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Wasted Paradise – Imagining the Maldives Without The Garbage Island of Thilafushi

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Abstract

To address the high level of waste production in the Maldives, the local government decided to transform the coral island of Thilafushi into an immense waste dumb in 1992.Meanwhile, each day, 330 tons of waste is ferried to Thilafushi. The policy had the positive consequence of relieving the garbage burden in Malé, the main island, and surrounding tourist atolls. However, it can also lead to serious environmental and economic damage in the long range. First, the garbage is in visual range of one of the most prominent tourist destinations. Second, if the wind blows a certain way, unfiltered fumes from burning waste travels to tourist atolls. Third, water quality can erode as hazardous waste from batteries and other toxic waste is floating in the ocean. Over time, these effects can accumulate to significantly hamper the number of tourists that travel to the Maldives – one of the state's main sources of financial income. In our paper, we lay out the situation in more detail and translate it into a simulation model. We test different policies to propose the Maldives government how to better solve the waste problem.

Keywords:

Maldives, waste management, system dynamics, quantitative analysis

Introduction

Because of the Maldives' unique location in the Pacific Ocean, its paradise-like natural environment with an "abundant, yet fragile tropical reef-and-atoll-ecosystem with an exclusive biodiversity" (Domrös, 2005) and cultural equipment, the small island state has an increasingly high attraction to tourists. The Maldives consist of nearly 1,200 "low-laying coral islands scattered across the equator in the vast expanse of the Indian Ocean, giving [..] a rare glimpse of what is aptly described as tropical paradise" (Kundur, 2012). The Maldives are seen as "one of the world's most beautiful countries" (Medina, 2012), with lush vegetation, white sandy beaches, turquoise waters and a marine environment rich in diversity. The perceived beautifulness of the small 'tourist resort islands' attracts a high number of tourists each year (Government of the Maldives, 2014a; Kundur, 2012) (see Figure 1).

Tourists first started traveling to the Maldives in significant numbers in 1972 after the first two resorts with a 280-bed capacity opened (Government of the Maldives, 2014b; Kundur, 2012). According to Kundur (2012), five phases of tourist management can be identified in the Maldives' tourist development since. During the first phase, until 1978, tourism was mainly unplanned and took place according to individual initiative in which tourists 'discovered' the Maldives (Domrös, 2001: 133). As resorts were simply equipped and located on atolls close to the Maldives' international airport in Malé, speed boats and fishing boats transferred tourists to their resort island. During this phase, tourism did not play a significant role in the Maldives' economy (Kundur, 2012). During the second phase (1979-1988), local entrepreneurs began to provide new facilities, and further 41 resorts were opened (Domrös, 2001; Kundur, 2012). In this phase, more sophisticated boat transportation between Malé airport and the atolls were installed. Also, in addition to local resort operators, foreign companies started to invest in the Maldivian tourist industry. Over these nine years, tourists traveling to the Maldives increased from 33,124 to 155,757 people, with a growth around 30% between 1979 and 1980. During the third phase of tourism development (1989-1997), 16 more resorts opened, attracting increasingly more tourists with 365,563 tourists traveling to the Maldives in 1997 (Government of the Maldives, 2014a). In the subsequent phase between 1998 and 2001, innovative and high-quality tourism services were introduced in addition to resorts, including spa resorts, over-water bungalows built on stilts in the shallow lagoons surrounding the resort islands, guest houses, yachts and safari boats began their operations, attracting ever more tourists. As increasingly more of these destinations were located further away from the Malé airport, seaplanes were introduced to bring tourists to their resorts (Kundur, 2012). Until 2001, the number of tourists increased to 460,984 people. In the subsequent phase, which endures until today, the number of tourists grew more than doubled until 1,125,202 tourists in 2013. The annual average growth rate from 1979 until 2004 is 12%. It gradually fell to around 10% in 2004. In 2005 we observe a sharp drop – actual growth data fell by 36% and thus actual tourists numbers dropped from 616,716 to 395,320 people. This decline can be assigned to the aftermaths of the tsunami that struck the Indian Ocean in December 2004 (Kundur, 2012): many tourist facilities were destroyed and tourists also hesitated to travel in this region (Government of the Maldives, 2014b; Kundur, 2012). However, this external shock was leveled out only a few years later as around 2010, tourist numbers recovered to 791,917 and increased back to the pre-tsunami growth level. It should be noted that only 47% of the resorts were operated by local operators, with the rest being operated by foreign companies or foreign shareholding companies by the end of 2006 (Kundur, 2012).

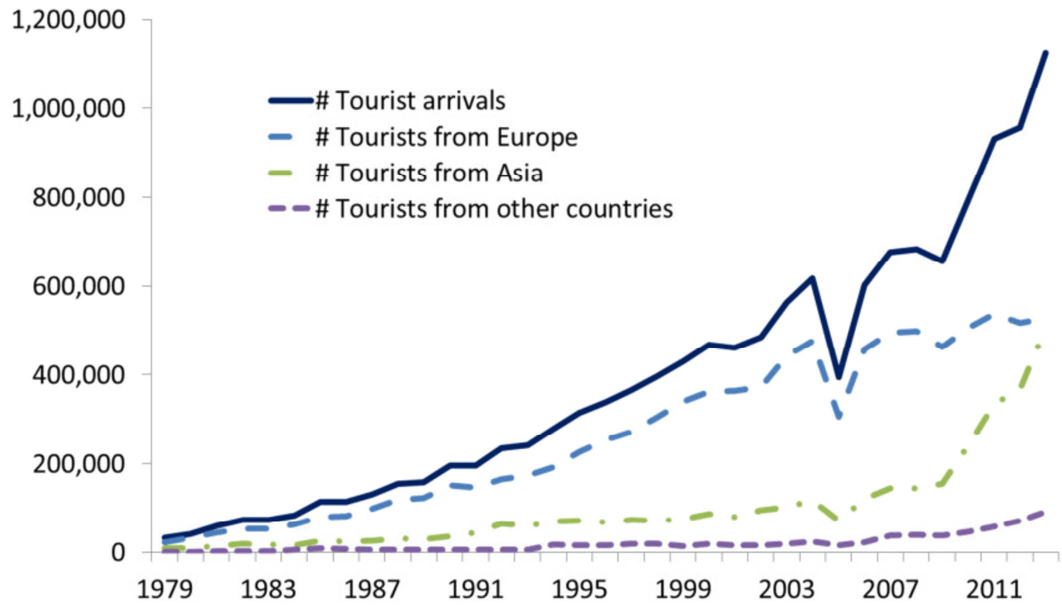

Figure 1: Tourists arriving in the Maldives 1979-2013.
Source: Maldives Ministry of Planning (2014)

With this development, tourism has also become to play a major role in the Maldives' economic and infrastructure development over the past decades. Tourism is especially important for the establishment of transportation links between the atolls and islands and the development of regional airports (Kundur, 2012). Tourism has become the largest economy in the Maldives to both, earning foreign exchange revenues and generating employment in the tertiary sector (Kundur, 2012). Overall, as can be seen in Figure 2, revenues from the tourism range between a fifth to a third of total revenues (Government of the Maldives, 2015). We observe a steady increase in revenues from tourism until 2006 from around 300 million to nearly 1,880 million Rufiyaa in 2012, with 12,000 million Rufiyaa total government revenues. Afterwards, revenues from tourists become more volatile, with a 25% increase from 2006 to 2007, followed by drops of 11% and 27%. There are no hints on the increased volatility in the official government reports (Government of the Maldives, 2014b).

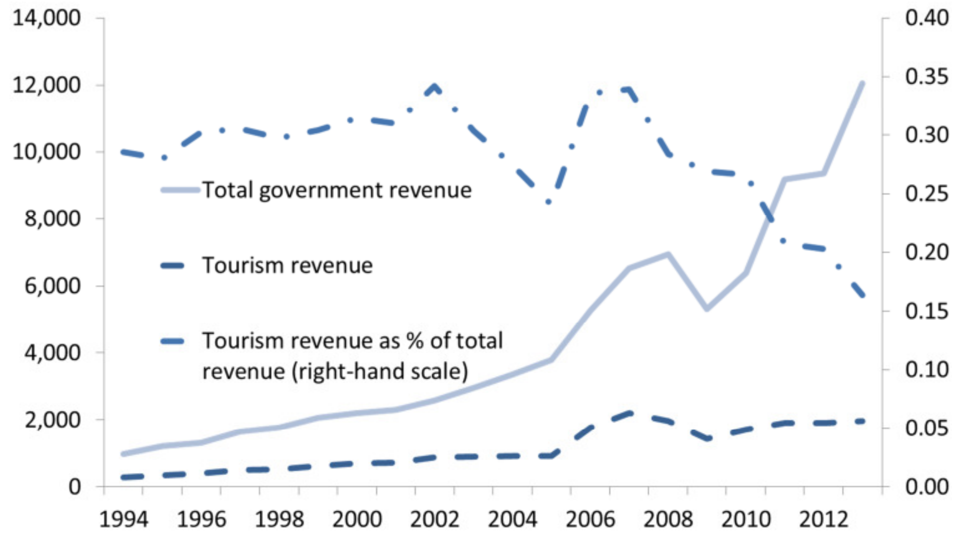

Figure 2: Total government revenue and Revenue from Tourism 1994-2013 in Million Rufiyaa. Source: Maldives Monetary Authority (2014)

While the monetary potential going along with tourists is tempting, the increasing number of tourists might jeopardize the unique ecosystem of the Maldives. As a consequence, environmentalists demand a controlled and environment friendly tourism that, on the one hand, does not endanger the ecosystem and, on the other hand, enables economic prosperity. This way of tourism is also asked for in the Brundlandt report, stating that "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). According to Domrös (2005), sustainable tourism requires an indispensable authenticity of nature and culture which goes along with the economic benefit for the (local) population. Instead, artificial life and constructed milieus of many touristic facilities endanger this idea by ignoring the identity of nature and culture: touristic facilities on the Maldives try to meet the high expectations of demanding Western tourists. Also, it is rather the country's elite that benefits from the revenues from tourism than the populace (Domrös, 2005). The high number of tourists visiting the Maldives thus has an unquestionable impact on the environment (Domrös, 2001). According to Domrös (2001), considerable economic returns were achieved at a very high cost to the environment: coral reefs have been degraded, and the flora and fauna of the ecosystems threatened, all because of a lack of awareness of environmental issues and the fragility of tropical reef ecosystems amongst tourists.

In addition, the capital of the Maldives, Malé, the island's largest city with more than 100,000 residents has been having a waste issue. Its inhabitants generate wastes of more than 120 tons/day (Medina, 2012) and as the city lacked and still lacks proper municipal waste management structures, the government was overwhelmed by the daily waste quantities. In the 1970s, available areas for landfilling of waste materials on Malé had been exhausted. Thus, the government of the Maldives decided to fill the lagoon of Thilafushi island with waste and ferry waste there (Peterson, 2013). According to the government, there was no other suitable existing land within a reasonable transfer distance. In 1992, the government officially decided to turn Thilafushi (Evans, 2015; Ramesh, 2009) into a waste-dump. Thilafushi is one of the archipelago about 4 miles away from Malé, thus in visibility range of the capital city island and located within the Malé atoll, in the center of the strip of islands that makes up the Maldives (Kundur, 2012). In the meantime, Thilafushi receives a minimum of 10 boats per day from resorts and a weekly average of 16 boats per day, which equates to a total of 96 boats per week (Peterson, 2013). Waste shipped to Thilafushi is not required to be covered by a net or another device to prevent spillage or blowing of waste into the sea (Peterson, 2013). Waste unloaded on Thilafushi is not measured by weight as there is no weigh scale. Operators also do not make a volume estimate. Nonetheless, the amount of waste delivered per boat ranges from a half to a full lorry load (Peterson, 2013). Once waste is unloaded on Thilafushi by an excavator, it is driven on a small truck to an open dump. Waste is then manually sorted (Ramesh, 2009) and it includes glass, disposable nappies, plastics, aluminum, sawdust, asbestos, food cans, untreated medical waste and toxic goods like led acid batteries and paint, et cetera from both Malé and about 70% from all tourist resorts (Evans, 2015; International Development Association, 2010; Peterson, 2013; Ramesh, 2009).

