bank sampah is dependent on the number of people which are handing the PET over to a bank sampah, which is assumed to be 12.7 kg a day.

As can be seen in Figure 7.9 the cost of the waste management elements have a high sensitivity for all variables. Thus a change in cost of the elements have a large effect on the shape of the PPF. The uncertainty of the cost of the elements results in uncertainty for the PPF curve. However, the costs for all elements have been estimated with creditable information and thus have been estimated relatively well.

11.3.9. Constant RF_{MPWH} Value

In the creation of the PPF it has been assumed that the RF_{MPWH} value stays constant between the scenarios. In other words, with different amounts of MPWH the percentages of people burning and dumping stays constant relative to each other. Meaning that independent of the MPWH 37% of the MPWH is burned and 63% dumped. This in-dependency is a very strong assumption.The results from the questionnaire could suggest that in case of lower collection rates (the case in desa Kenderan) people tend to burn more rather than dumping (Table 7.4). However, caution is needed with these results because of its sensitivity to social desirable answering. Research by Irianti and Prasetyoputra [139] also indicated that in case of lower household collection rates burning is preferred over dumping. Although there are some indications that the percentages of MWPH burned or dumped shift depending on the total amount of MPWH, the relation between the two is not quantified so far. The RF_{MPWH} has a strong influence on the eventual PW-load value of the scenarios. Especially, on the PW-load of the scenario without a waste management system, as in this scenario the MPWH is equal to the total PW-Production. Therefore, assuming a certain relation could result in even less correct pollution values for the individual scenarios. Hence, it has been chosen to keep the RF_{MPWH} value constant.

11.4. Limitations

Lastly, this research has some limitations. These limitations are a results of the choice of methodology. The limitations have an influence on the result and especially the generalisation of the results of the research.

11.4.1. Survey Design

The stated preference and thus the utility curve has been based upon the survey solely. The stated preference has been obtained by providing respondents with multiple choice-sets [84]. In every survey there were eight choice-sets of the sixteen possible choice-sets (2 blocks, both 8). In total there were six surveys with different orders of the choice-sets and different combinations within the choice-set, to prevent bias [140]. In all these choice sets, the costs of the 'service' are monthly. For the time, this was expressed in minutes per day. This was chosen as the fees for the waste management service are paid monthly and every day people spend time on waste management. However, it could have biased the choices, because at first sight it can appear like a trade-off between a certain amount of IDR per day and a couple of minutes per day (walking time). To reduce this bias, the costs were also presented per day and the time per month underneath the choice sets.

Although precaution is taken while designing the survey to prevent biased results, stated preference data capture behavioural intentions, not actual behaviour. Discrete choice experiments "remain controversial because of their hypothetical nature. [...] Since respondents are asked to answer hypothetical questions, hypothetical bias may arise, i.e. respondents' expressed preferences may differ from their actual behaviour under real economic circumstances" [141]. In general, people tend to overestimate their WTP for a certain good [142]. It is advised to take this into account while implementing the results of this research. The utility isolines could shift into the bottom left direction if respondents overestimated their WTP.

Secondly, the levels of the attributes were determined during the desktop study, at the beginning of the research. The attribute-level 'monthly costs for disposal' varies between 20,000 and 140,000 IDR/month. These level values are determined based on privately operated waste service providers, like Ecobali. During the fieldwork it was discovered that these companies are mostly used by expats and businesses, because the rates are too high for the average resident. The 'normal' households paid approximately between 10,000 and 40,000 for the waste management services. As a result, the attribute-levels for 'monthly cost' are partly too high for a real-life situation (holds for the options 100,000 and 140,000 IDR/month). As a result, respondents have to choose between two options that are probably too expensive for them. This implies that the utility curve might be overestimating their WTP as well.

Moreover, to make sure the utility curve interferes with the PPF curve, a strong assumption is made about the stated preference of the respondents. It is assumed that respondents are aware of the effect of a disposal method on the PW-load in the Petanu river. This assumption is needed to transform the preference for a disposal method to a corresponding contribution to PW-load. As a result, the modelled PW-load contribution, i.e. environmental quality, is 0.09 and 0.36 kg per household per day for the disposal methods Burn and Dump respectively. This assumption however, is not completely in line with the estimated parameters in the utility model with dummy variables. In this method the burn parameter was estimated at -0.81 and the dump parameter at -0.75, meaning that the utility of these parameters for the respondents is quite similar. In other words, it is unlikely that respondents are aware of the fact that dumping is more polluting than burning in terms of contribution to PW-load. This is enhanced by the fact that also the attitudes of the respondents regarding the environmental impact of the disposal methods are similar: respondents rated the environmental quality of burn and dump equally bad as the distribution over the options are identical (Figure 6.6). The difference between modeled environmental quality and the assumed environmental quality by respondents can be partly be explained by the fact that air polluting effect of open burning are neglected (Section 11.4.2), while calculating the modeled environmental quality of this disposal method. To avoid this assumption, the survey design could have been adjusted; The amount of kilograms of waste that ends up in nature on average (or the percentage) by using a particular disposal method could have been stated in the survey at the disposal method pictograph. In this way, respondents were aware of the consequence of their stated preference. Because it was thought that respondents cannot make a correct estimation about the amount of plastic in one kg of waste, it was decided to omit this, to avoid bias.

Lastly, there is a possibility that respondents misinterpreted the question about the number of people in their household, since there is a percentage of respondents that stated they live in a large household of more then 10 persons (even up to 42 persons). Although this is possible, it is also possible these respondents interpreted the question as the number of persons living in their compound. A compound is a housing block where multiple families live and share facilities, a common way of living in Bali. Therefore, caution is needed with the answers of this question and has it been chosen to use the number of households in the individual desas stated in the research by the Badan

Pusat Statistik Kabupaten Gianyar [36, 37, 38, 41, 42].

11.4.2. Environmental Effects Open Burning Plastic Waste

It was chosen to focus the economic-environmental model on the environmental qualities of the different disposal methods of plastic waste on waterways rather than on the environment as a whole. As a result the negative effects of open burning, are only counted in terms of the percentage of plastic waste remaining as bottom ash and grate siftings. This means that the air pollution [55] and the corresponding health issues [56] of open burning are neglected in this research. Therefore, caution is needed during interpretation of the results. Moreover, in the question where the respondents are asked to rank the disposal methods in terms of pollution, it was not specified that the pollution related is to the pollution of waterways. Hence, the respondents could rank the burning of plastic higher in terms of pollution as they could have included the air pollution from open burning.

12
Recommendations

In this chapter recommendations are given. The recommendations are dived into three different parts: recommendations for the government of Gianyar, recommendations for further research and recommendations for the continuation of the Pantai Project.

12.1. Recommendations for the Government of Gianyar

The results of this research suggest that on average the inhabitants of Gianyar are willing to pay more for the waste management system than they currently do, if this results in less plastic pollution. Here lies an opportunity for the government of Gianyar. Improvements can be made in different areas. The most essential improvements, learned from both calculations and the expert interviews, are: opening more TPS3R facilities (so more waste is recycled, and less ends up in a landfill) and making sure every desa is served by a truck and a bank sampah. At the same time the current extension of landfill capacity should be continued. It is recommended to start facilitating a garbage truck in desas that are most polluting at the moment, for example desa Kenderan. Policies on avoiding the illegal dumping by waste haulers should also be developed, from experts is learned that they often do so to avoid fees at the landfill. Subsidising these fees could be a possibility.

Improvements could also be made at the cost side. Currently the garbage trucks and sorting facilities do not run at their full capacity, especially in desas with less inhabitants. By centralizing the waste management system more and, for example, use the same truck and TPS3R for multiple desas, cost can be reduced. The easiest way to achieve this is to have neighboring desas share waste management facilities.

Studies into the age-segments revealed that younger people are willing to pay more for the improvement of the waste managements system compared to older people. This can be explained by the higher awareness of younger people regarding the environmental impact of different disposal methods. The current education programs in schools probably explain this, they seem to have effect. It is therefore recommended to extend these programs to gatherings with older people, for example, banjar meetings.

Lastly, since the attribute 'time' has a significant contribution to the disposal method choice. It is recommended for a recycling strategy to succeed that the effort that households need to put into the disposal method is maintained low. For example waste separating in the truck/facility instead of separating at home. Furthermore, it is recommended that pick-up of waste by garbage trucks is done at the doorstep of the houses and not only at main roads and more bank sampahs are opened in the DAS Petanu.

12.2. Recommendations for Further Research

The real-world coupled economic-environmental model in this research gives a good first indication of the trade-off made by households between plastic waste load and the cost of the waste management system. However, it is recommended to further improve the production possibility frontier (PPF) and utility curve of this research in order to give a more exact advice to the Government of Gianyar. Improvement can be achieved by studies on:

Mismanaged Waste at Household Level A counter-check of the percentage of (plastic) waste that gets dumped or openly burned by households would eliminated the subjectivity of the PPF to social desirable answers. Both dumping an burning have a high environmental impact on the river and are an indication of the amount of waste that is still collectable per desa. Therefore, more precise determination of the percentages and/or total amount of plastic waste that is mismanaged at household level per desa would result in a better understanding of the impact of every desa on the total plastic waste load. These exact impacts can then be used to give a very detailed advise on: 1) the optimal location for a TPS3R or other recycling facility to achieve the highest plastic waste load reduction, 2) where garbage trucks should be bought and 3) where education on waste management is most needed.

Entry Locations of Plastic Waste in the Petanu River Measurements of the plastic waste load in the Petanu river before and after every desa would be an helpful tool to improve and validate the created model. These observation can be used to modify the simplified model such that its outcomes lies closer to the observed values and thus are more realist. As a result, the created PPF will become closer to reality since all scenarios are based upon the current plastic waste load. Furthermore, a preciser identification of the most polluting desas is possible. This information can then be used for the intervention-strategy.