In general, open burning of waste is the usual mean to reduce the volume of waste for disposal (Peterson, 2013), while the more common combustion is smoldering, indicating incomplete combustion and leading to toxic air emissions and particulates that are indicated by the smoke (Peterson, 2013). In addition, a small portion of the solid waste is ferried away: a private company regularly crushes and exports stockpiled PET and recyclable metal wastes to India (Medina, 2012; Peterson, 2013; Ramesh, 2009). However, according to Peterson (2013), recycling has not gained significant attention. Paper is not recycled, for example.

In 2013, more than half a million ton of waste was being ferried to the island of Thilafushi (Waste Management Section; Malé City Council, 2015): more than 200,000 tons of waste were transported from Malé to Thilafushi, more than 500 tons per day. In addition, more than 350,000 tons were carried from other islands to Thilafushi, nearly 1,000 tons per day (see Figure 3), including waste from tourist resorts. Even though the islands available for tourism have expanded to the entire country by today, two-thirds of resort bed capacity is located on the two atolls that were initially developed, which puts the majority of resort generated waste in relatively close proximity to the waste treatment center on Thilafushi Island (Peterson, 2013).

According to Peterson (2013), the land for the solid waste site on Thilafushi has a total surface area of 230 ha. Twenty ha of capacity are still remaining for disposal, which could last for another 25 to 30 years (Medina, 2012; Peterson, 2013). This assumes, however, that suitable treatment processes will be needed to put in-place to reduce the volume of waste for disposal (Peterson, 2013).

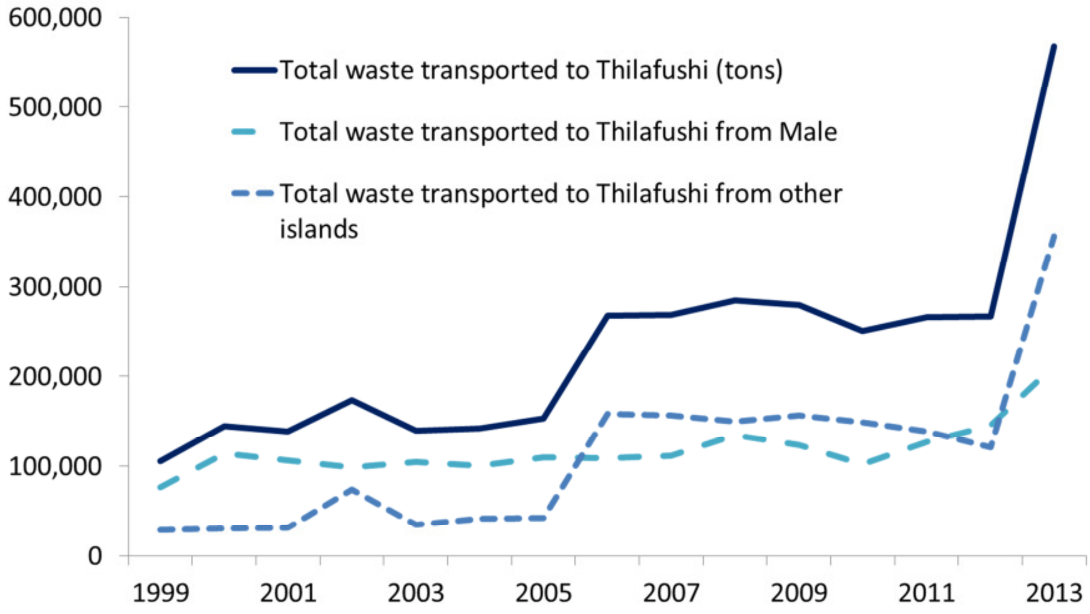

Figure 3: Waste transports to Thilafushi 1999-2013 in tons per year.
Source: Maldives Ministry of Planning (2004, 2014)

Even though the government officially supports an environmentally sustainable development of tourism (GreenTech Consultants Ltd., Riyan Pvt. Ltd., and CDE Pvt. Ltd., 2010), the Maldives are facing severe environmental threats (Medina, 2012). While this does not have an impact on tourism yet, Maldivian environmentalists are warning about a possible future impact on the environment (Evans, 2015; Medina, 2012). Over time, the impact on the environment could threaten tourists from visiting the Maldives, along with impacts on revenues from tourists.

Interplay between Environmental Pollution and Tourism on the Maldives

We translate our findings on tourism and the environment in the Maldives into a formal system dynamics simulation model (Sterman, 2000). We identify five major feedback loops which we describe below. Figure 1 shows that the number of tourists has increased immensely over the past decades. We depict this with the stock of annual Tourists (T) traveling to the Maldives (see Figure 4).

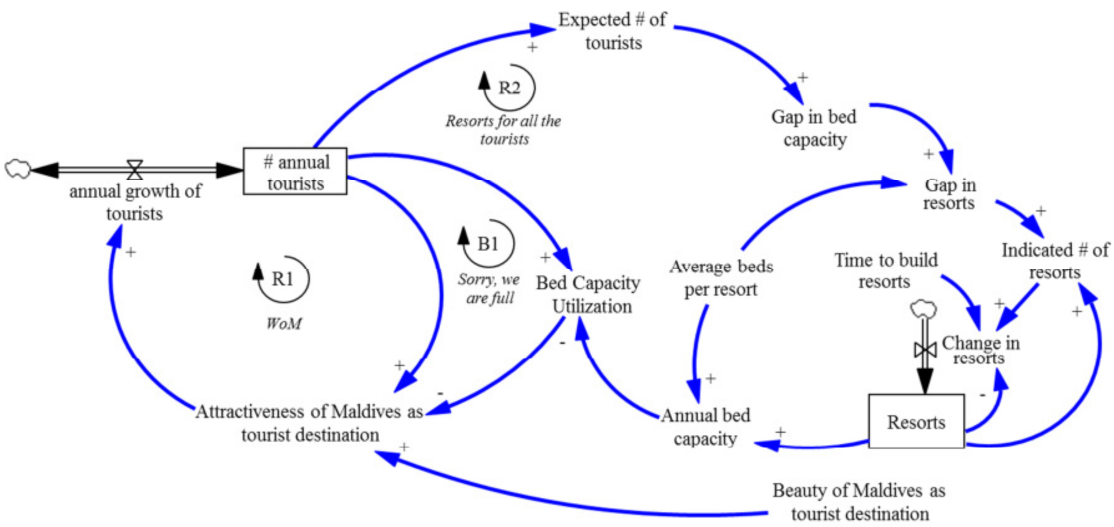

Figure 4: Tourist attraction to the Maldives (source: authors' representation).

As mentioned above, Tourists T travel to the Maldives because of the island's Attractiveness (A), which is determined by three drivers. First, tourists who have traveled to the Maldives talk to their friends about their positive holiday experience with great enthusiasm, thus kicking off favorable word-of-mouth (R1 – WoM). Second, the beauty of the Maldives in general is another determinant (Evans, 2015; Government of the Maldives, 2014a; Kundur, 2012). The recent increase in the levels of water and air pollution represents a significant threat to the beauty of the Maldives as a tourist destination. Third, as long as the number of Beds Required by Tourists is low relatively to the Annual Bed Capacity (ABC), Bed Capacity Utilization (BCU) is low. The attractiveness of the Maldives increases as Tourists (T) know they can easily find places to stay in non-crowded resorts. The relationships described above influence the growth rate of tourists through nonlinear effects. We capture the attractiveness of the Maldives as a multiplicative effect of the three factors: Tourists Word of Mouth (E_T), Bed Capacity Utilization (E_{CU}) and Pollution (E_P).

$$A = E_T * E_{CU} * E_P \quad (1)$$

The growth rate in the number of tourists is given by the normal tourist growth rate (g_N) multiplied by the overall attractiveness of the Maldives (A) and the current number of tourists (T).

$$\frac{dT}{dt} = T * A * g_N \quad (2)$$

The effect of Tourists Word of Mouth (E_T) is captured by a non-linear function (f_1) where tourists who have traveled to the Maldives talk to their friends about their positive holiday experience with great enthusiasm, thus kicking off favorable word-of-mouth (R1 – WoM). However, if too many tourists travel to the Maldives, then they will experience crowded resorts and less attractive holidays, limiting the positive growth due to word-of mouth. The nonlinear function (f_1) takes the shape of a logistics function such that $f_1(0)=0.35$; $f_1(1)=1$; $f_1'(0)=0$; $f_1'(1)=0$.

$$E_T = f_1(\frac{T_R}{T}) \tag{3}$$

A non-linear function (f_2) captures the effect of Bed Capacity Utilization (E_{CU}), relative to the desired bed capacity utilization (CU^*), on the Maldives' Attractiveness (A). When bed capacity utilization is low relative to the desired level, tourists are able to easily and quickly find a suitable place to stay, leading to high attractiveness. However, as more Tourists (T) travel to the Maldives, bed capacity utilization (CU) increases, making beds scarce. Bed Capacity Utilization (CU) is the ratio of between the Required Bed Capacity (RC) and the Annual Bed Capacity (AC). So, when Tourists would like to spend their holidays on the Maldives and miss to book early, beds might not be available anymore. The difficulty in booking resorts leads to a reduction in overall attractiveness (B1 – Sorry, we are full). The logistics function (f_2) has the following characteristics: $f_2(0)=0.05$; $f_2(1)=1$; $f_2'(0)=0$; $f_2'(1)=0$

$$E_{CU} = f_2(\frac{CU^*}{CU}) \tag{4}$$

The effect of Pollution (E_P), relative to the reference level of pollution (P_R), is captured by non-linear function (f_3). Low pollution levels lead to higher overall attractiveness of the Maldives. High levels of water and air pollution significantly threaten the beauty of the Maldives, reducing its overall attractiveness. The logistics function (f_3) capturing the effect of pollution is such that $f_3(0)=0.1$; $f_3(1)=1$; $f_3'(0)=0$; $f_3'(1)=0$.

$$E_P = f_3(\frac{P_R}{P}) \tag{5}$$

At the same time, with more Tourists traveling to the Maldives, expectations are formed on future number of tourists (R2 – Resorts for all the tourists). With an increasing number of Tourists (T), resort managers expect more tourists in the future (ET). Consequently, Bed Capacity (C) has to be increased and possibly more resorts (R) have to be established. If tourism managers observe a Gap in Resorts (GR) the Indicated number of Resorts (IR) increases as well. As the number of Resorts (R) increases, so does the Annual Bed Capacity (AC), given by the product of Resorts (R), the average number of Beds per Resort (BpR) and the total number of days in the year.

$$AC = 365 * R * BpR \tag{6}$$

In parallel, Required Bed Capacity (RC) is given by the product of the number of Tourists (T) and the average number of nights stay (ANS).

$$RC = ANS * T \tag{7}$$

As the Annual Bed Capacity (AC) increases, it lowers Bed Capacity Utilization (CU) and thus increases the Maldives' Attractiveness (A), again attracting more Tourists (T) (Kundur, 2012). An increase in Bed Capacity Utilization (CU) toward desired levels (CU*) closes the gap in Bed Capacity Utilization (GCU) and consequently the Gap in Bed Capacity (GC) and the Gap in Resorts (GR). Hence, fewer Resorts (R) need to be built (B2 – Infrastructure investment). The actual number of Resorts (R) that will ultimately be built is anchored on its current state R, but changes fractionally (dR/dt) to meet the indicated number of resorts (IR).

$$\frac{dR}{dt} = (IR - R)/\tau \tag{8}$$

with $IR = R + GR$

$$GR = \frac{GC}{BpR}$$

$$GC = Expected\ Tourists * GCU$$

$$GCU = MAX(0, CU - CU^*)$$

$$CU = \frac{RC}{AC} = \frac{T * ANS}{365 * (R * BpR)}$$

The Tourists traveling to the Maldives produce revenues, which we capture in the flow of Annual Tourism Revenues (ATR), which is driven by the Annual Spending per Tourist (ASpT). This leads to the following equation:

$$ATR = T * ASpT \tag{9}$$

The feedback loops laid out above all support the growth of the Resorts, which goes in favor for the Total Revenues by Tourists. Yet, on the downside there is a 'side-effect' (Sterman, 2000) which, as laid out above, gets increasingly strong over the years with a rising number of tourists traveling to the Maldives (see *Figure 5*).