Relation between Rainfall Intensity and Re-Mobilisation of Plastic Waste It is already known that dumped plastic waste is re-mobilised by surface runoff during a heavy rainfall event. However, the exact relation between rainfall intensity and the re-mobilisation is unknown to date. This relation can be used to determine the fraction of dumped waste, that eventually ends up in a river. This fraction is used for both the production possibility frontier and the utility curve and a more precise relation would therefore enhance the outcome of the coupled economic-environmental model.

Inclusion of the Catering Industry and Public Buildings It would be interesting to expend the research by including the catering industry, e.g. hotels and restaurants, and other large public buildings like schools. It is expected that hotels and restaurants produce large amounts of plastic waste, as those buildings are directly linked to tourists, who generate more plastic waste than local people do. On the same time, those public places are supposed to have a waste management system that is operated by the regencies instead of the villages or neighborhoods. Examination of the adequacy of this separate waste stream would be useful tool in order to get a complete overview of the waste management system in Gianyar.

Illegal Dumping by Waste Haulers Collected waste is partly illegally dumped by waste haulers, however exact amount are unknown. Furthermore, strategies to mitigate illegal dumping are needed to decrease the plastic waste load in the Petanu river. Therefore, a study dedicated to investigating illegal dumping and possible mitigation strategies would be a recommended follow-up of this research.

12.3. Recommendations for the Pantai Project

The Pantai Project is a great initiative, with great potential. One of the challenging aspects of the Pantai Project is that multiple groups join the project. Al these different groups spend a limited time period of about 2-3 months on the project. In this short period of time, the groups have to get 'a feeling' for the project, 'a feeling' for the situation at Bali, execute their own project and finally write a report. It is difficult in this short time period to really make a difference for the local people. In the end this is one of the goals of the Pantai Project.

To make a difference for the local people some kind of central coordination is required. This is however, currently missing in the Pantai Project. Also for us it was unclear at the beginning, who or what the Pantai Project was and whether to sign up or ask for permission to participate in the project [1]. The founders of the Pantai Project currently do some of the coordination between groups, but in essence the groups act individually. This provides a lot of freedom for the groups: they can investigate what they want, as long as it is concern with plastic pollution. But as a result, the Pantai Project and Bali currently figures more as 'case study platform'. Where all kinds of studies are tried out, but without real direction.

In our opinion, the Pantai Project should choose which direction it wants to go: stay in the current 'case study platform' form, or switch to a more centrally coordinated foundation. The research groups can all be directed in one direction by means of central control. As a result, we expect that more can eventually be achieved (for example, setting up a recycle facility) and that a difference can be made in a sooner stage. Another advantage of central guidance, is that cooperation with other NGOs is likely to be easier if the project has a clearer direction. There are a lot of NGOs full-time active on Bali with the same goal: stop plastic pollution. Collaborating is essential to avoid reinventing the wheel. The NGO Mckinsey.org already showed interest in a collaboration. McKinsey.org's aim is to *"optimizing waste collection, for example by educating households about waste separation, improving the efficiency of TPS3R sorting facilities, through training and incentivisation, and securing demand, by working with companies who have committed to use recycled materials"* [143]. Currently they manage the TPS3R in desa Sanur Kauh and are planning to extend their work to other areas of Bali. The precise details of a partnership have yet to be determined. But one possibility, as suggested by McKinsey, is that the different Pantai groups may contribute to individual pieces of McKinsey's major research.

[1] This recommendation was written before Thomas van Welsenes, one of the founders send an email to all the Pantai Project participators about plans "to take the Pantai Project to the next step." We contacted him about the recommendations we have as a group, as stated above

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Appendices

A
MULTI CRITERIA ANALYSIS CRITICAL AREAS

In this appendix, a comparison between three critical areas is made using a multi criteria analysis. These three areas, i.e. Gianyar Region, Bangli Region and the Negara Region, followed from combining the study of Pantai Project Group 2 [18] with a study of The Bali Partnership Assembly [11]. Due to time constraints, only one study area could be selected. The multi criteria analysis is used as tool for the selection of the study area of this report.

A.1. ASSESSMENT CRITERIA

The used assessment criteria are 1) plastic pollution, 2) tourism, 3) socio-demographic and geographic factors and 4) the area of the catchment. These criteria were chosen because the study area should represent the island Bali as good as possible and have a sizable plastic problem. Furthermore, it should not have a too large area in order to be able to conduct the fieldwork within two weeks.

A.1.1. PLASTIC POLLUTION IN THE RIVER CATCHMENT

The value for this criterion is determined based on the data by the Bali Partnership [11]. For different rivers in Bali they determined how much plastic waste per day leaks in the environment. As can be seen in Figure A.1. Level 1, the most polluting level and biggest circle, means that more than 10.000 kg plastic waste leaks into the environment every day, Level 2 means that about 10.000 kg plastic waste leaks into the environment every day, etc.

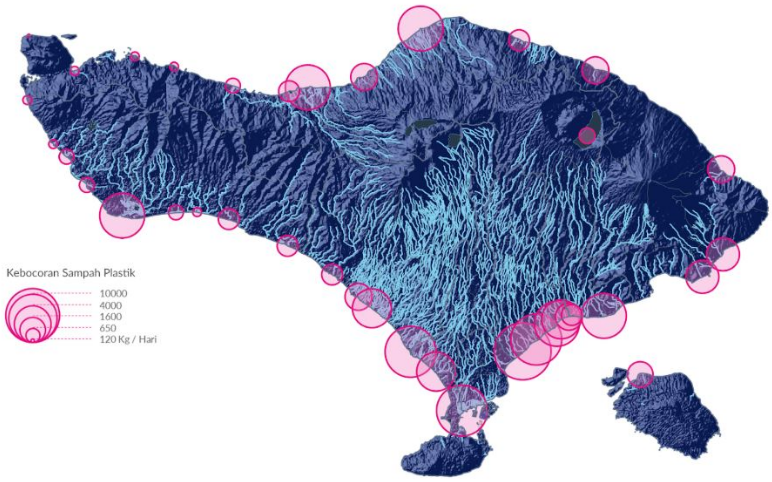

Figure A.1: Plastic Pollution Levels of the Main Rivers in Bali

A.1.2. TOURISM IN THE AREA

The value for this criterion is calculated by taking the number of tourist visits to this region, and dividing it by the total number of inhabitants of the region. Both domestic and international tourist visits in the year 2018 are taken into account. The data for tourist visits is retrieved from the Bali Government Tourism Office [144]. Less tourist is considered better, since this research focuses on households rather than tourists.

A.1.3. SOCIO-DEMOGRAPHIC AND GEOGRAPHIC ASPECTS

For this criterion different socio-demographic and geographic factors of each region are merged into a score. The following socio-demographic and geographic factors are taken into account:

1. **Religion:** percentage Hindu, Islamic and others [145]
2. **Financial:** the APBD (anual government budget), the PAD (income in the region from sources from within the region) and the DAU (money allocated to the area by the provincial government) [145].
3. **Education:** percentage of the inhabitants under the age of 24 still following an educational program [145].
4. **Population Density:** Number of inhabitants per square kilometer, based on data from the website of City Population [146]
5. **Landscape:** percentage of the area that is natural forest land, plantation land or other (non-forest, non-plantation) land. Based on the website of Global Forest Watch [147].

The higher the score, the more the region is a representation of the socio-demographic and geographic characteristics of Bali as a whole.

A.1.4. TOTAL AREA OF THE CATCHMENT

The area of the catchment is determined with GIS software. A smaller catchment area is considered better, because of the limited time available for this research. The area is transformed into a factor score, compared to the smallest area.

A.2. CRITERION VALUES

The criterion values are shown in Table A.1.

Table A.1: Criterion Values for the Three Locations

Criterion	**Negara Region**	**Gianyar Region**	**Bangli Region**
Pollution [1000 kg plastic waste load per day]	10	>10	10
Tourism [% of tourist visits as compared to local community]	1.5	22.3	4.9
Socio-Demographic/Geographic [score]	7	12	11
Catchment Area [factor relative to the smallest area]	1.5	1	2

A.3. CRITERION SCORES AND WEIGHTS

For all criteria, the best scoring location scored 3 points, the worst scoring location scored 1 point and the middle scoring location got 2 points. The assessment criterion are weighted based on the researchers opinion of the importance of the criterion. The amount of pollution is considered as the most important criterion, because in the most polluted area research into the waste management system is most needed. The socio-demographic and geographic factors score is ranked as second most important criterion. This is because, if these factors are similar to those of Bali, the research could potentially scaled up to the whole island Bali. Catchment area has a weight of 0.2, since a smaller catchment area is convenient, but not essential. Tourism has a weight of 0.1 since also in areas with a lot of tourists, it is still possible to investigate the households situation.

A.4. MCA RESULTS

As can be seen in Table A.2, the Gianyar Region scored the highest of the three locations. The Gianyar region therefore became the study area of this research.

Table A.2: MCA Results for the Three Locations

	Weight	**Negara Region**	**Gianyar Region**	**Bangli Region**
Pollution	0.4	2	3	2
Tourism	0.1	3	1	2
Socio-Demographics/Geographics	0.3	1	3	2
Catchment Area	0.2	1	3	2
Total Score		**1.6**	**2.8**	**2**

B

Overview Administration Levels Indonesia

Figure B.1 gives a general overview of the existing administration levels in Indonesia.