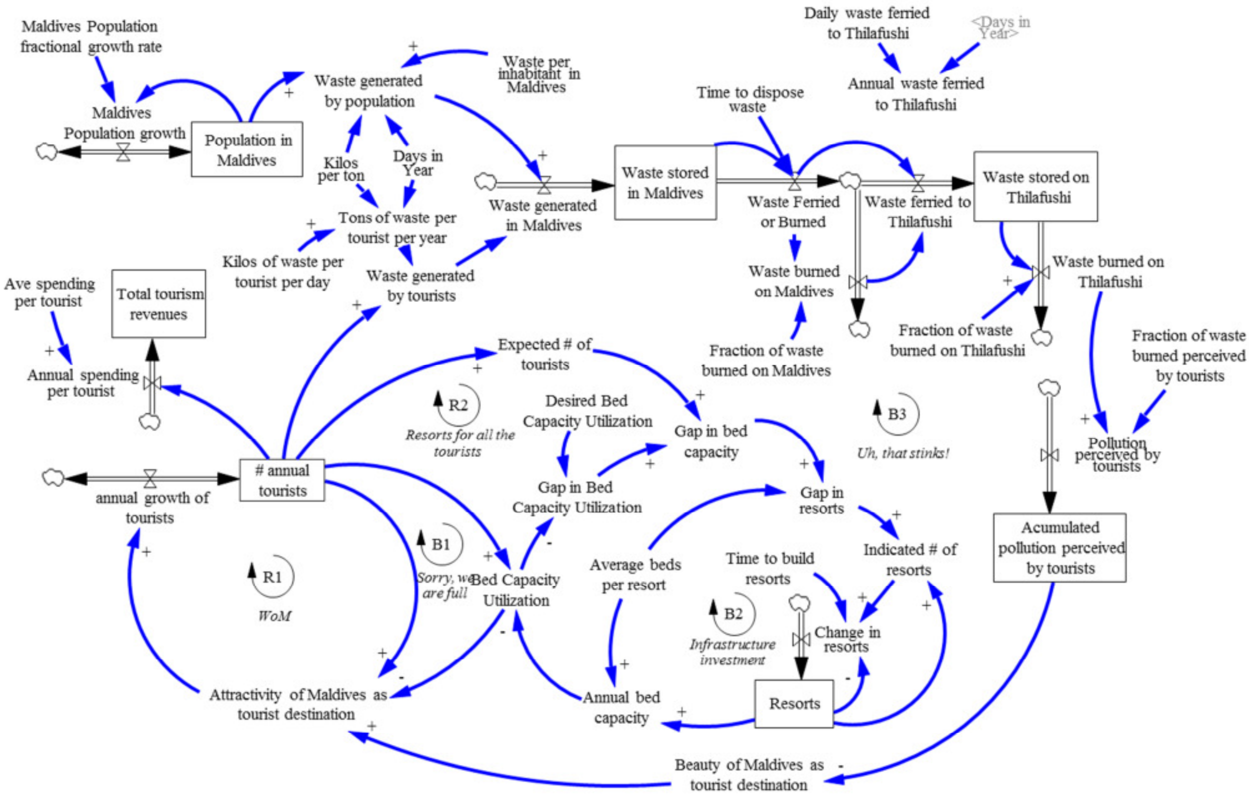

Figure 5: Stock-and-flow diagram of tourist and waste dynamics on the Maldives.

Tourists traveling to the Maldives produce on average 3.5 kg of Waste per day (WpTd) (Fiedler, 2014; Medina, 2012; Ramesh, 2009). This adds to the 1.5 kg Waste produced per day (WpPd), by the Maldives' Population (P) (Fiedler, 2014). We thus capture Waste Generation on the Maldives (WgM) in the extended model structure as depicted in *Figure 5*, with the following equation:

$$WgM = T * WpTd + P * WpPd \tag{10}$$

As laid out above, the islands of the Maldives have difficulties handling waste. Waste management activities are captured by the aging chain structure in the upper part of the model depicted in Figure 5. Waste is transported to Thilafushi. A fraction of this waste stays on Thilafushi and accumulates there. Another fraction is washed away in the Indian Ocean, thus polluting the ocean. And yet another fraction is burned without filtering, polluting the air. This pollution can indeed be perceived by tourists. First, for example, tourists may note visible plumes of smoke on the horizon when approaching Malé airport, when flying to their resort islands (Kundur, 2012), or when spotting dark smoky plume of burned particulates waste on the horizon from their resorts – as 67.5% of all resorts, which comprise the majority of tourist bed capacity, are located on the two atolls Alifu and Kaafu near Malé, and thus Thilafushi (Evans, 2015; Peterson, 2013). Second, they may notice waste drifting on the water surface – waste washed away from Thilafushi after storm surges or waste having spilled over or blown into the sea during the ferry ride (Evans, 2015; Peterson, 2013). Finally, tourists may hear about pollution when the word spreads (Evans, 2015) via newspaper, internet, or TV. For reasons of simplicity we subsume the different ways to perceive and be aware of the garbage in the stock Accumulated Pollution perceived by Tourists (P). Waste perception by tourists affects the tourists' perception of the Beautifulness of the Maldives as a tourist destination (B). The more Tourists (T) experience and observe the pollution of their tourist destination, the less beautiful the Maldives are perceived. This reduces, over time, the Attractiveness of the Maldives (A). Equation 11 summarizes the behavior associated with the resulting dynamics in tourists over time:

$$
\begin{aligned}
\frac{dT}{dt} &= T * g_N * A \qquad (11)\\
&= T * g_N * E_T * E_{CU} * E_P\\
&= T * g_N * f_1(\frac{T_R}{T}) * f_2(\frac{CU^*}{CU}) * f_3(\frac{P_R}{P})
\end{aligned}
$$

Comparison to Historical Behavior

Model testing includes a wide range of tests (Sterman, 2000), including model structure, historical fit and model behavior tests. We verify the structure of the model structure through literature research. Our waste management simulation model of the Maldives starts in 1979, when data on the topic becomes available for the Maldives. In the following, we assess model behavior against real-world data. Figure 6 shows the fit for Population (P), Tourists (T), Tourist growth rate (TGR), Capacity (C), Capacity utilization (CU), and Revenues from tourism (TTR). All major stocks have a very good fit to the available data. First, the model captures remarkably well the growth of the population (averaging 3% increase per year). Over the historical period from 1979 to 2014, the Maldives population, spread over 196 islands, grew from 152,146 people to 341,256 people (Government of the Maldives, 2014b; Kundur, 2012) (see upper-left graph in Figure 6).

The model also nicely captures the general evolution of tourists traveling to the Maldives (see upper-right graph) between 1979 and 2005. As described above, the number of tourists increased from

33,124 in 1979 to 1,125,202 tourists in 2013. While the simulation model properly captures the general increase in the number of tourists, it does not capture the drop in tourists in 2005, the year after the 2004 Indian Ocean Tsunami. It also does not capture the recovery following a systematic drop in prices, increased marketing and other strategies aimed at increasing the revival of tourism to the area. Furthermore, the simulation slightly underestimates actual tourist numbers traveling to the Maldives after 2009.

Tourist growth rates are depicted in the middle-left graph. Figure 6 shows a 3-period smoothed average of the actual annual growth rates. Our simulation underestimates actual growth data, maintaining a consistent bias during the period. The growth in the number of tourists follows a similar process to that of the growth in the population. Between 1979 and 2004, the growth data shows a steady decline from around 30% to roughly 10% per year (Government of the Maldives, 2014b). We observe more pronounced fluctuations (a major drop and subsequent recovery) after the 2004 Indian Ocean Tsunami. Since then, tourist growth data increases again to lower double-digit numbers. In our simulation model, we have not captured explicitly the impact of the tsunami and its recovery.

As can be seen from the middle-right graph, bed capacity on the Maldives has increased nearly linearly over the last 40 years, from 1,690 beds in 1979 to 29,811 in 2013 (Government of the Maldives, 2015; Kundur, 2012). As stated above, the Maldives government has primarily focused on resort-like tourist housing. Capacity utilization over the same time horizon has increased from 50% to around 70%. Interestingly, resort managers have managed to keep a high bed capacity utilization (i.e., higher than 65%) despite the high growth of in the number of resorts and overall available bed capacity in four decades.

Data for tourism revenues are only available since 1994 (lower right-hand graph). The model captures the general trend in the dynamics of both, capacity and capacity utilization well, but, as before, not the actual oscillations. The lower-right graph depicts revenues from tourism. Likewise the number of tourists traveling the Maldives, the simulation captures well the development until around 2004. The model does not get the following peaks and troughs, but the general increase of revenues from tourists.

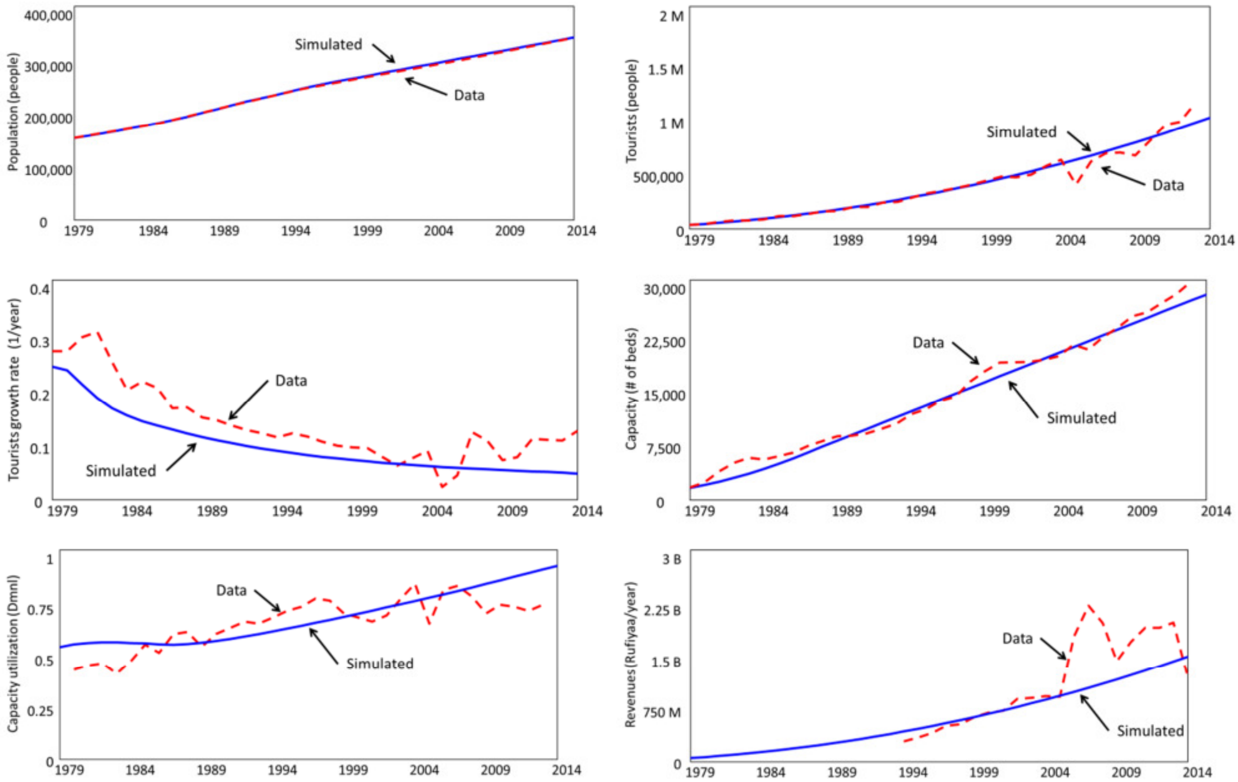

Figure 6: Selected comparisons of simulated and actual data from upper-left to lower-right, left-to-right: Population, Tourists, Tourist growth rate, Capacity, Capacity utilization, Revenues from tourists. Source for data: Maldives Ministry of Planning (2014) and Maldives Monetary Authority (2014).

Figure 7 depicts real-world data and the simulation for the total amount of waste ferried to Thilafushi. Available data go back until 1999 (Government of the Maldives, 2004, 2014b). In 1999, more than 100,000 tons have been ferried to Thilafushi. Ten years later, the amount had nearly tripled. Another 5 years later, the amount had increased again, this time nearly doubling. From 1999 to 2014, the total amount of waste ferried to Thilafushi experienced an average growth rate of 17% per year, representing a doubling time (Sterman, 2000) for waste ferried to Thilafushi of only 4 years. Our simulation does not capture the behavior for the waste ferried to Thilafushi fully endogenously. We explicitly acknowledge changes in government waste policies by capturing the increased shipping volumes of waste ferried to Thilafushi Island with endogenous step functions. As explained earlier, today not only Malé ships its waste to Thilafushi, but also an increasing number of tourist resorts (Evans, 2015; Peterson, 2013).

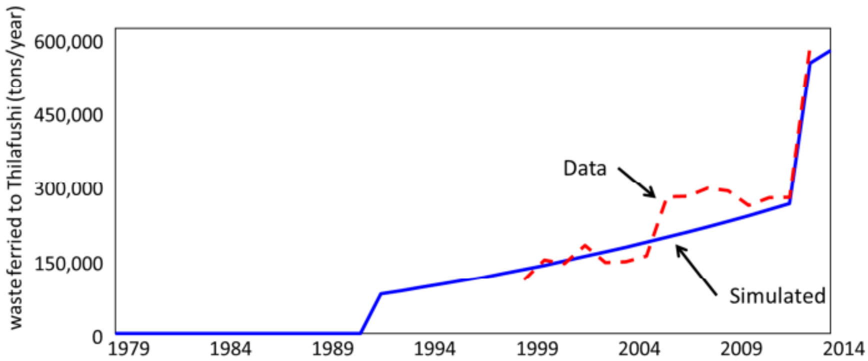

Figure 7: Comparison of simulated and actual data for Waste ferried to Thilafushi.

Source for data: Maldives Ministry of Planning (2014).

Base Run: Business as Usual

The base run starts from 1979, when data is first available, and ends in 2050, well beyond available data ending in 2013. We assume that the Maldives' population continues to increase, nearly doubling its size in 35 years (see upper-left graph in Figure 8). As the government relies on receiving hard currency from tourists, it continues to prepare atolls to open for tourism. Thus, in the base case, we assume that bed capacity still increases, nearly doubling until 2050 (upper-right) to reach nearly 60,000 beds. This number is highly likely. The current government plan indicates more than 10,000 beds in resorts and hotels to be opened in the very near future (Government of the Maldives, 2014b). Considering the numbers stated in this government report, it could be rather expected that the simulated number is more likely to be too conservative. Nonetheless, additional bed capacity will attract further tourists (lower-right). Note, however, that the number of tourists visiting the Maldives continues to grow with a decreasing rate, reaching around 1.8 million tourists in 2050. The smaller growth is attributed to increased pollution levels (upper-left and right-hand). Whereas in the past, the volume of waste shipped to Thilafushi was nearly invisible to the tourists, it then becomes increasingly recognized: plastic waste (e.g., plastic bottles) float on the water after being washed away from Thilafushi by a storm, muddying diving grounds. Alternatively, tourists see and smell the smoke from open burning. This increasingly irritates tourists who on average pay a premium price for spending their holidays on the Maldives. Consequently, the Maldives lose attractiveness for some tourists (lower-left). As less tourists travel to the Maldives, the tourists' spending increases similarly with a decreasing rate (lower-right) to reach 2,76 billion Rufiyaa in 2050. Summarizing, the base case captures scholars' (Evans, 2015; Medina, 2012; Peterson, 2013) predictions, namely that increasing pollution of the Maldives will likely affect tourism.

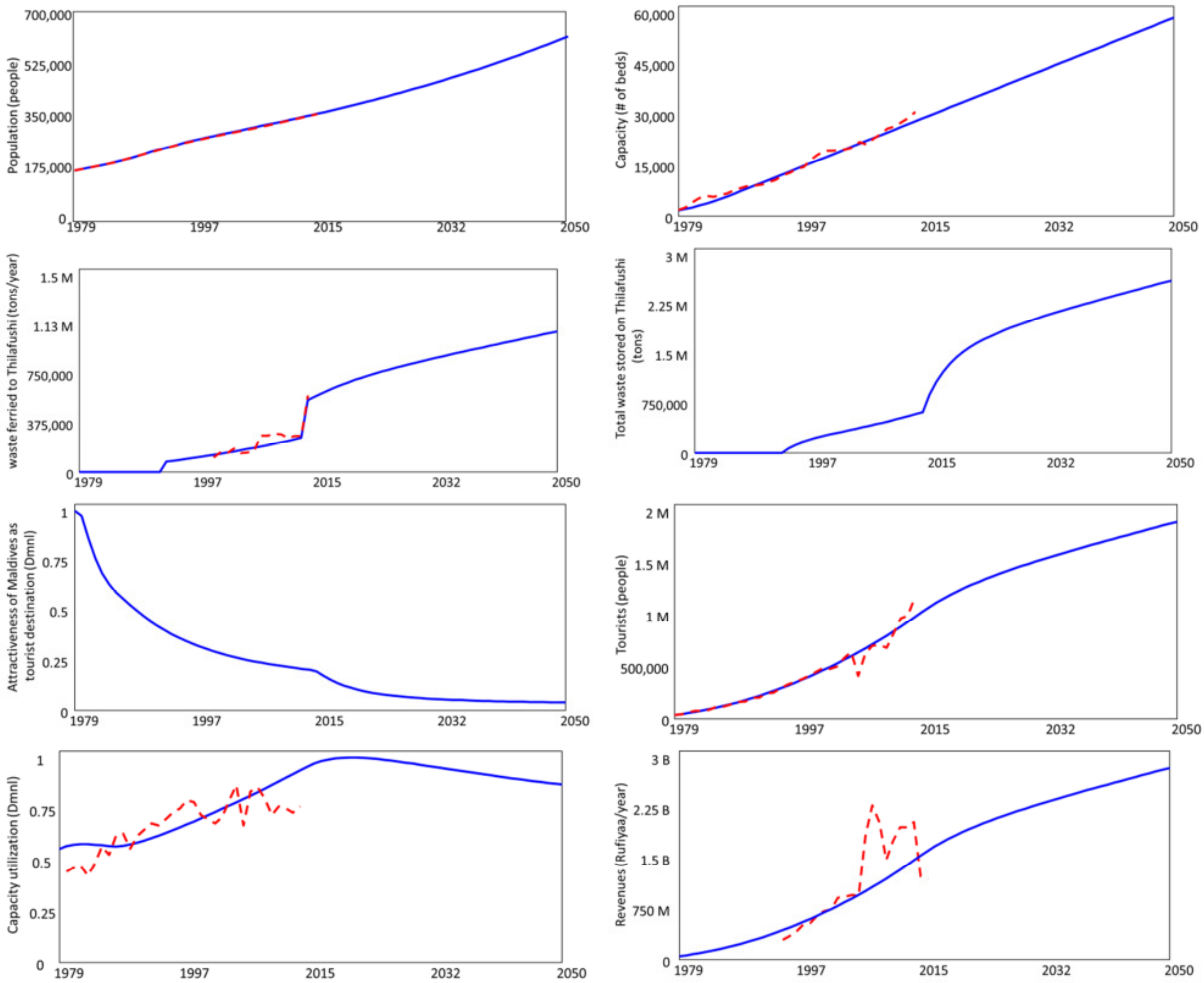

Figure 8: Base run – business as usual for selected variables from upper-left to lower-right, left-to-right: Population, Capacity, Waste ferried to Thilafushi, Total waste stored on Thilafushi, Attractiveness of the Maldives to Tourists, Tourists, Capacity utilization, and Annual tourist spending

By shipping waste away from Malé and tourist resorts to Thilafushi, the government neglects the waste problem and adopts an 'out-of-sight, out-of-mind' attitude. While experts predict that waste will negatively affect the Maldives' attractiveness as a tourist destination, this seems to be neglected by government officials. Given the inadequacy of the existing waste management policy in the Maldives, policy-makers are likely unaware of the possible impact that pollution may have on tourism. Hence, it is likely that policy-makers expect the number of tourists and tourism related spending to continue to grow. Most probably, as more tourist resorts are constantly being opened at an increasing rate, policy-makers likely expect the number of tourists traveling to the Maldives to develop in a similar way. Along with increasing tourists visiting the Maldives, their spending increases also – assuming current growth numbers and neglecting the effect of pollution on the Maldives attractiveness, tourists and annual revenues from tourist will more than double with about 3,45 million tourists generating more than 5 billion Rufiyaa in 2050 (see Figure 9).

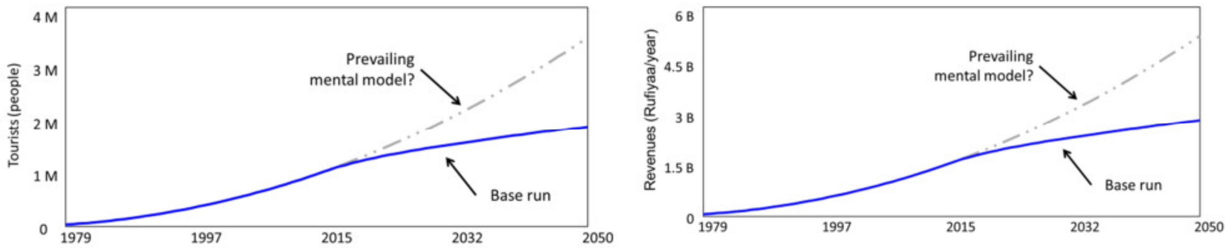

Figure 9: Prevailing mental model of expected tourists and Annual tourist spending?

Policy Considerations

To consider possible policies to address the Maldives' waste problem, we follow the UN Environmental Programme (2010) waste hierarchy. Figure 10 shows the hierarchy of options to dispose of solid waste. According to the International Solid Waste Association (2009), "the waste hierarchy is a valuable conceptual and political prioritization tool which can assist in developing waste management strategies aimed at limiting resource consumption and protecting the environment". The least preferred option for managing waste is landfill. However, this waste management option is the one the Maldives' government is currently following. Waste or ashes from open burning are used for landfill or reclamation of land by filling lagoons (Peterson, 2013). In addition, as many islands have inadequate land available for solid waste disposal, they dump waste into the sea or ferry it, from Malé and the surrounding islands and atolls, to Thilafushi. The second least preferred option is to produce energy from waste which is currently not done on the Maldives. Some of the PET and metal wastes are indeed collected and shipped to India for recycling. Re-use and prevention are hardly done on the Maldives. While Zunft and Fröhlich (2009) perceive the transition from waste to product between recycling and re-use, we follow Quicker's (2009) interpretation with products starting with on the level of recycling for the case of the Maldives.

To capture the impact of specific waste management policies suggested by the hierarchy, we first keep track of its waste composition. The solid waste that is ferried to Thilafushi includes both the waste generated by the Maldives population (in Malé and some other atolls) as well as the waste generated by tourists in different resorts. According to Medina (2012), the composition of the waste coming from Malé is such that food waste accounts for 22.2%; yard waste, 52.8%; plastics 2.5%; inorganic, 18%; and other 4.7%. Analogously, according to Peterson (2013), the composition of the waste coming from tourist resorts is such that food waste accounts for 40%; yard waste, 38%; plastics 5%; inorganic, 11%; and other 6%. Roughly 90% of the 40% food waste generated in tourist resorts is discarded into the sea. Peterson (2013) notes that food waste is usually shipped a sufficient distance at sea so that the waste does not wash back onto to island beaches.

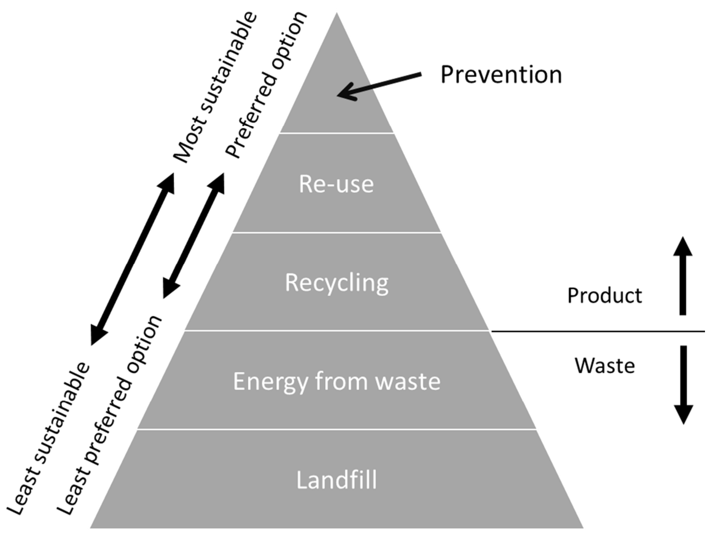

Figure 10: Hierarchy of Solid Waste Management Options.