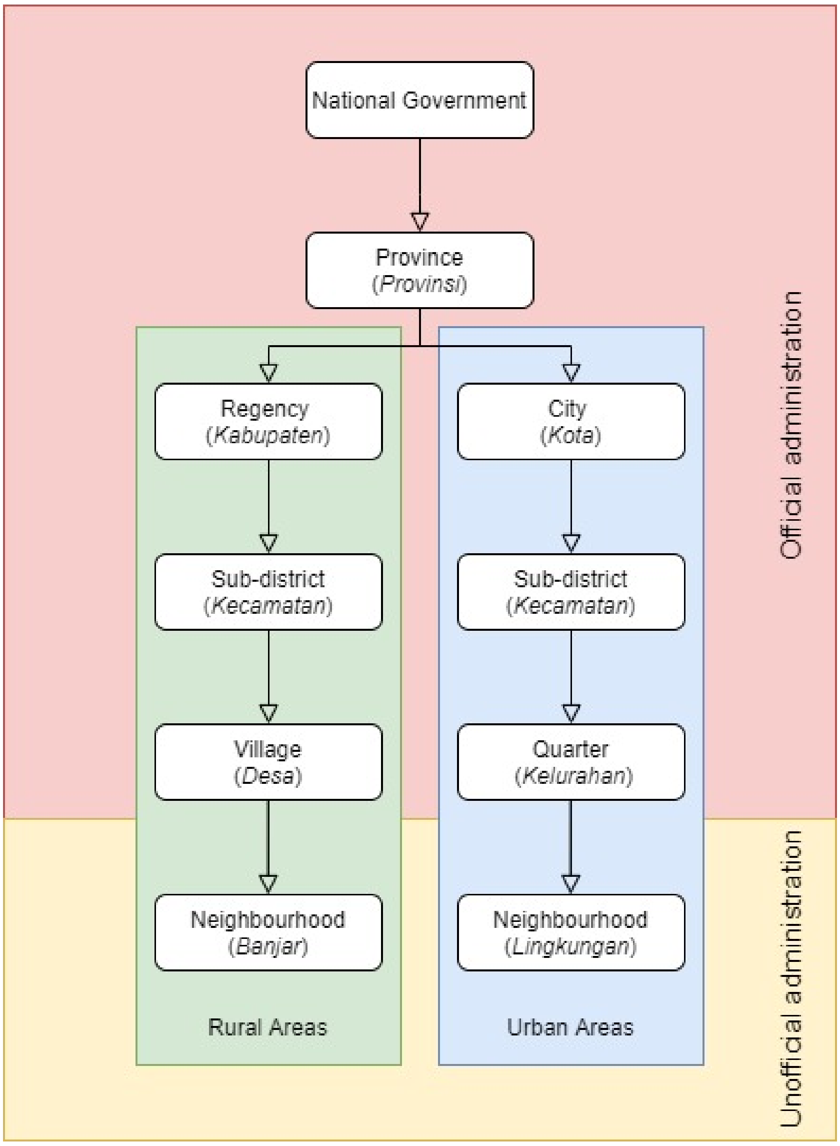

Figure B.1: Overview Administration Levels Indonesia

C

Expert Interview Tony Manusama

This appendix summarises the knowledge acquired during the meeting and tour with Tony Manusama, on the 18th of February 2020 about the current waste management system on Bali.

C.1. Tony Manusama

Tony Manusama is a privately operating learning and development consultant, he has been active on Bali for more than 10 years. He advises and collaborates with parties involved in the waste management on the island. Besides that he is the founder of different education programs for the Balinese youth.

C.2. Knowledge Retrieved from Tony

Tony shared quite a lot of information during the day. At first we had a short interview with Tony afterwhich we went on a tour to all different elements of the waste management system in Kabupaten Denpasar. An overview of the relevant information is given below.

The first thing that Tony shared was that the waste management system is totally decentralized; the way waste and plastic specifically is managed differs in every desa or even between banjars within the same desa. This is the case because every desa receives a certain amount of money, based upon the amount of people living in the desa, which can be spend upon either waste management, road maintenance or public facilities like the Kantor Desa. Proof of the spending of the money has to be shown to make sure desa leaders do not spend the money for the benefit of themselves, e.g. new car or house. However, because the money is not specifically for waste management only, desas can make different choices regarding the spending. Moreover, the Balinese government is investing more money in tourism than in waste management, this results in an island-wide waste problem.
Secondly, there are multiple NGOs active in Indonesia to help with this waste problem. This has positive and negative effects. The positive side of the NGOs is that they act quicker, in general, than the Indonesian government. The Indonesian government needs a full project plan before they are willing to invest in a project and these project plans can take multiple years before they are accepted. NGOs, on the other hand, are normally quicker with their investments and therefore very prominent in the waste management system on Bali. The downside, however, is that these NGOs are not working together, or even totally independent from each other. The communication between the NGOs, local government and large companies is lacking at this moment. Examples of these NGOs are Ocean Mimic (clean-ups), McKinsey.org (waste facilities), Trash Hero (clean-ups and education), Eco-Bali (plastic banks) and Plastic Fisher (waste-traps in rivers).

McKinsey.org is helping the local government with the management of large waste sorting facilities on Bali. These are called TPS3R, with the 3R standing for reduce, reuse and recycle. The government has built these facilities, however, due to a lack of management, 90% of the facilities are not operating. Currently, McKinsey.org is helping with the management, and training students how to manage the waste properly and how to make profit from the waste, so the facilities are economically sustainable.

Lastly, there are four general ways of waste disposal on Bali: 1) disposal in nature, 2) pick up by trucks/motorbikes, 3) burning and 4) taking the waste to a waste facility yourself. A large part of the waste is brought to landfills (TPA), of which, the landfill in Gianyar is getting full by now. Therefore, trucks also bring the waste to the landfill in Denpasar. Some desas have a TPS3R recycling facility, others only have a TPST facility or no facility at all. In Section C.3 the function of the different facilities will be explained.

C.3. KNOWLEDGE VISUALLY RETRIEVED FROM THE TOUR

Tony took us on a tour to different elements of the waste management system. We visited a TPS3R facility, a PET recycle facility, a 'bank sampah', a TPST facility and a 'Pengepul ' business location.

TPS3R FACILITY IN DESA SANUR KAUH

The TPS3R is a collaboration between: (government): Desa Dinas Sanur Kauh, Desa Pakraman Intaran, DLHK Denpasar. (NGO): McKinsey.org, PRAISE, EcoBali and others.
The TPS3R facility handled 3.4 tonnes of waste / day, coming from 350 clients in the last 10 months it operated while making a profit (Figure C.1). On average 60% of the inhabitants of the Desa Sanur Kauh gets their waste picked up and brought to this TPS3R. Households pay around 50.000 IDR per month for the TPS3R service, including waste pick-up.

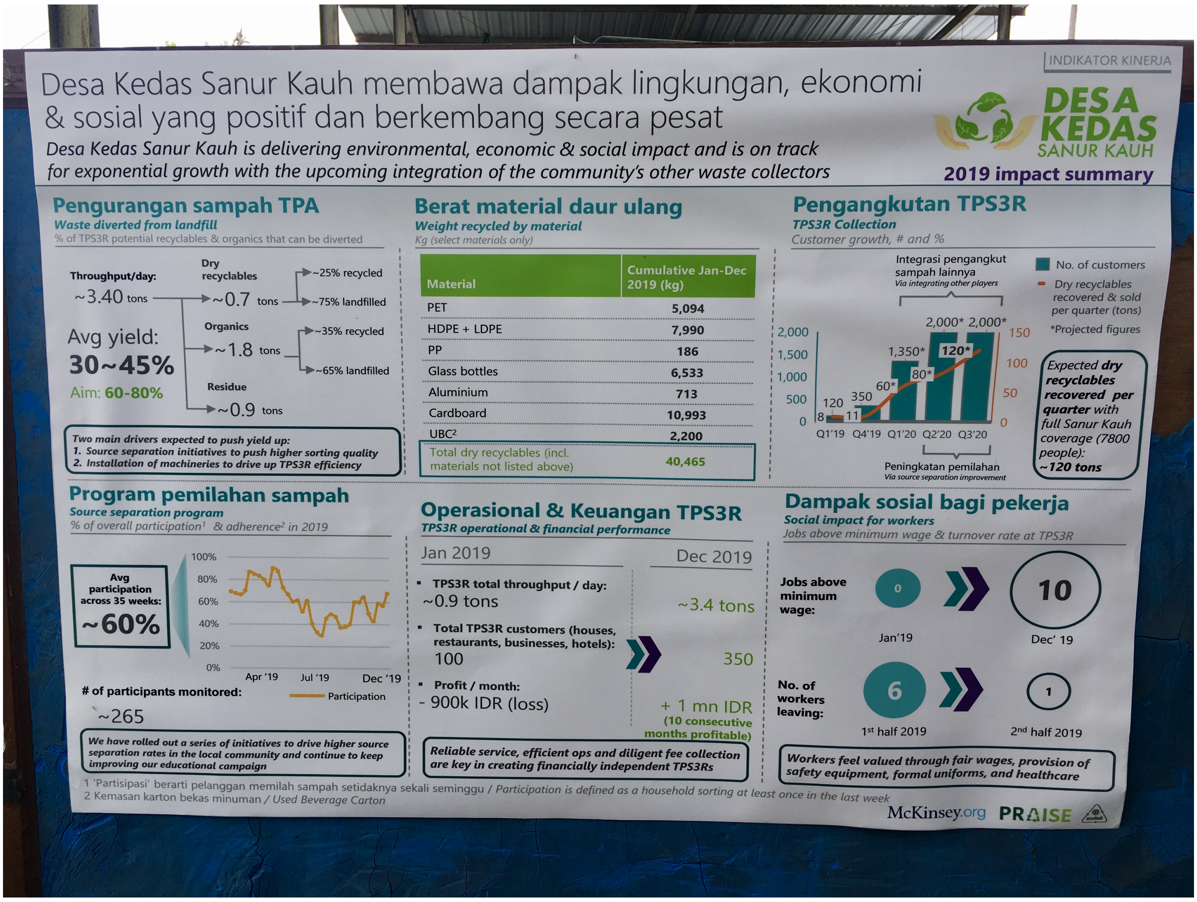

Figure C.1: Facts and Figures from Operation Year 2019

What happens at the TPS3R facility:

1. Waste is collected from participating clients (houses, restaurants, businesses and hotels) with garbage trucks and tricycles.