Source: United Nations Environmental Programme (2010) and Zunft & Fröhlich (2009).

While the composition of the waste generated by the Maldives' population differs from that generated by tourists, they share some commonalities. In particular, the total amount of waste that can be compostable, burnt and recycled is similar. For instance, organic waste (including food and yard waste) accounts for 75% of the solid waste generated by the population and 78% of the waste generated by tourists in resorts. All organic waste can be composted. Plastics and inorganic waste can be recycled. They account for 20% of the population waste and 17% of the tourist waste. Other waste can be burned to generate energy. They account for 5% and 6% of the population and tourist waste, respectively. Figure 11 shows a stacked graph of waste composition by type ferried to Thilafushi from both, Malé and surrounding atolls (left hand graph). The quantities for waste types are estimates based on the data provided for the total amount of waste ferried to Thilafushi until 2013 ((Government of the Maldives, 2014b) and the waste compositions (Medina, 2012; Peterson, 2013). The right-hand graph depicts the waste arriving on Thilafushi, again by waste type. Note that we assume that the increasing waste nearly all gets shipped to Thilafushi as Malé and the resorts can no longer handle the increased volume of waste.

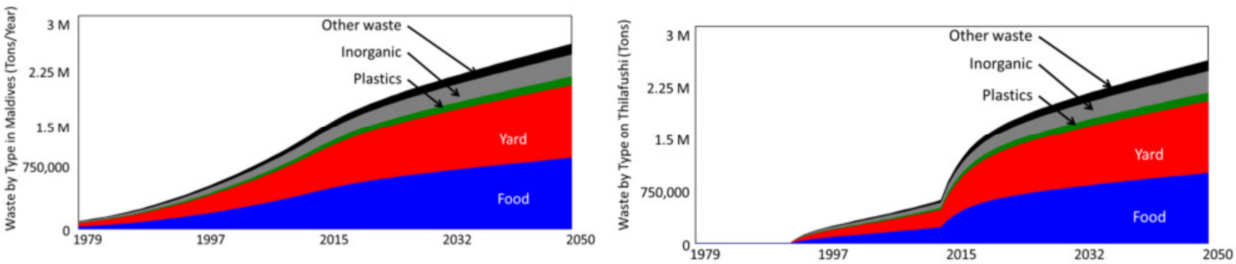

Figure 11: Stacked graph of waste by type in the Maldives (left) and shipped to Thilafushi (right) in the base run for . Total waste quantities until 2013 is based on data.

Peterson (2013) stresses that technology options suitable for the Maldives are limited because of the relatively small quantity of solid waste that is generated over a geographically highly dispersed area. Because of the Maldives' special geography some options might not be suitable. We consequently consider this when laying out policy options. We assume that all policies are in place at the beginning of 2015. In addition, building on the options highlighted on the solid waste management hierarchy, we investigate policies that focus on composting, energy from waste, recycling, and prevention.

Energy from Waste Policy

Waste-to-energy is an important and essential part of sustainable waste management (Zunft and Fröhling, 2009). It is used to dispose not-avoided and not-recyclable waste in a harmless way. On the one hand, waste-to-energy reduces waste volume by burning waste in a controlled environment. On the other hand, waste is transferred into energy that can be used by the population. A policy that generates energy from waste requires heavy investment. It focuses on burning waste types 'other' than organic (food and yard) and recyclable (plastics and inorganic) waste. Other waste types account only for a minority of the total waste produced (5% and 6% of the population and tourist waste, respectively), so this policy is unlikely to have a huge impact. Yet, the Maldives Government has recently made the decision to develop a waste-to-energy project on Thilafushi. According to Peterson (2013), the project has been delayed because of contractual issues.

The upper graphs in Figure 12 show the results of implementing a policy that generates energy from waste. As expected the policy has only a slight 4% decrease on the total waste stored in Thilafushi by 2030, having almost no impact in the amount of pollution perceived by tourists. Attractiveness of the

Maldives as a tourist destination only slightly increases compared to the base-run, which results in slightly more tourists (lower-right). They generate slightly more revenues (lower-right). Overall, still, with slightly more tourists traveling to the Maldives who, in total, produce more waste, the policy helps to reduce waste on Thilafushi.

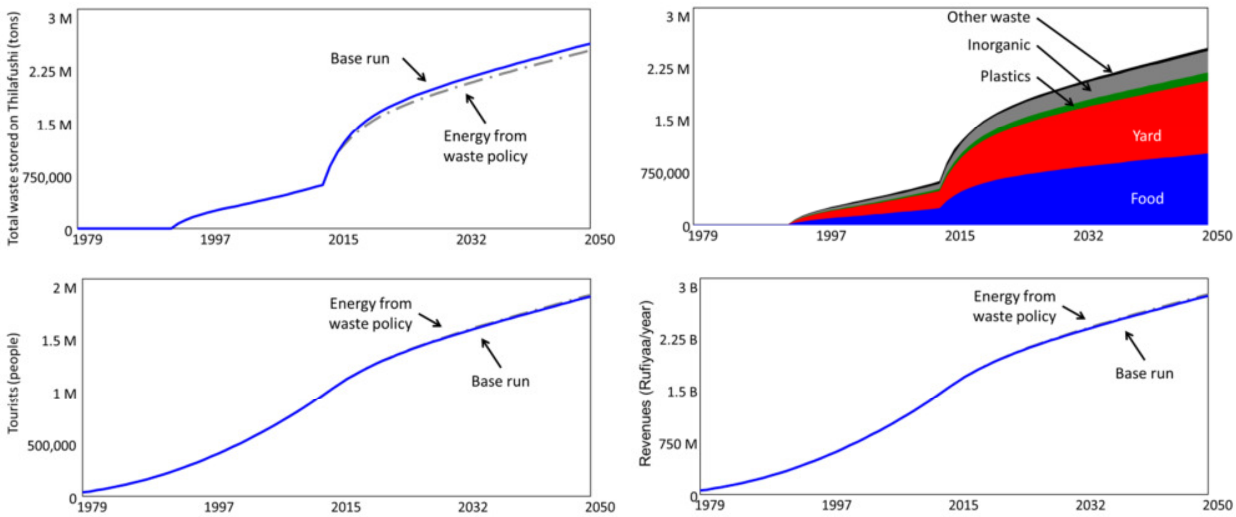

Figure 12: Energy from Waste Policy: As waste accounted to be burned only accounts for a small fraction of total waste on Thilafushi, the impact of the Energy from Waste Policy on waste stored on Thilafushi is 4%. Clockwise from upper left: Total waste stored on Thilafushi, stacked graph of waste stored on Thilafushi, Revenues from tourism, Tourists.

Recycling Policy:

Another way to reduce waste quantities is recycling. A recycling policy explores the impact of enforcing the recycling of all plastics and inorganic waste. This waste management policy is partly done already in the Maldives, as described in Peterson (2013). However, it only covers a small fraction of the generated waste as the difficulty lies in the long transportation way of the buyer of recyclables located in India. The recycling policy assumes that all plastics and inorganic waste are recycled. While quantities of recyclables in resorts and small islands are fairly small, Peterson (2013) still assumes possibilities for economies of scale achieved when Maldivian provinces cooperate. Since plastics and inorganic waste account for 20% of the population waste and 17% of the tourist waste, an effective recycling policy can lead to a significant reduction in the total waste accumulated on Thilafushi (see upper graphs in Figure 13). It yet has to be acknowledged that the market for recyclables is limited on the Maldives. So, a deeper cooperation with scrap brokers that sell recyclables to India should be considered for being extended.

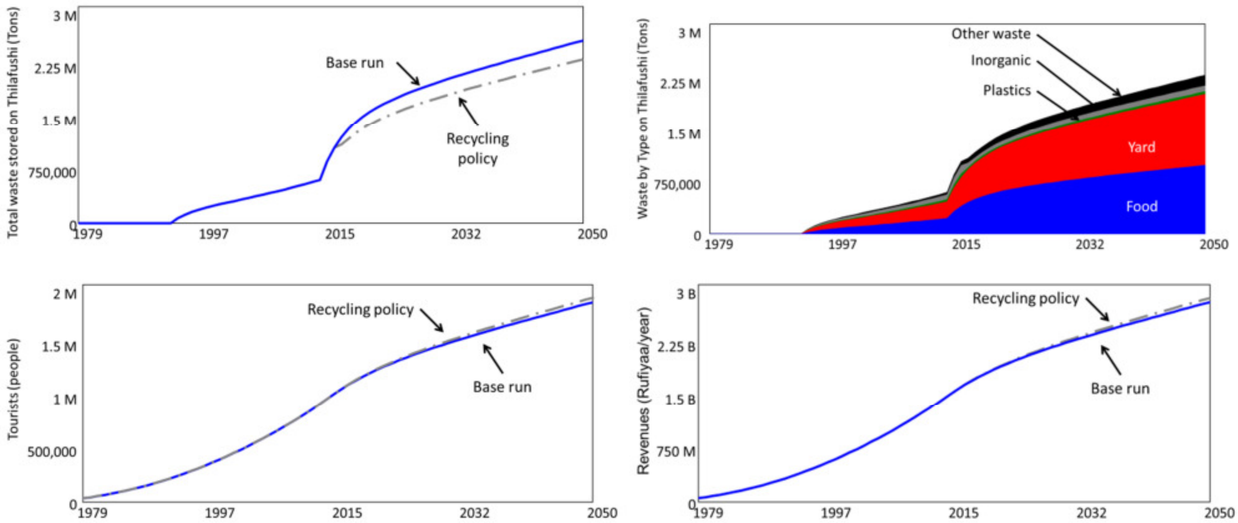

Figure 13: Recycling Policy: The impact from the recycling is 12% as a higher fraction of waste on Thilafushi is recyclable in 2030. Clockwise from upper left: Total waste stored on Thilafushi, stacked graph of waste stored on Thilafushi, Revenues from tourism, Tourists.

Figure 13 show the results of a recycling policy. The policy leads to an 11% decrease in the total amount of waste accumulated in 15 years. While the impact of the recycling policy is considerable, recycling alone provides only a small relief on the waste problem. The impact on the Attractiveness of the Maldives for tourists only increases slightly. Thus, the number of tourists traveling to the Maldives and the revenues generated from tourism increase slightly.

Waste Reduction Policy:

Whereas the waste management policies described above impact waste after it has been generated, this policy explores the impact of a waste reduction policy, where the Maldives' government puts in place measures that allow tourists to reduce waste by both tourists and inhabitants. In other words, this policy prevents waste from being produced – and thus does not have to be managed. This could, for example, be implemented, by an advanced waste disposal charge (Peterson, 2013). Products get more expensive – thus, reducing consumption and the additional money can be used to cover costs related with waste management. In addition, transportation costs for waste to be ferried to Thilafushi are already prohibitively expensive with roughly € 30,000 per month for an average tourist resort (Peterson, 2013) – and they could be increased as well. It is thus in the interest of any inhabited island to reduce waste to be shipped to Thilafushi to its minimum. The remaining waste has to be disposed on the island itself. We investigate the impact of waste reduction policies that decrease the amount of total waste generated in 10%, 20% or 30%.