2. The waste is then sorted by hand in the facility (Figure C.2). The sorting categories are: Dry Recyclables, Organics and Residue.
3. After the sorting, recyclable waste is shipped to recycle locations, mainly on Java.
4. Non recyclables are brought to the Denpasar landfill.

Figure C.2: Sorting at the TPS3R Facillity in Desa Sanur

C.3.1. Bali PET facility

Bali PET is a PET recycle facility sponsored by Aqua Danone.
What happens at the Bali PET facility:

1. Households and businesses bring their PET bottles to collection points, like a bank sampah (Section C.3.2).
2. These bottles are brought to the facility by Pengepul who are paid by the facility. They are temporarily stored at the facility as can be seen in Figure C.3.
3. At the facility, the labels and caps are removed. Thereafter the bottles are cleaned and processed in plastic flakes, as can be seen in Figure C.4.
4. These flakes are then packaged and then sold to businesses who use the plastic flakes in their products.

Figure C.3: PET Bottles in Storage at the Bali PET Facility

Figure C.4: Production Line in the Bali PET Facility

C.3.2. Bank Sampah

The bank sampah is a PET bottle collection point (Figure C.5). Households and businesses can hand in their PET bottles for a small reward. This bank sampah is sponsored by the concern SC Johnsen. The bank sampah pays slightly more than a Pengepul for the PET bottles as there are less people involved in this waste chain. From the bank sampah the bottles are transported to the Bali PET facility. The employee of a bank sampah earns between 2 and 4 million IDR per month depending on the amount of plastic that is brought to the bank sampah.

Figure C.5: Bank Sampah in Denpasar

C.3.3. TPST, Pengepul and Pemulung

Lastly Tony took us to a TPST facility (Figure C.6) and pengepul office. A TPST facility is a waste dump location. Pemulung pick recyclable materials from the waste pile, which they subsequently sell to pengepul . At the end of the day, the waste from the TPST is brought to a landfill (TPA). Besides collecting recyclable materials from the TPST facility, they also go door-by-door with a truck or car, (Figure C.7) and gather all recyclable materials from there. These pemulung earn 70.000 IDR per car which they mostly need to share with three people. Per day they normally can fill up one car. As a result most of them work 300 days per year. The pengepul collect waste from multiple pemulung and sort and sell it to recycle facilities mostly in Java.

Figure C.6: A TPST Facility

Figure C.7: A Pemulung

D

Expert Interview McKinsey.org

This appendix gives a summary of the meeting on 26 February 2020 with Elle Flaye and her team from McKinsey.org.

D.1. McKinsey.org

McKinsey.org is "A nonprofit founded by McKinsey & Company to have lasting and substantial impact on complex social challenges." [143]. It operates on Bali in cooperation with PRAISE, the Packaging and Recycling Association for Indonesia Sustainable Environment. Their goal is to optimize the waste collection, by providing education on waste separation and increasing the efficiency of the existing TPS3R facilities [143].

D.2. Summary Meeting

The main problem the McKinsey team identified, is the lack of of an effective waste management system. This refers to the fact that the waste collection in Bali is organised per desa. So there is no communication nor collaboration between desas about waste management and its enforcement. PET is worth money, this is a known fact, however companies are not very enthusiastic to incorporate recycled plastics (mainly PET) in their production line. This is due to the fact that there is no steady supply of recyclable plastics (ie. differentiation in quantities and quality).

The government introduced the TPS3R factories, every desa could apply for funding to build one. However, due to the lack of central organisation on a governmental level, the central government does not know exactly how many TPS3R factories actually exists in Bali (around 1000). Besides that, the funding application does not require a 'business plan'. Because of this most factories are not operational after construction. Resulting in unused facilities, trucks, and other equipment. Lack of expertise results in the fact that the factories are not making money or breaking even.

In Bali, each desa has cultural and formal enforcement. The cultural enforcement is responsible for the waste collection. Because the cultural leaders/enforcers often have multiple roles, nobody is solely committed to the waste collection and treatment. Because the collection fee is not incorporated in the local taxes, it is hard to get inhabitants of the desa to pay for the pickup services.

On a larger scale other problems were identified. One of the main problems is the so-called PET-mafia. The supply chain of PET-recycling is very long and has many players in it. The PET-mafia operates in the part where the PET is bought from local collectors for extremely low fees. This causes local collectors to become totally dependent from the buyers. McKinsey.org indicates that transparency in this supply chain is one of the most important factors for effective waste management. This is to stop the PET-mafia and to create a value chain. According tho them this can be achieved by reducing layers of aggregation, clustering multiple TPS3R facilities, and standardizing operations.

McKinsey.org is currently partnering up with local and governmental institutions to create a sustainable value chain in waste management. One of their pillars is to create a TPS3R 'academy' where the locals can be trained to become facility mangers, but also for educational purposes for the younger generations. Besides that, the academy will provide digital and financial solutions for effective waste management.

E

Expert Interview I Wayan Subawa

This appendix describes the interview with I Wayan Subawa, head of the DLH office of the Kabupaten Gianyar on 10th of March 2020. The document is not a full transcript of the interview, but rather an aggregation of the retrieved information put together in the original interview design. Reason for this, is that the interview was carried out half in English, half in Bahasa Indonesia using a translator.

E.1. I Wayan Subawa

I Wayan Subawa is the head of the DLHK office of Kabupaten Gianyar. The DLHK office is the local environment agency. The agency is, among other things, concerned with the waste management system in the Kabupaten Gianyar . As head of the office, I Wayan Subawa is concerned with the long term planning and strategy of the office. He has extensive knowledge of waste management handling in the Kabupaten Gianyar.

E.2. Interview

1. What is the function of DLHK Gianyar?
We received a pdf during the interview, which explains the function of the DLHK. Especially page 1,2 and 3 are usefull for this question. To not lose time this question was skipped after receiving the pdf.

2. What is your function within the DLHK Gianyar?
Also this question can be found in the pdf and to save time is skipped in the interview.

3. General waste management: a. Could you explain the overall waste management of Gianyar, starting from the houses of the people till the landfill or recycling faculty?
A full overview of the general waste management system can be found again in the pdf, however a short summary was given during the interview.
There are two separate waste flows in Bali that start differently and afterwards follow the same path:

1. Public space: The government picks up the plastic from public facilities like markets, hospitals, governmental places and the city Gianyar. Only the market vendors pay a small fee of 500 IDR (€0.03) per day per person to get their waste picked up.

2. Private houses: A desa (or Banjar) can have its own truck that picks up the waste at the houses of the inhabitants of the desa. The organisation of this truck is the responsibility of the desa or banjar, so I can not provide more information. Besides the truck, people can also bring their PET-plastic and all other recyclables to the 43 small Bank Sampahs in Kabupaten Gianyar. They have to organise this themselves; there is no truck picking the waste up to bring it to the bank sampah. The people get a small amount of money for the recyclables they bring to a bank sampah.

After picking up the waste from either the houses or the public facilities, the waste goes to a so called YPST where they separate the waste into organic waste, recyclable material and residue. Every truck can contain, if filled correctly (and not like normally overfull), 6 m^3 of waste.

The residue is brought to the landfill (TPA Temesi) on the same terrain as the YPST. There is only a small problem, which is that the TPA Temesi is full already since 2017. Therefore we are planning on building a new TPA this year. For now we rent 2000 m^2 of land on which we have now a temporary open dump. This year we planned to buy the 2000 m^2 and an additional 2000 m^2. Then next year we will design the sanitary landfill. And we plan to start the building of the sanitary landfill in 2022. We will capture the leachate, methane and make energy from it. Furthermore, we want to have some education possibilities at the landfill site.

The recyclable material goes to the main bank sampah of Gianyar, where again some money is given for the recyclables. The bank sampah, on its turn, sells the recyclable material to Java.
The organic waste is brought to the compost. However, there is a problem here. There is only a capacity of 50 tonnes of organic waste per day, but every day 300 tonnes of organic waste is brought to the YPST. So 250 tonnes of organic waste is now also brought to the landfill, as the capacity of the compost is insufficient. However, as said before, also the landfill is full. So now we ask the people to not bring the organic waste to the landfill. For an overview of the system see also Figure E.1