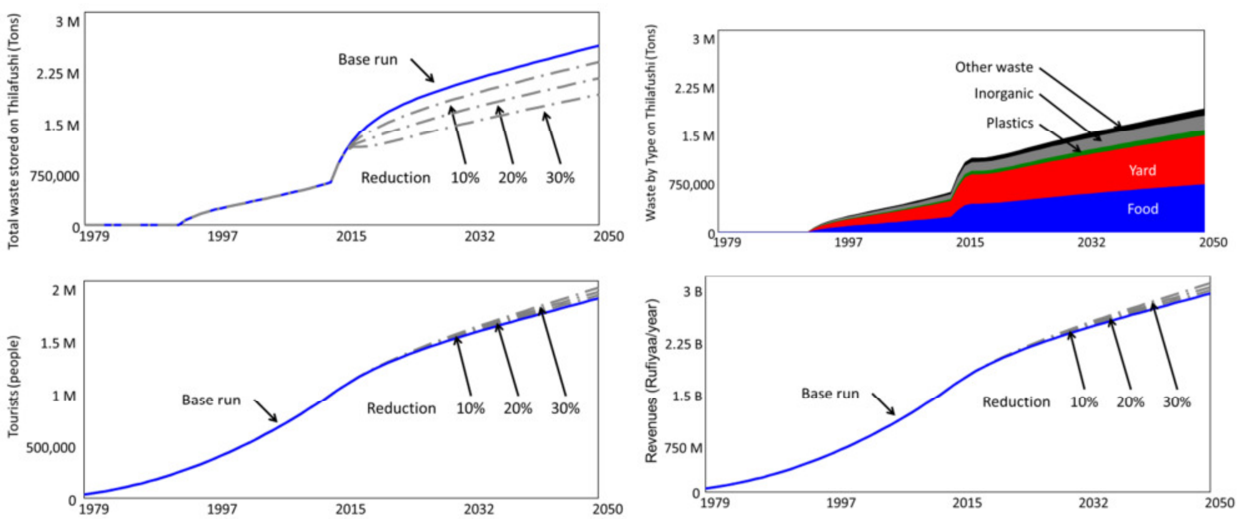

Figure 14: Waste Reduction Policy: This policy reduces waste production by 10%, 20%, and 30% from both, population and tourists. With increasing population and tourists, the current level of waste is met again in only a few years into the future. Clockwise from upper left: Total waste stored on Thilafushi, stacked graph of waste stored on Thilafushi (30% reduction only), Revenues from tourism, Tourists.

Figure 14 shows the results of a waste reduction policy. The policy leads to 10%, 20% and 30% decreases in the total amount of waste accumulated over time. The policy also shows that despite the considerable impact it achieves, reducing waste is not effective so long as the total amount of waste produced continues to increase. As can be seen in the upper-left graph, with reducing waste by 10% or 20%, the amount of waste on Thilafushi continues to increase, yet at a slightly slower rate than in the base run. Only when reducing waste production by 30%, the amount generated does not initially increase, but stays constant. The upper-right graph depicts this for the 30% reduction scenario. It also shows that the quantities of all waste types are smaller than the ones in the base run depicted in Figure 11. However, only seven years later, in 2022, waste on Thilafushi has already reached a similar level as the base run in 2015, the time of the policy implementation. Waste on Thilafushi continues to increase with a slightly smaller growth rate than the base run. As the overall waste stored on Thilafushi and pollution continues to grow, Attractiveness of the Maldives as a tourist destination is not that much different from the base run. Only a little more tourist travel to the Maldives, spending only slightly more than in the base run.

Composting Policy:

This policy again impacts waste management after waste has been produced. It explores the impact of a strict composting policy, such that all food and yard waste is composted. As mentioned above, food and yard account for the majority of the waste generated in the Maldives both by the population (75%) and tourists (78%). The high fraction of compostable waste also suggests that composting is likely to be an important policy to be considered. There are different approaches for composting (Peterson, 2013). First, low technology composting systems are inexpensive but land-intensive. This windrow process takes about 60 days until humus emerges, which can then be packaged for sale. Second, higher technology systems reduce the land-use but are more expensive as they require the investment in equipment. The latter is done on one resort on a small scale, for example, where a pre-composting mechanical mixer produces mulch after some hours of mixing. The product requires some additional days of aerobic composting to become suitable. This is a much faster process than the natural composting, reducing waste quantities faster.

Composting can thus be done on the more local level on the tourist resorts islands, for example, to reduce waste transported to Thilafushi, and on a larger scale on Thilafushi (Peterson, 2013). Compost can be used as a soil conditioner for on-site landscaping. About 30% of the humus produced can be used for landscaping purposes by resorts. Excess compost could be sold to other communities for both garden and agricultural use. Compost, or humus, decreases soil density and enhances seed germination and releases nutrients to soil. At any case, to make composting successful, people need to be trained in biological processes and in developing business ideas on what to do with the composted material (Peterson, 2013). In our policy run we assume large scale composting after waste has been shipped to Thilafushi.

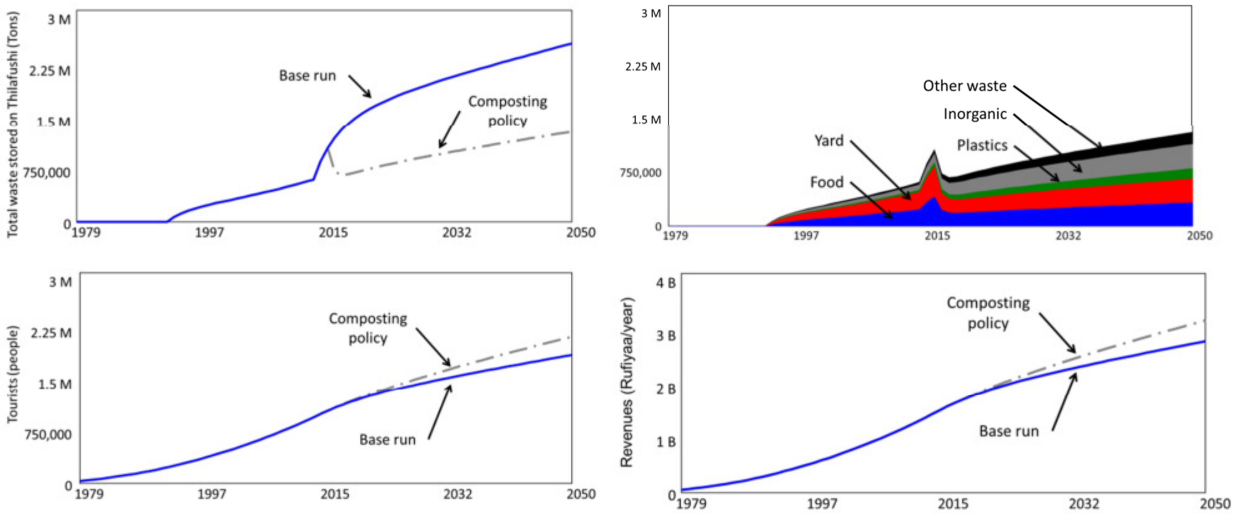

Figure 15: Composting Policy: This policy is the most promising one, with a significant decrease. Clockwise from upper left: Total waste stored on Thilafushi, stacked graph of waste stored on Thilafushi, Revenues from tourism, Tourists.

Figure 15 shows the results of implementing a composting policy. Given the significant percentage of waste that can be composted (see upper-right), this policy leads to a significant decrease in the total amount of waste accumulated in Thilafushi (upper-left). It highlights the importance of composting as one of the main policies to manage waste in Thilafushi. Also, the impact on Attractiveness of the Maldives for tourists is noticeable. 6% (14%) more tourists travel to the Maldives (lower-right), spending 6% (14%) more money (lower right) in 2030 (in 2050). Still, this policy only relieves the pressure from waste for a limited time. Twenty-one years after the implementation of this policy, the amount of waste on Thilafushi has again reached the same level as in 2015, only to further increase afterwards.

Combined Policy:

This policy explores the combined effect of all of the above waste management policies (i.e., recycling, composting, energy from waste and a 30% reduction in waste) on the total waste generated in the Maldives. Figure 16 depicts the result of this policy. This policy massively reduces the amount of waste of all types (upper-right), relieving the pressure from waste on Thilafushi. While 30% less waste of all types is produced, less waste is shipped to Thilafushi. Subsequently, waste is burned in controlled environments to produce waste, recyclables are recycled and shipped to appropriate companies in India and other countries, and yard and food waste is composted.

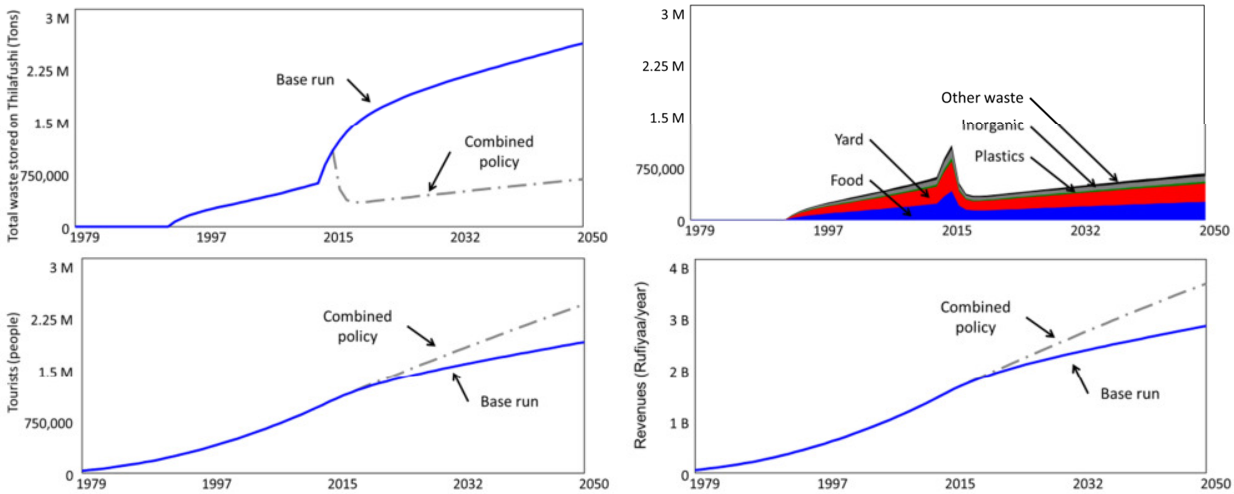

Figure 16: Combination Policy: Only the combination of all policies will relax the waste situation on Thilafushi, leading to considerable less waste. Clockwise from upper left: Total waste stored on Thilafushi, stacked graph of waste stored on Thilafushi, Revenues from tourism, Tourists.

Installing all of these policies requires large investments and rigorous and enforced implementation and commitment by all parties. Yet, there is an expected payback with 12% more tourists and revenues from tourism in 2030 and nearly 30% more tourists and revenues in 2050 compared to the base run. Accumulated addition revenues from tourists add up to 12 billion Rufiyaa over the next 35 years.

General Discussion

It is stated that waste generation on the Maldives will eventually lead to increased environmental pollution. Over time, this will increasingly affect tourism (Evans, 2015; Medina, 2012; Peterson, 2013), the largest contributor to the economy of the Maldives. We test five different policies for waste management and on their impact on the number of tourists and the revenues from tourism. Below, we show the comparison of all prior policies on waste management on the Maldives.

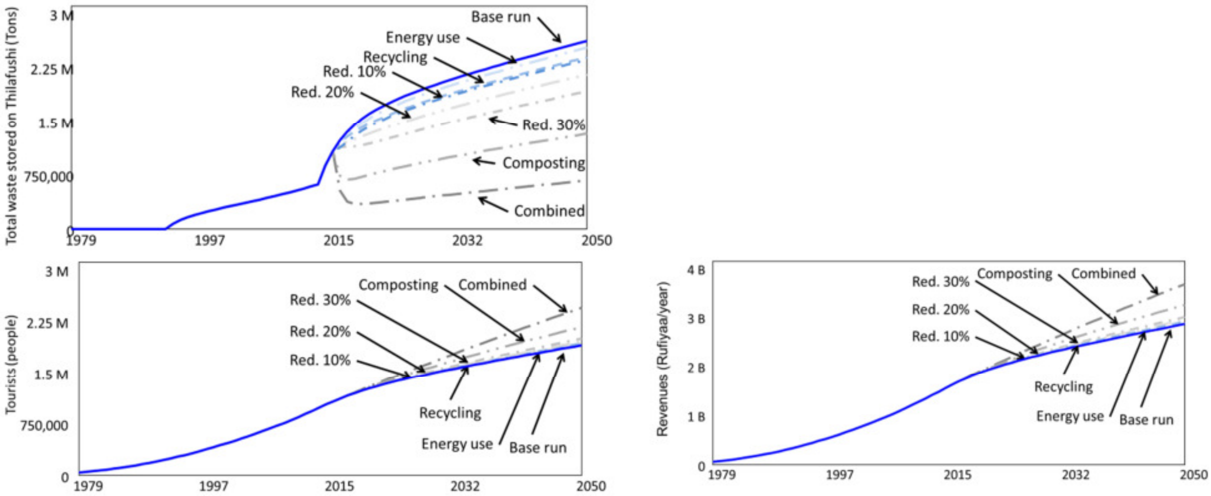

Figure 17: All policies compared. Clockwise from upper left: Total waste stored on Thilafushi, Revenues from tourism, Tourists.

The first policy we tested, waste-to-energy, has not proved to be promising. Waste on Thilafushi is only 4% lower over the next 35 years compared to the base run. In 2050, instead of 1.84 million tourists (base run), 1.85 million tourists travel to the Maldives, generating 2.78 Rufiyaa instead of 2.746 Rufiyaa. When looking at the difference in the accumulation of revenues, the difference is less than a billion Rufiyaa over 35 years. Considering the large investments for power plants and the supporting infrastructure, this policy is not likely to pay off financially. The reason for the low impact of this policy is because of the small percentage of waste types suitable for waste-to-energy.

Recycling, the second policy, however, focuses on recycling of all plastics and inorganic waste which make up to 17% of all waste on Thilafushi. The actual amount of waste affected by this policy is larger than in the first policy. Accumulated waste on Thilafushi until 2050 is less than in the base run and in the waste-to-energy policy, but still increasing. Thus, the impact on both, the number of tourists traveling to the Maldives, and the revenues from tourism is fairly low. In 2015, only 3,000 tourists more travel to the Maldives, compared to the base run, generating 2.81 billion Rufiyaa instead of 2.76 billion Rufiyaa. The accumulated difference is roughly 1 billion Rufiyaa.

The third policy, reduction of waste before it is being generated is more promising, but only if enforced with a 30% reduction. Nearly 10,000 tourists more travel to the Maldives compared to the base run (1.93 instead of 1.84 million tourists) in 2050. They generate 2.9 billion Rufiyaa instead of 2.76 billion Rufiyaa, which is 5% more. The difference accumulates to 2 billion Rufiyaa over the next 35 years.

Composting, the fourth policy we tested, is the first that has a considerable effect. It is also the first policy in which the pattern for the development of waste on Thilafushi looks different. While with the previous policy runs, growth of waste is simply slowed down, waste on Thilafushi first decreases by nearly half in order to slowly increase in the following years with applying this policy. In 2050, waste on Thilafushi is significantly decreased from 2.53 million tons in the base run to 1.27 million tons. This is nearly 50% less compared to the base run – but still more than 20 million tons more than in 2015. When implementing this policy, more than 200,000 additional tourists travel to the Maldives compared in the base run (2.09 million tourists compared to 1.84 million) in 2050 alone. They generate 14% more revenues in 2050 than in the base run. If looking at the accumulated revenues, this is 6 billion Rufiyaa more over the next 35 years than in the base run. Financially, on the one hand, this is more than double the amount compared to the policies discussed above. On the other hand, we have to acknowledge that there are considerable investments for composting to be done.

Still, it is most promising to combine all policies. Only with a combination of all policies, we observe a sustainable lower amount of waste on Thilafushi, with 38% fewer waste on Thilafushi in 2050 than in 2015 and nearly 75% less waste than in 2050 compared to the base run. The fewer waste increases the attractiveness of the Maldives as a tourist destination and thus attracts more tourists. Nearly 30% more tourists will travel to the Maldives in 2050, compared to the base run, generating 3.55 billion Rufiyaa in 2050. Over time, the additional tourists generate nearly 13% more revenues (113 billion Rufiyaa compared to 101 billion Rufiyaa). This policy serves both implicit goals, improving the environment and the Maldives' financial situation. Not filling up Thilafushi with waste is also necessary considering the Maldives' average natural ground levels of 1.5 meters above sea level and a projected sea level rise of 1.2 meters in the A1 FI Minicam business-as-usual scenario of the IPCC (2014). With a rising sea-level all toxic waste on Thilafushi will eventually be flooded into the Indian Ocean, and will thus enter the food chain, which finally ends up in all species around the world.

Limitations and Further Research

We lay out limitations of the work and areas for further research in the following. The logistic shape for each of the table functions is indeed plausible. However, the model behavior depends heavily on the slope of the functions and their minimum values. Since we do not have specific data on individual effects, we cannot properly estimate the shape of each function. Sensitivity analysis over a range of plausible parameters for the functions and exploration of their impact on model behavior would be a simple way to improve the existing model.

Moreover, the model does not present high sensitivity to pollution over the pollution ranges simulated and over the proposed time horizon. Naturally, this may be a limitation of the model and the assumption could be further tested. As people grow more aware of the detrimental effects of pollution, they become more sensitized and willing not only to avoid it, but also to take action to combat it. If so, we would expect a significant effect of pollution on reducing the number of tourists travelling to the Maldives. A significant reduction in the numbers of tourists, followed by a reduction in revenues from tourism would likely lead to more significant efforts by the government and resorts to confront the pollution problem.

Also, we have not taken into account the costs for building up the infrastructure for realizing the different waste management policies, including power-to-waste plants, composting machines, for example. Considering these costs it would not financially pay off. Further research on infrastructure investments and their discount for comparing net present values is required. Finally, we do not capture the effect of price on the attractiveness of the Maldives. A significant increase in price would likely reduce the attractiveness of the Maldives as a tourist destination rendering it more exclusive, but less affordable to many tourists. As highlighted in the policy section, a reduction in the number of tourists travelling to the Maldives would have the positive effect of reducing the total pollution generated in the resorts. This policy may be difficult to implement, since the government and resorts may be concerned about its influence in tourist revenues and the possible ambiguous results that it could have. Nonetheless, an increase in prices (if done properly) could generate more revenues to resorts, bringing them more money to invest proper waste management technologies and training.

Conclusion

With this model we have laid the groundwork for a dynamic perspective on waste management on the Maldives. We examine and depict the interplay between the tourists traveling to the Maldives, the revenues they generate, but also the waste they generate and the feedback on the attractiveness of the Maldives as a tourist destination in a small causal loop diagram. From the variables' behavior over time and their analyses, we learn that scientists', researchers', and journalists' statements on the threat of waste on tourism is highly likely. We discuss policy options and further learn that a tremendous financial and political effort is necessary to soundly address the Maldives waste problem. There is an opportunity to inform the Maldives Government about the holistic waste management vantage point, and potentially adjust their prevailing mental model to invest in specific waste management policies, and discuss the increase in prices and making the Maldives more exclusive again as a direct way to manage pollution.

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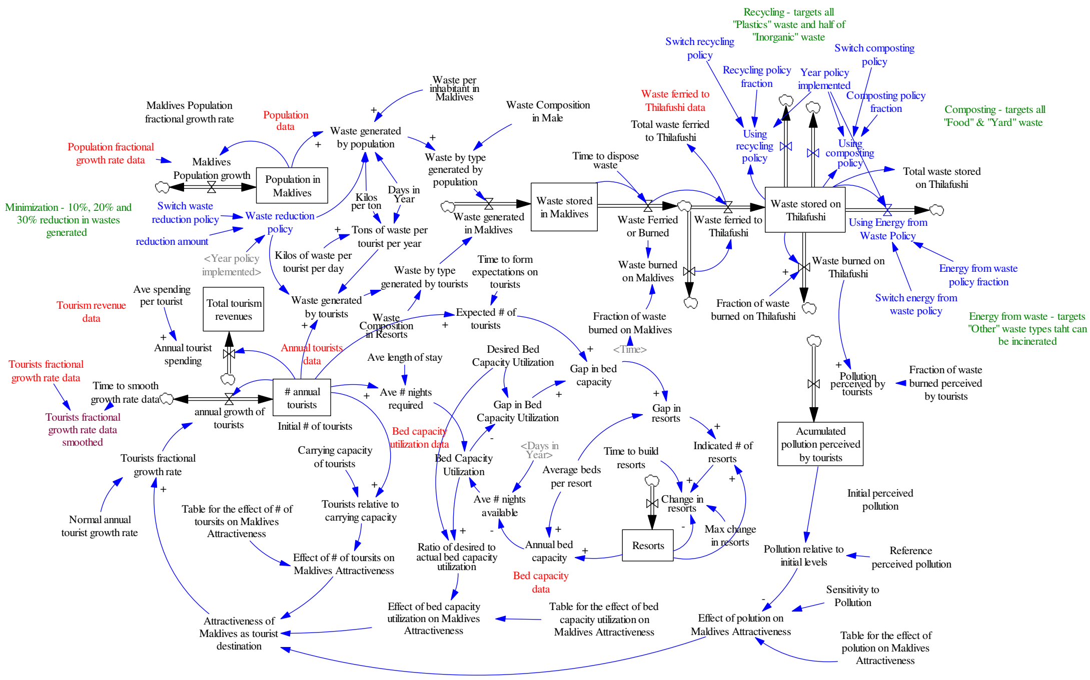
Appendix



Model equation, Vensim DSS, Version 6.1c

Sensitivity to Pollution=

1

~ Dmnl

~ This parameter can change the sensitivity of tourists on pollution. If \

they are not sensitive, it is 0, if they are very sensitive, it is 1.

|

Effect of polution on Maldives Attractiveness=

(Table for the effect of polution on Maldives Attractiveness (Pollution relative to initial levels\

))^Sensitivity to Pollution

~ Dmnl

~ The more the Maldives are polluted, the higher is their effect on \

Attracttiveness.

|

Pollution relative to initial levels=

Reference perceived pollution/ Acumulated pollution perceived by tourists

~ Dmnl

~ This variable calculates the relative pollution.

|

Reference perceived pollution=

3000

~ Tons

~ This parameter sets the reference pollution for the pollution perception.

|

Year policy implemented=

STEP(1, 2015)

~ Dmnl

~ It is assumed that all policies are implemented in 2015.

|

Using Energy from Waste Policy[waste type]=

Energy from waste policy fraction[waste type]*Switch energy from waste policy* Year policy implemented\

*Waste stored on Thilafushi[waste type]

~ Tons/Year

~ This flow calculates how much waste is tranformed into energy.

|

Using composting policy[waste type]=

Switch composting policy*Year policy implemented*Composting policy fraction[waste type\

]*Waste stored on Thilafushi[waste type]

~ Tons/Year

~ This flow calculates how much waste is composted.

|

reduction amount=

0.2

~ Dmnl

~ This parameter indicates how much of the waste is being reduced.

|

Using recycling policy[waste type]=

Switch recycling policy*Year policy implemented*Recycling policy fraction[waste type\

]*Waste stored on Thilafushi[waste type]

~ Tons/Year

~ This flow calculates how much waste is recycled.

|

Waste generated by tourists=

"# annual tourists" * Tons of waste per tourist per year *Waste reduction policy

~ Tons/Year

~ |

Switch waste reduction policy=

0

~ Dmnl

~ This is a switch

0 = policy off

1 = policy on

|

Waste reduction policy=

(1 - reduction amount * Switch waste reduction policy*Year policy implemented)

~ Dmnl

~ This variable calculates how much waste is reduced.

|

Total waste stored on Thilafushi=

SUM(Waste stored on Thilafushi[waste type!])

~ Tons

~ This variable calculates the total waste on the Thilafushi (all waste \

types).

|

Waste generated by population=

(Days in Year*Waste per inhabitant in Maldives * Population in Maldives *Waste reduction policy\

)/ (Kilos per ton)

~ Tons/Year

~ This variable caculates the total waste generated by the population

|

Waste stored on Thilafushi[waste type]= INTEG (

+Waste ferried to Thilafushi[waste type] -Waste burned on Thilafushi[waste type] - Using Energy from Waste Policy\

[waste type]- Using recycling policy[waste type]- Using composting policy[waste type\

],

0)

~ Tons

~ This stock indicates the total waste on Thilafushi by waste type.

|

Switch composting policy=

0

~ Dmnl

~ This is a switch

0 = policy off

1 = policy on

|

Switch energy from waste policy=

0

~ Dmnl

~ This is a switch

0 = policy off

1 = policy on

|

Energy from waste policy fraction[waste type]=

0,0,0,0,1

~ 1/Year

~ This parameter indicates which waste types are affected by the enrgy from \
waste policy.

|

Recycling policy fraction[waste type]=

0,0,1,1,0

~ 1/Year

~ This parameter indicates which waste types are affected by the recycling \
policy.

|

Total waste ferried to Thilafushi=

SUM(Waste ferried to Thilafushi[waste type!])