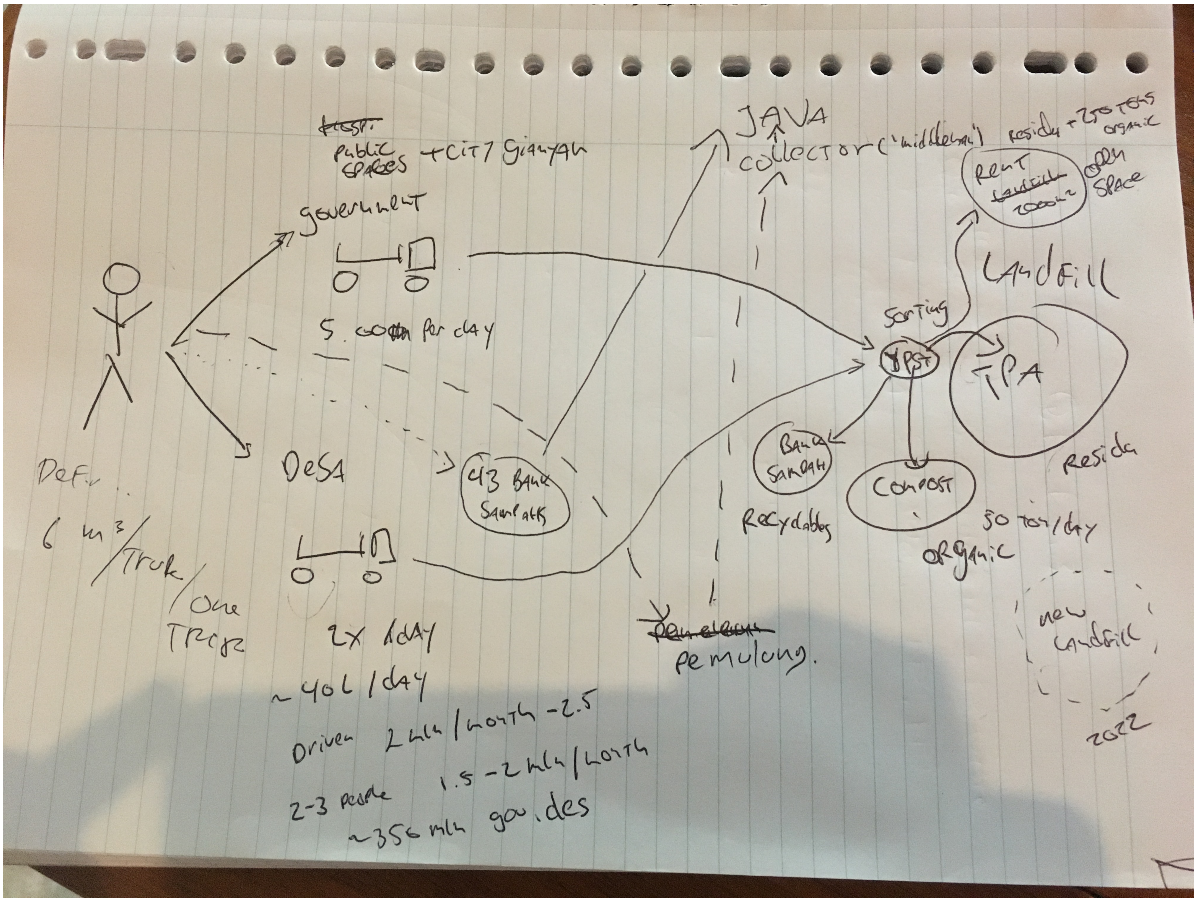

Figure E.1: The Made Scheme to Counter-Check the Translation of the Waste Management System

3. General waste management: b. What are the future plans regarding waste management?
We believe that it's possible to handle all the plastic. Not only to recycle all recyclable plastic, but also reduce the plastic usage of the inhabitants and tourists of Bali. In the long term we expect to have almost no plastic in the environment anymore.

For the future we hope to have a TPS3R in every desa. We will start from the upstream area to the downstream area. With the money of the government they already made one TPST at the monkey forest in Ubud and there are seven TPS3R planned in Gianyar for this year; in desa Pejeng, Kramas, Bonjaka, Bedulu, Tulikup, Taro and Bona. In the next two months the operation of Pejeng will start the building is finished. Inside the recycling place we will also make a Bank Sampah. To do this, we already cooperate with a organisation from Germany (Misses Ni Luh Budi Restiti) called, Bumi Sasmaya. This organisation is located in Ubud. They help with their organisation with money for the facilities, education on plastic waste and controlling the process of education. Every desa gets 5 million IDR per facility from Ni Luh.

4. Responsibility: What are the responsibilities for the: a. The Kabupaten, b. The Kecamatan, c. The Desa and d. The Banjar
This information can again be found in the pdf and is skipped during the interview.

5. Plastic specific waste management: a. Are there special facilities for plastic waste and where are they located? i. TPS3R & TPA, ii. Bank Sampah, iii. PET recycling
There is only one TPA in the kabupaten Gianyar which was mentioned before: TPA Temesi that is full. At the moment there is only one TPS3R in Kecamatan Sukawati. We will provided you with an overview of the 43 Bank Sampah in Kabupaten Gianyar. At this moment we don't have a PET recycling facility. There is, however, one in Denpasar.

5. Plastic specific waste management: b. What is the strategy for coping with the plastic problem at this moment?
First of all, the plastic problem on Bali is already 'viral'. In other words, there is a lot of reporting on it. This means the people and the tourists are confronted with the problem often. Therefore, I made a plan to start education in every desa or even banjar, because I believe that the waste problem is not about not having the facilities to cope with the waste, but more importantly about the mentality of the people. At this moment, the mindset of the people is wrong, so a new facility will not work. Therefore, we focus on the education of the people. We started two years ago and step-by-step experts go from banjar to banjar in every desa to explain how plastic (or waste in general) should be handled. It is a very time consuming practice.

Moreover, in the Balinese culture it is important to have the support of the Desa Adat. The Desa Adat is has two function; 1) leading social-religious activities and ancestor worship , 2) a social-political function. In the last function in a lot of desas also the waste management is included. Therefore, we focused especially on the desa adat in every village. Due to his spiritual and political influence he can influence 'his' people and help them to change their mindset. Besides the Desa Adat, we also targeted the leaders in the individual Banjars and Desas. So at this moment, we are focused on the education, but as said in the previous question, we are also building new facilities slowly.

5. Plastic specific waste management: c. Pengepul and Pemulung : What kind of regulations are there on them?
This is a side stream of waste collection that works next to the truck system. The pengepul and pemulung only focus on the recyclable waste. Most of the time the pemulung are people from Java that collect the waste at the houses of the people. They pay the people a small amount for their recyclables and afterwards they get paid by the pengepul, who on his turn, sells the recyclable material to Java. *An overview of all Pengepul and Pemulung in Kabupaten Gianyar was hand over to us during the interview.*

5. Plastic specific waste management: d. How are the NGOs & private companies regulated and do they need a license to operate?
Most NGOs are normally only here for cleaning. They focus on education on how to clean up. They have activities to clean up the beaches and river embankments. However, I do not believe that

cleaning up is the solution, we need to change the mindset. Moreover, at this moment Gianyar needs donations/technology/facilities from NGOs, because we don't get enough money from the government. The NGOs must have a permission of the DLH Kabupaten Gianyar to operate. This is in order to protect Bali and let them pay taxes.

5. Plastic specific waste management: e. Are there difference between different desas or even banjars? i. Saba, ii. Batuan Kaler, iii. Pejeng Kawan, iv. Kenderan, v. Kemenuh, vi.Mas
Every villages is different and every villages get their own money based on their size from the DLH Kabupaten Gianyar. However I don't know exactly how much for these specific desas.

6. Prices: a. What are the prices of the different elements of the (plastic) waste management system?
A Desa pays the truck themselves. A truck is approximately 350 million IDR. The truck operates two times every day, i.e. two trips every day. A single trip needs 20 liters of petrol. Normally a truck operates twice a week (with two trips per operation day) and the driver of the car gets approximately 2-2,5 million every month, the other people that work in the car and already sort some of the waste (2-3 people) earn 1,5-2 million per month.

F

THE QUESTIONNAIRE

In this appendix the questionnaire that is used during the survey is presented. In practice, this questionnaire was translated into Bahasa Indonesian. It consists of four parts, containing a total of 21 questions. The first part (Section F.1) consists of questions on the socio-demographic situation (gender, income, education, etc.). The second part (Section F.2) asks about the current disposal method of the respondent and the associated costs and time. The third part of the questionnaire (Section F.3) forms the stated choice experiment, which consists of eight choice situations. And concluding, the fourth and last part of the questionnaire (Section F.4) contains additional questions on the environmental impact of the four different disposal methods and on the plastic waste production per day of the respondents' households.

F.1. PART 1: SOCIO-DEMOGRAPHIC QUESTIONS

Table F.1: Socio-Demographic Questions

Variable	Question	Possible Answers	Scale of Measure
Gender	What is your gender?	• Male • Female	Nominal
	Apa jenis kelamin anda?	• *Pria* • *Wanita*	
Birth year	What is your birth year?	[Open answer]	Interval
	Sebutkan tahun lahir Anda?	*(Same as in English)*	
Residence (Desa)	Which Desa do you live in ?	• Saba • Mas • Pejeng Kawan • Kemenuh • Batuan Kaler • Kenderan • Other	Nominal
	Di desa mana Anda tinggal?	*(Same as in English)*	
Residence (Banjar)	Which Banjar do you live in?	[Open answer]	Nominal
	Di lingkungan mana Anda tinggal? (Banjar)	*(Same as in English)*	
Education level	What is your education level?	• No study • Elementary school • Middle school • High school • College/University • Other: [Open answer]	Nominal
	Tingkat pendidikan:	• *Tidak sekolah* • *Sekolah dasar* • *Sekolah Menengah Pertama* • *Sekolah Menengah Atas* • *Perguruan Tinggi / Universitas* • *Lain-lain: [..]*	
Household size	How many people live in your household in total (including yourself)?	• 1 • 2 • 3 • 4 • 5 • 6 • Other: [Open answer]	Interval
	Berapa banyak orang yang tinggal di rumah Anda (termasuk Anda sendiri)?	*(Same as in English)*	
Number of children in household	How many of these household members are young children (below the age of 13 years old)?	• 0 • 1 • 2 • 3 • More: [Open answer]	Interval
	Berapa banyak anak kecil di rumah Anda (di bawah usia 13 tahun)?	*(Same as in English)*	

Table F.2: Continuation Socio-Demographic Questions

Variable	Question	Possible Answers	Scale of Measure
Income	What is your total income before taxes per month (IDR)?	• 0 – 1,2 mil IDR • 1,2 mil – 4,6 mil IDR • 4,6 mil – 14,2 mil IDR • More • I don't know • I prefer not to tell	Ordinal
	Berapa total penghasilan Anda per bulan (IDR - sebelum pajak)?	• *0 – 1,2 mil IDR* • *1,2 mil – 4,6 mil IDR* • *4,6 mil – 14,2 mil IDR* • *Lebih dari* • *Saya tidak tahu* • *Saya memilih untuk tidak menjawab*	

F.2. PART 2: CURRENT WASTE MANAGEMENT QUESTIONS

Table F.3: Current Waste Management Questions

Variable	Question	Possible Answers	Scale of Measure
Way of plastic disposal	How do you dispose your plastic waste most of the time?	• It gets picked up • I bring it to a recycling facility or pick-up point • I burn it • I dump it in the river • I dump it in land • Other: [Open answer]	Nominal
	Bagaimana biasanya Anda membuang sampah plastik?	• *Diambil oleh petugas* • *Saya bawa ke fasilitas daur ulang atau titik penjemputan* • *Saya bakar* • *Saya buang di sungai* • *Saya buang di darat* • *Lain-lain: [...]*	
Disposal time	How much time does it cost you per day to dispose you plastic waste?	• 0 – 1 minute • 2 – 4 minutes • 4 – 6 minutes • 6 – 8 minutes • More: [Open answer]	Ordinal
	Berapa lama waktu yang Anda habiskan untuk membuang sampah plastik?	• *0 – 1 menit* • *2 – 4 menit* • *4 – 6 menit* • *6 – 8 menit* • *Lebih dari: [...]*	
Disposal costs	How much does the disposal of your plastic cost (IDR) per month?	• 0 – 40.000 IDR • 40.000 – 80.000 IDR • 80.000 – 120.0000 IDR • 120.000 – 160.000 IDR • I don't know • I spend more: [Open answer]	Ordinal
	Berapa biaya yang Anda keluarkan (IDR) per bulan untuk membuang plastik?	• *0 – 40.000 IDR* • *40.000 – 80.000 IDR* • *80.000 – 120.0000 IDR* • *120.000 – 160.000 IDR* • *Saya tidah tahu* • *Saya mengeluarkan lebih dari: [...]*	

F.3. PART 3: STATED CHOICE EXPERIMENT QUESTIONS

Figure F.1 and F.2 below are two examples of a choice situation. Every respondent received eight of such questions. The choice-set were translated to Bahasa Indonesia. It has been chosen to only give the English version here for the sake of clarity. A detailed overview of all choice-sets and alternatives is given in Appendix G.

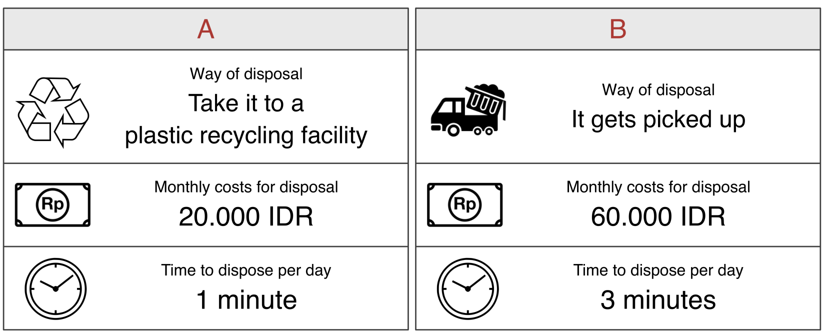

Figure F.1: Example 1 of a Choice Set

A		B	
	Way of disposal Burn it		Way of disposal Dump it
Rp	Monthly costs for disposal 100.000 IDR	Rp	Monthly costs for disposal 140.000 IDR
	Time to dispose per day 5 minutes		Time to dispose per day 7 minutes

Figure F.2: Example 2 of a Choice Set

F.4. PART 4: ADDITIONAL QUESTIONS

Table F.4 shows the last two questions of the questionnaire. Figure F.3 shows the figure that is used as additional material to the question about 'daily plastic waste production', to make estimating the plastic waste production easier.

Table F.4: Questions regarding Respondents' Perception on Disposal Methods and their Plastic Waste Production

Variable	Question	Possible answers	Scale of measure
Perception on pollution of disposal ways	Please give the different ways of disposal a value between 0 (not polluting) and 5 (very polluting) for their level of polluting the environment: • Take it to a plastic recycling facility • It gets picked up • Burn it • Dump it	• 1 (not polluting) • 2 (a little polluting) • 3 (neutral) • 4 (quite polluting) • 5 (very polluting)	Interval
	Mohon untuk dapat memberikan nilai antara 1 dan 5 terhadap cara-cara berikut ini sesuai yang Anda anggap,paling tidak mencemari untuk lingkungan (1) hingga yang paling mencemari untuk lingkungan (5): • *Dibawa ke fasilitas daur ulang plastik* • *Diambil oleh petugas* • *Dibakar* • *Ditumbun*	• *1 (tidak mencemari)* • *2 (sedikit mencemari)* • *3 (netral)* • *4 (cukup mencemari)* • *5 (sangat mencemari)*	
Daily plastic waste	Please point which bag represents the amount of plastic that is produced by your household (per day) the best.	• 1 • 2 • 3 • Other: [open answer]	Ordinal
	Harap sebutkan kantung mana (1, 2 atau 3) yang mewakili jumlah plastik ang diproduksi oleh rumah tangga Anda (per hari)	*(Same as in English)*	

Figure F.3: Figures That Are Used in the Questionnaire to Depict the Sizes of the Three Bags, Representing the Amount of Plastic Waste Disposed per Household per Day

G

SURVEY PROFILES

This appendix elaborates on the 16 created alternatives for the stated choice experiment (part 3 of the survey). Section G.1 shows the alternatives and corresponding attribute levels that are used in the choice sets of block 1 and block 2 respectively. Section G.2 visualises the six part 3 versions in the survey. Note that the Profile IDs in the tables refer to the Profile ID and thus alternatives in Section G.1.

G.1. NGENE OUTPUT

Table G.1: Block 1

Profile ID	Disposal Method	Cost (x1000 IDR)	Minutes	Combined with	Profile ID	Disposal Method	Cost (x1000 IDR)	Minutes
3	Dump	60	1		5	Burn	20	5
4	Recycle	20	3		2	PickUp	100	1
5	Burn	20	5		7	Dump	60	3
9	Recycle	140	5		12	Burn	140	3
10	PickUp	100	3		8	Burn	20	7
11	PickUp	60	5		3	Dump	60	1
12	Burn	140	3		15	Dump	100	7
15	Dump	100	7		9	Recycle	140	5

Table G.2: Block 2

Profile ID	Disposal Method	Cost (x1000 IDR)	Minutes	Combined with	Profile ID	Disposal Method	Cost (x1000 IDR)	Minutes
1	Dump	100	5		4	Recycle	20	3
2	Pick-up	100	1		14	Recycle	140	7
6	Burn	140	1		11	Pick-up	60	5
7	Dump	60	3		10	Pick-up	100	3
8	Burn	20	7		16	Recycle	20	1
13	Pick-up	60	7		1	Dump	100	5
14	Recycle	140	7		13	Pick-up	60	7
16	Recycle	20	1		6	Burn	140	1

G.2. QUESTIONNAIRE VERSIONS

Table G.3: Versions of Questionnaire, Block 1

Block 1, version 1		Block 1, version 2		Block 1, version 3	
Profile ID	**Profile ID**	**Profile ID**	**Profile ID**	**Profile ID**	**Profile ID**
3	5	10	8	12	15
4	2	5	7	11	3
5	7	3	5	5	7
9	12	12	15	9	12
10	8	11	3	15	9
11	3	15	9	4	2
12	15	4	2	3	5
15	9	9	12	10	8

Table G.4: Versions of Questionnaire, Block 2

Block 2, version 1		Block 2, version 2		Block 2, version 3	
Profile ID	**Profile ID**	**Profile ID**	**Profile ID**	**Profile ID**	**Profile ID**
1	4	6	11	8	16
2	14	7	10	14	13
6	11	13	1	2	14
7	10	16	6	13	1
8	16	1	4	6	11
13	1	8	16	16	6
14	13	2	14	1	4
16	6	14	13	7	10

H

PERMISSION LETTER KANTOR DESA SABA

Canggu, February 21th, 2020

Obj : Waste Management Gianyar Region

Kepada Yth. Bapak / Ibu - SABA DESA Tukad Petanu

Pantai Project

Dengan hormat,

Bersamaan dengan surat ini, kami Project Pantai, ingin mendapatkan izin untuk menghubungi para pemimpin banjar di dekat Tukad Petanu. Project Pantai adalah inisiatif mahasiswa non-profit dari Belanda yang meneliti sistem pengelolaan sampah di Bali.
Kami ingin mendapatkan izin untuk mengunjungi pertemuan banjar dan melakukan survei kuesioner di sana untuk mendapatkan pemahaman yang lebih baik tentang sistem pengelolaan sampah di Kabupaten Gianyar secara khusus.
Kami pikir pemimpin banjar bisa sangat membantu untuk ini. Bisakah Anda membantu kami mencapai pemimpin banjar, atau orang-orang yang tinggal di desa ini dekat dengan sungai?

Demikian undangan dan permohonan ijin kami sampaikan, atas perhatian dan ijin yang diberikan kami ucapkan terima kasih.

Hormat Kami,

Gijs Alberts atas nama Pantai Project

Whatsapp:	+316 480 222 58
Text and call:	+62 878 5987 0236
Email:	pantaiproject-citg@tudelft.nl

Canggu, February 21th, 2020

Obj : Waste Management Gianyar Region

Dear Sir or Madam SABA DESA Tukad Petanu

Sincerely,

Along with this letter, we the Pantai Project, would like to get permission to get in touch with the banjar leaders of banjars close to river Petanu. The Pantai Project is a non-profit student initiative from the Netherlands researching the waste management system in Bali.
We would like to get permission to visit a banjar meeting and conduct questionnaire surveys there to gain a better understanding of the waste management system of the Gianyar region specifically.
We think the banjar leaders could be very helpful for this. Can you help us reaching the banjar leaders, or the people living in this village close to the river?

Thank you for your attention and permission. Thank you for your kind attention and permission.

Kind regards,

Gijs Alberts on behalf of the Pantai Project

Whatsapp:	+316 480 222 58
Text and call:	+62 878 5987 0236
Email:	pantaiproject-citg@tudelft.nl

I

Calculations Plastic Waste Load per Reactor and per Location

The plastic waste load entering per reactor and per location (A, B and C) is calculated, leading to the results in Table I.1 which is equal to Table 7.6. An overview of the reactors and locations is provided in Figure 7.2.

Table I.1: Plastic Waste Load per Reactor and per Location (A, B and C)

Reactor/Location	**Plastic Waste Load [kg/day]**	**Plastic Waste Load [g/s]**
Reactor I	338.74	3.92
Reactor II	117.76	1.36
Reactor III	325.21	3.76
Reactor IV	140.45	1.63
Reactor V	84.46	0.97
Reactor VI	91.43	1.06
Reactor VII	180.98	2.09
Location A	655.28	7.58
Location B	12.64	0.15
Location C	68.59	0.79

The performed steps to obtain the results in Table I.1 are:

1. Determining the percentage of each desa that is located in a certain catchment/runoff area. *Note: these percentages do not necessarily sum up to 100 %, since a desa can also be partly located in the catchment or runoff area of another river. And moreover, the sum of the percentages within a single reactor does neither have to be 100 %, since the percentage refer to desas instead of reactors.*

2. Multiplying these percentages by the plastic waste load per desa to obtain the plastic waste load contribution of each desa to the plastic waste load within each reactor or at each location. *Note: The plastic waste load at locations A, B and C represents the accumulation of plastic waste loads into the catchment area upstream of those locations.*

3. Summing up the contributing plastic waste loads of each reactor and each location (A, B and C) to obtain the total plastic waste loads within those reactors and at those locations.

The results of each step are shown in Table I.2 and Table I.3, showing the results regarding the reactors and the results regarding the locations, respectively. The percentages are obtained by using QGIS. The Total PW-load is the total amount of plastic waste that ends up in the DAS Petanu river in one day.

Table I.2: Percentage of Each Desa That Is Located in the Runoff Area of a Certain Reactor and the Accumulated Plastic Waste Load (PW-Load) [kg/day] per Reactor

Desa	I	II	III	IV	V	VI	VII	**Total PW-Load [kg/day]**
Researched Desas								
Saba	-	-	-	14.2 %	-	-	52.5 %	64.0
Batuan Kaler	-	-	-	-	-	79.3 %	-	28.0
Mas	-	-	-	-	44.2 %	0.1 %	-	79.0
Kemenuh	-	3.4 %	-	62.5 %	21.7 %	12.0 %	-	76.4
Pejeng Kawan	-	54.5 %	45.5 %	-	-	-	-	23.6
Kenderan	72.4 %	-	-	-	-	-	-	200.7
'Non-Res.' Desas								
Pupuan	-	-	-	-	-	-	-	162.5
Sebatu	-	-	-	-	-	-	-	107.5
Kedisan	3.0 %	-	-	-	-	-	-	128.1
Tegallalan	29.5 %	2.0 %	-	-	-	-	-	81.1
Batuan	-	-	-	-	-	19.3 %	4.0 %	65.3
Sukawati	-	-	-	-	-	-	32.9 %	119.3
Tampaksiring	16.0 %	-	-	-	-	-	-	131.9
Sanding	64.2 %	-	1.5 %	-	-	-	-	62.2
Pejeng Kaja	28.6 %	2.3 %	69.1 %	-	-	-	-	126.2
Pejeng	-	-	97.2 %	-	-	-	-	145.9
Pejeng Kangin	-	-	26.5%	-	-	-	-	32.7
Manukaya	-	-	-	-	-	-	-	45.3
Bedulu	-	-	21.0 %	30.6 %	-	-	-	118.6
Peliatan	-	43.0 %	-	3.9 %	-	-	-	161.0
Pengotan	-	-	-	-	-	-	-	5.6
Tiga	-	-	-	-	-	-	-	7.9
Sekaan	-	-	-	-	-	-	-	29.4
Bayung Gede	-	-	-	-	-	-	-	8.6
Batur Tengah	-	-	-	-	-	-	-	4.5
PW-Load [kg/day]	**338.7**	**117.8**	**324.2**	**140.5**	**84.5**	**98.7**	**181.0**	

Table I.3: Percentage of Each Desa That Is Located in the Catchment Area of Location A, B or C and the Accumulated Plastic Waste Load (PW-Load) [kg/day] per Location

Desa	Location A	Location B	Location C	**PW-Load [kg/day]**
Researched Desas				
Saba	-	-	-	64.0
Batuan Kaler	-	-	-	28.0
Mas	-	-	7.1 %	79.0
Kemenuh	-	-	0.4 %	76.4
Pejeng Kawan	-	-	-	23.6
Kenderan	27.6 %	-	-	200.7
'Non-Researched' Desas				
Pupuan	100 %	-	-	162.5
Sebatu	51.8 %	-	-	107.5
Kedisan	93.5 %	-	-	128.1
Tegallalan	4.7 %	-	-	81.1
Batuan	-	-	-	65.3
Sukawati	-	-	-	119.3
Tampaksiring	39.5 %	-	-	131.9
Sanding	-	15.5 %	-	62.2
Pejeng Kaja	-	-	-	126.2
Pejeng	-	-	-	145.9
Pejeng Kangin	-	0.7 %	-	32.7
Manukaya	16.6 %	-	-	45.3
Bedulu	-	-	-	118.6
Peliatan	-	-	26.0 %	161.0
Pengotan	6.4%	-	-	5.6
Tiga	4.9 %	-	-	7.9
Sekaan	72.2 %	-	-	29.4
Bayung Gede	18.2 %	-	-	8.6
Batur Tengah	6.7 %	-	-	4.5
PW-Load [kg/day]	**655.28**	**12.6**	**68.6**	

J
Python Code Production Possibility Frontier

To create the PPF and to perform the corresponding sensitivity analysis a Python code was written in the Jupyter Notebook lay-out. To run the code two excel files with general information about the researched and non-researched desas. The information in these excel files are given Tables J.1 and J.2 and Table J.3 respectively. The fraction within the DAS (ACF) is the sum of the percentages of the area of a desa in a reservoir or upstream area of the Petanu river given in Appendix I. The PW-Production and the distribution of the disposal methods that are used in the researched desas are derived from the questionnaire.

Table J.1: Used Information of the Researched Desas in the Python Code

Desa	Population [#]	Households [#]	ACF	PW-Production [kg/d]
Saba	10156	2031	0.67	834.78
Batuan Kaler	4148	830	0.79	370.26
Mas	13512	3001	0.51	1516.78
Kemenuh	11777	2355	1.00	1072.70
Pejeng Kawan	3851	731	1.00	321.83
Kenderan	8425	1694	1.00	800.52

Table J.2: Continuation Used Information of the Researched Desas in the Python Code

Desa	Disposal methods			
	Self-Service	Pick-Up	Burn	Dump
Saba	0.10	0.70	0.18	0.02
Batuan Kaler	0.16	0.78	0.03	0.03
Mas	0.06	0.90	0.00	0.04
Kemenuh	0.06	0.90	0.04	0.00
Pejeng Kawn	0.06	0.93	0.00	0.01
Kenderan	0.20	0.14	0.57	0.09

Table J.3: Used Information of the Non-Researched Desas in the Python Code

Desa	Population [#]	Households [#]	ACF
Pupuan	6634	1333	1
Sebatu	8467	1700	0.52
Kedisan	5411	1087	0.97
Tegallalan	9148	1170	0.36
Batuan	11420	2284	0.23
Sukawati	14809	2962	0.33
Tampaksiring	9709	2678	0.55
Sanding	3127	678	0.81
Pejeng Kaja	5151	1040	1.00
Pejeng	6126	1205	0.97
Pejeng Kangin	4921	1305	0.27
Manukaya	11116	3108	0.17
Bedulu	9395	2348	0.52
Peliatan	9006	1992	0.73
Pengotan	3600	1010	0.06
Tiga	6631	1243	0.05
Sekaan	1664	493	0.72
Bayung Gede	1937	613	0.18
Batur Tengah	2746	794	0.07

J.1. PYTHON CODE

```
import matplotlib.pyplot as plt
import numpy as np
import math
%matplotlib inline
import pandas as pd

def truncate(n, decimals=0):
    multiplier = 10 ** decimals
    return int(n * multiplier) / multiplier

#data used
nonresearch = pd.read_excel('nonreasearchdesa.xlsx', index_col=[0])
research = pd.read_excel('researchdesa.xlsx', index_col=[0])  # last column is not a fact
production = 0.38 #kg/per person, Gianyar region
plastic_production = 0.1708 # % of waste, Gianyar region

#calculation plastic production within the DAS and amount of households located in the DAS
nonresearch['Plastic_Production_DAS'] = nonresearch.Population * production*plastic_production*nonresearch.Fraction_DAS
nonresearch['Households_DAS'] =[math.ceil(nonresearch.iloc[i,1] * nonresearch.iloc[i,2]) for i in range(len(nonresearch['Households']))]
research['Households_DAS'] = [math.ceil(research.iloc[i,1] * research.iloc[i,2]) for i in range (len(research['Households']))]
research['Plastic_Production_DAS'] = research.Plastic_Production*research.Fraction_DAS
households = sum(research.Households_DAS)+sum(nonresearch.Households_DAS)

#assumptions
fraction_dumped = 0.33  #bali Partnership 33% dumped
fraction_burned = 0.19  # Bali Partnership 19% burned
dump_river = 1 # 100% dumped ends up in river
burn_river = 0.25 #25% of burned ends up in river
truck_river =0.065 # 6.5% of pickup ends up in river
PET_per = 0.30 #percentage PET in waste

#current situation
current_cost = 29101 #IDR/month/household
PET_factor = 0.048  # %PET mismanaged

# elements
plastic_bank = 12.7  # kg/d
plastic_truck = 462  # kg/d capacity of one full truck
cost_op_truck = 31731000 # operational costs IDR/month (assumed every day in use)
cost_inv_truck = 2920000 # investment costs IDR/month
cost_TPS3R = 10830000  # both investment and operational costs
cost_bank = 3200000  # both investment and operation costs IDR/month

def sensitivity(frac_dump, frac_burned, per_dump, per_burn, per_truck, per_PET_waste, PET_mis, currcost, cap, costs,
            returning = False): # all parameters that are assumed, needed for sensitivity analyses

    # calculate the percentage of polution for self-service
    SS_river = (1-PET_per*per_PET_waste)*truck_river*per_truck #factor % Self_service in river

    #create empty lists to fill with datapoints
    point_plastic = []
    point_cost = []

    #calculate all standard needed values (these are also subjected to assumptions therefore defined here)
    df = pd.DataFrame() #nonresearched desas

    # plastic production
    df['Production'] = nonresearch.Plastic_Production_DAS
```

```
    # MPWH in all desas also outside the DAS
    df['MPWH_tot'] =nonresearch.Population * production*plastic_production* (fraction_dumped*frac_dump +
                                                                         fraction_burned*frac_burned)
    # MPWH and MPWLH in the DAS
    df['MPWH'] = nonresearch.Plastic_Production_DAS * (fraction_dumped*frac_dump + fraction_burned*frac_burned)
    df['MPWLH'] = nonresearch.Plastic_Production_DAS * (fraction_dumped*frac_dump *dump_river*per_dump +
                                                    fraction_burned*frac_burned * burn_river*per_burn)

    df2 = pd.DataFrame() # researched desas
    df2['Production'] = research.Plastic_Production_DAS
    df2['MPWH_tot'] = research.Plastic_Production *(research.Burn + research.Dump)
    df2['MPWH'] = research.Plastic_Production_DAS * (research.Burn + research.Dump)
    df2['MPWLH']= research.Plastic_Production_DAS * (research.Burn*burn_river*per_burn +
                                                    research.Dump*dump_river *per_dump)
    # illegal dumping by waste haulers
    df2['Illegal_dump'] = research.Plastic_Production_DAS * (research.PickUp*truck_river*per_truck+
                                                         research.Self_Service*SS_river)
    #now combine nonresearched desas and researched desas
    combination =df.append(df2, sort=False)

    # information needed to determine time in use and corresponding costs of the trucks in the different desas
    combination['Truck_filled'] = combination.MPWH_tot/plastic_truck*cap
    combination['Month_days'] = [math.ceil(percentage*365/12) for percentage in combination.Truck_filled]
    combination['Month_days']=[ 30 if number > 30 else number for number in combination.Month_days ]
    combination['Costs'] = combination.Month_days * cost_op_truck*12/365*costs + cost_inv_truck*costs

    # the final needed values in the scenarios
    MPWH = sum(combination.MPWH)
    PW_production = sum(combination.Production)
    MPWLH = sum(combination.MPWLH)
    PW_load = sum(combination.MPWLH) + np.nansum(combination.Illegal_dump)
    illegal_dump_now = np.nansum(combination.Illegal_dump)
    RF = MPWLH /MPWH

    #2 extra trucks (sukawati and Kenderan)
    pickup_truck = combination['MPWH'].loc['Sukawati']*plastic_truck*cap/combination['MPWH_tot'].loc['Sukawati'] + \
    plastic_truck*cap
    reduction_mismanaged  = MPWH - pickup_truck
    mismanaged_river = reduction_mismanaged * RF
    illegal_dumping_extra = pickup_truck*truck_river*per_truck
    total_load = mismanaged_river + illegal_dumping_extra + illegal_dump_now
    point_plastic.append(total_load)
    costs_pickup = (combination['Costs'].loc['Sukawati']+combination['Costs'].loc['Kenderan']+ cost_TPS3R *costs)/households
    total_costs = costs_pickup+current_cost*currcost
    point_cost.append(-1*total_costs)

    #25 extra trucks (in every desa one)
    pickup_truck25 = np.sum(combination['MPWH'])-(combination['MPWH'].loc['Sukawati']+combination['MPWH'].loc['Kenderan'])+\
    combination['MPWH'].loc['Sukawati']*plastic_truck*cap/combination['MPWH_tot'].loc['Sukawati'] + \
    plastic_truck*cap
    reduction_mismanaged  = MPWH - pickup_truck25
    mismanaged_river = reduction_mismanaged * RF
    illegal_dumping_extra = pickup_truck25*truck_river*per_truck
    total_load = mismanaged_river + illegal_dumping_extra + illegal_dump_now
    point_plastic.append(total_load)
    costs_pickup25 = (np.sum(combination['Costs'])+ 13* cost_TPS3R *costs)/households
    total_costs = costs_pickup25+current_cost*currcost
    point_cost.append(-1*total_costs)


    # 10 extra bank sampahs
    amount_banksampah = truncate(MPWH * PET_factor*PET_mis / (plastic_bank*cap))
    reduction_mismanaged = MPWH - amount_banksampah*(plastic_bank*cap)
    total_load = reduction_mismanaged * RF + illegal_dump_now
    cost = (current_cost*currcost) + amount_banksampah*cost_bank/households*costs
    point_plastic.append(total_load)
    point_cost.append(-1*cost)

    #current scenario
    total_load = PW_load
    point_plastic.append(total_load)
    point_cost.append(-1*(current_cost*currcost))


    #nowastemanagement scenario
    mismanaged_waste = PW_production
    total_load = mismanaged_waste*RF
    point_plastic.append(total_load)
    point_cost.append(0)

    #fitting
    fit = np.polyfit(point_plastic,point_cost,2) # fitten 5 points with a quadratic equation
    if returning == True:
        return point_plastic, point_cost, fit #also the datapoints are returned
    else:
        return fit # only this is needed for the sensitivity analysis

# plotting PPF
plastic_load = np.linspace(480,5090) # random x-waardes
plt.figure(figsize=(10,10))
data_plastic, data_cost, fit = sensitivity(1,1,1,1,1,1,1,1,1,1,True)
PPF_costs= np.polyval(fit,plastic_load)
np.savetxt('PPF_costs.txt',PPF_costs )
plt.plot(data_plastic, data_cost ,'.', label ='Scenarios')
plt.plot(PW_load,-current_cost,'d', label ='Current Situation')
plt.vlines(PW_production,-60000,0 ,linestyle='dashed', label ='Physical Limits')
plt.vlines(0,-60000,0 ,linestyle='dashed')
plt.xlabel('Plastic Waste Load [kg/d]')
plt.ylabel('Impact on Purchasing-Power of a Household [IDR/month]')
plt.plot(plastic_load, PPF_costs,label='PPF')
plt.annotate('', xy=(0, -0.1), xycoords='axes fraction', xytext=(1, -0.1),
                arrowprops=dict(arrowstyle="|-|", color='k'))
```

```
plt.text(7915,-68500,'Low Environmental Quality' , ha='center')
plt.text(0.0,-68500,'High Environmental Quality' , ha='center')
plt.ylim(-60000,0)
plt.xlim(7920,0)
plt.legend();

# sensitivity analysis
from SALib.sample import saltelli
from SALib.analyze import sobol

problem ={
    'num_vars': 10,
    'names': ['Frac. Dump','Frac.Burn','$\%Dump_{river}$','$\%Burn_{river}$',
    '$\%PickUp_{river}$', '$\%PET_{waste}$','$\%PET_{mismanaged}$', 'Current Cost',
    'Capcity Element', 'Cost Element' ],
    'bounds': [[0.9,1.1],
               [0.9,1.1],
               [0.9,1.1],
               [0.9,1.1],
               [0.9,1.1],
               [0.9,1.1],
               [0.9,1.1],
               [0.9,1.1],
               [0.9,1.1],
               [0.9,1.1]]
}

param_values = saltelli.sample(problem, 1000,calc_second_order=True)

fit_sensitive=np.zeros((len(param_values),3))
for i in range(len(param_values)):
    fit = sensitivity(param_values[i,0],param_values[i,1],param_values[i,2],
                                    param_values[i,3],param_values[i,4], param_values[i,5],
                                    param_values[i,6], param_values[i,7], param_values[i,8],
                                    param_values[i,9],False)
    fit_sensitive[i] = fit

name = ['a','b','c']

Sensitive = np.zeros((3,10))
for i in range(3):
    print(name[i])
    Si = sobol.analyze(problem, fit_sensitive[:,i], print_to_console=True)
    Sensitive[i] = Si['ST']

# plotting SA
plt.figure(figsize=(20,5))
x = np.array([1,2,3,4,5,6,7,8,9,10])
plt.bar(x-0.2, Sensitive[0],width = 0.2, label='Sensitivity for a')
plt.bar(x, Sensitive[1], width=0.2, label ='Sensitivity for b')
plt.bar(x+0.2, Sensitive[2], width=0.2, label ='Sensitivity for c')
plt.hlines(0.05,0,11,linestyle='dashed', label='Significance (0.05)')
plt.legend(loc='upper left')
plt.ylabel('Total Order Sensitivity Indices')
plt.xlim(0.5,10.5)
plt.xticks(x,problem['names']);
```