~ Tons/Year

~ This variable indicates the sum of all waste types ferried to Thilafushi.

~ :SUPPLEMENTARY

|

Switch recycling policy=

0

~ Dmnl

~ This is a switch

0 = policy off

1 = policy on

|

Composting policy fraction[waste type]=

1,1,0,0,0

~ 1/Year

~ This parameter indicates which waste types are affected by the composting \
policy.

|

waste type:

Food, Yard, Plastics, Inorganic, Other

~ Dmnl

~ |

Waste Composition in Resorts[waste type]=

0.4, 0.38, 0.05, 0.11, 0.06

~ Dmnl

~ |

Waste by type generated by population[waste type]=

Waste generated by population * Waste Composition in Male[waste type]

~ Tons/Year

~ This variable calculates the waste generated by the population - by waste \
type.

|

Waste by type generated by tourists[waste type]=

Waste generated by tourists * Waste Composition in Resorts[waste type]

~ Tons/Year

~ This variable calculates the waste generated by tourists - by waste type.

|

Waste generated in Maldives[waste type]=

Waste by type generated by population[waste type] + Waste by type generated by tourists\

[waste type]

~ Tons/Year

~ This flow changes the stock of waste generated in Maldives.

|

Waste Composition in Male[waste type]=

0.22, 0.528, 0.025, 0.18, 0.047

~ Dmnl

~ Thie parameter indicates the waste composition in Male.

|

Change in resorts=

MIN(Max change in resorts ,("Indicated # of resorts" - Resorts) / Time to build resorts\

)

~ resorts/ Year

~ This flow changes the stock of resorts.

|

Maldives Population growth=

Population fractional growth rate data * Population in Maldives

~ people/Year

~ This flow changes the stock of Maldives population.

|

Max change in resorts=

5

~ resorts/Year

~ At maximum, 5 resorts can be opened in a year.

|

Ave length of stay=

9.5

~ day

~ On average, tourists stay 9.5 days on the Maldives.

|

Bed Capacity Utilization=

MAX (0, "Ave # nights required"/"Ave # nights available")

~ Dmnl

~ Bed capacity utilization puts the nights required and the nights available \
into relation with each other.

|

"Ave # nights available"=

Annual bed capacity * Days in Year

~ people*day

~ This variable translates the annual bed capacity into the nights available.

|

"Ave # nights required"=

"# annual tourists"* Ave length of stay

~ people*day

~ |

Time to smooth growth rate data=

3

~ Year

~ The smoothing is 3 years.

|

Tourism revenue data

~ Rufiyaa/Year

~ ~ :SUPPLEMENTARY

|

Tourists fractional growth rate=

Normal annual tourist growth rate * Attractiveness of Maldives as tourist destination

~ 1/Year

~ Actual tourist fractional growth rate is the product of the Normal annual \
tourist growth rate and the Attractiveness of the Maldives as tourist \
destination.

|

annual growth of tourists=

Tourists fractional growth rate * "# annual tourists"

~ Tourists/Year

~ |

Tourists fractional growth rate data smoothed=

SMOOTHI(Tourists fractional growth rate data, Time to smooth growth rate data , Tourists fractional growth rate data\
)

~ 1/Year

~ The data are smoothed to get the strong fluctuations out.

~ :SUPPLEMENTARY

|

Population fractional growth rate data

~ 1/Year

~ This is the DATA for polulation fractional growth rate.

|

Annual tourists data

~ people

~ This is the DATA for annual tourists traveling to the Maldives.

~ :SUPPLEMENTARY

|

Waste ferried to Thilafushi data

~ Tons/Year

~ This is the DATA for waste ferried to Thilafushi.

~ :SUPPLEMENTARY

|

Population data

~ people

~ This is the DATA for population.

~ :SUPPLEMENTARY

|

Tourists fractional growth rate data

~ 1/Year

~ This is the DATA for fractional growth rate.

|

Bed capacity data

~ people

~ This is the DATA for bed capacity.

~ :SUPPLEMENTARY

|

Bed capacity utilization data

~ Dmnl

~ This is the DATA for bed capacity utilization.

~ :SUPPLEMENTARY

|

"# annual tourists"= INTEG (

annual growth of tourists,

"Initial # of tourists")

~ Tourists

~ The number of tourists traveling to the Maldives per year.

```
	|

{UTF-8}
Time to form expectations on tourists=
	5
	~ Year
	~ It takes 5 years for tourists to decide to travel to the Maldives.
	|

Acumulated pollution perceived by tourists= INTEG (
	Pollution perceived by tourists,
	  Initial perceived pollution)
	~ Tons
	~ This is the accumulated pollution that the tourists perceive.
	|

Effect of bed capacity utilization on Maldives Attractiveness=
	Table for the effect of bed capacity utilization on Maldives Attractiveness ( Ratio of desired to actual bed capacity utilization\
	  )
	~ Dmnl
	~ The higher the bed capacity utilization, the more attractive the Maldives \
	  as a tourist destination.
	|

"Expected # of tourists"=
	SMOOTH3I( "# annual tourists" , Time to form expectations on tourists , "# annual tourists"\
	  )
	~ Tourists
	~ This variable calculates how many tourists are expected to travel to the \
	  Maldives. It is a SMOOTH3 function.
	|
```

"Initial # of tourists"=

33124

~ Tourists

~ |

Attractiveness of Maldives as tourist destination=

"Effect of # of toursits on Maldives Attractiveness" * Effect of bed capacity utilization on Maldives Attractiveness\

* Effect of polution on Maldives Attractiveness

~ Dmnl

~ Attractiveness is the product of three effects: Effect of tourists, Effect \
of bed capacity utilization, and Effect of pollution, all ranging between \
0 and 1.

|

Ratio of desired to actual bed capacity utilization=

Desired Bed Capacity Utilization / Bed Capacity Utilization

~ Dmnl

~ |

"Table for the effect of # of toursits on Maldives Attractiveness"(

[(0,0)-(0.7,1)],(0,0.35),(0.05,0.36),(0.65,0.98),(0.7,1),(1,1),(10,1))

~ Dmnl

~ The more tourists travel to the Maldives, the more they talk about the \
Maldives, kicking off the Word-of-Mouth loop, increasing the \
attractiveness.

|

Carrying capacity of tourists=

30000

~ Tourists

~ The carrying capacity is assumed to be 30,000 tourists.

|

Table for the effect of polution on Maldives Attractiveness(

[(0,0)-(1,2)],(0,0.1),(0.02,0.11),(0.95,0.99),(1,1),(10,1))

~ Dmnl

~ The more the Maldives are polluted, the higher is their effect on \

Attracttiveness.

|

"Effect of # of toursits on Maldives Attractiveness"=

"Table for the effect of # of toursits on Maldives Attractiveness"(Tourists relative to carrying capacity\

)

~ Dmnl

~ The more tourists travel to the Maldives, the more they talk about the \

Maldives, kicking off the Word-of-Mouth loop, increasing the \

attractiveness.

|

Initial perceived pollution=

100

~ Tons

~ |

Normal annual tourist growth rate=

0.25

~ 1/Year

~ Normal fractional growth rate is 0.25.

|

Table for the effect of bed capacity utilization on Maldives Attractiveness(

[(0,0)-(1,1)],(0,0.05),(0.1,0.05),(0.95,0.99),(1,1),(10,1))

~ Dmnl

~ The higher the bed capacity utilization, the more attractive the Maldives \

as a tourist destination.

|

Tourists relative to carrying capacity=

Carrying capacity of tourists / "# annual tourists"

~ Dmnl

~ This variable puts the actual number of tourists in relation to the \

carrying capacity.

|

{UTF-8}

Annual bed capacity=

Resorts * Average beds per resort

~ people

~ |

Maldives Population fractional growth rate=

0.023

~ 1/Year

~ Normal fractional growth rate is 0.023.

~ :SUPPLEMENTARY

|

Annual tourist spending=

"# annual tourists" * Ave spending per tourist

~ Rufiyaa/Year

~ |

Fraction of waste burned on Thilafushi=

0.4

~ 1/Year

~ 40% of the waste is burned on Thilafushi.

|

Ave spending per tourist=

1500

~ Rufiyaa/(Year*tourist)

~ On average, each tourists spends 1,500 Rufiyaa.

|

Average beds per resort=

160

~ people/resort

~ Average number of beds per resort

|

Time to dispose waste=

0.5

~ Year

~ Average time to dispose waste in the island. 6 months is the time that \
waste sits around before it is disposed.

|

Days in Year=

365

~ days/Year

~ There are 365 days in a year.

|

Desired Bed Capacity Utilization=

0.5

~ Dmnl

~ 75% desired bed capacity utilization

|

Fraction of waste burned on Maldives=

IF THEN ELSE(Time>=2013, 0.6, IF THEN ELSE(Time>=2006, 0.8, IF THEN ELSE(Time>=1992\
, 0.8 , 1)))
~ Tons/Year
~ Prior to 1992 no waste was sent to Thilafushi. after 1992, the fraction of \
waste burned was 85% (15% shipped to Thilafushi). Then in 2006 it was \
decreased to 75%, amount shipped increased to 25%). Then, from 2013 it was \
decreased to 60% (amount shipped was increased to 40%).
|

Fraction of waste burned perceived by tourists=
0.001
~ Dmnl
~ 0.1% of the entire waste is burned.
|

Gap in bed capacity=
"Expected # of tourists" * Gap in Bed Capacity Utilization
~ people
~ This variable calculates how many beds are needed in the near future.
|

Gap in Bed Capacity Utilization=
ABS(Desired Bed Capacity Utilization - Bed Capacity Utilization)
~ Dmnl
~ This variable calculates the gap in bed capacity utilization.
|

Gap in resorts=
Gap in bed capacity / Average beds per resort
~ resorts
~ This variable calculates the resorts needed in the near future.
|

"Indicated # of resorts"=

Resorts + Gap in resorts

~ resorts

~ This variable is the sum of all resorts plus the required resorts.

|

Waste burned on Maldives[waste type]=

Waste Ferried or Burned[waste type] * Fraction of waste burned on Maldives

~ Tons/Year

~ This flow indicates the waste burned on the Maldives.

|

Kilos per ton=

1000

~ kg/ton

~ There are 1,000 kilograms in a ton.

|

Waste Ferried or Burned[waste type]=

Waste stored in Maldives[waste type] / Time to dispose waste

~ Tons/Year

~ Part of the waste is ferried to Thilafushi or burned.

|

Waste stored in Maldives[waste type]= INTEG (

Waste generated in Maldives[waste type] - Waste Ferried or Burned[waste type],

0)

~ Tons

~ This stock indicates the total waste on the Maldives.

|

Pollution perceived by tourists=

SUM(Waste burned on Thilafushi[waste type!])* Fraction of waste burned perceived by tourists

~ Tons/Year

~ This accumulation calculates how much pollution is perceived by the \
tourists.

|

Resorts= INTEG (

Change in resorts,

10)

~ resorts

~ It is assumed that there are 10 resorts in 1979.

|

Time to build resorts=

4

~ Year

~ Average time to build a resort is 4 years.

|

Tons of waste per tourist per year=

Days in Year*Kilos of waste per tourist per day/ (Kilos per ton)

~ Tons/tourist/Year

~ Each tourist of Maledives generates 3.5 kg of garbage per day.

Source: \

http://www.welt.de/vermischtes/article131144033/Im-tuerkisblauen-Wasser-ein\

e-Insel-aus-Muell.html

|

Waste burned on Thilafushi[waste type]=

Waste stored on Thilafushi[waste type] * Fraction of waste burned on Thilafushi

~ Tons/Year

~ This flow indicates the waste burned on Thilafushi.

|

Waste ferried to Thilafushi[waste type]=

Waste Ferried or Burned[waste type] - Waste burned on Maldives[waste type]

~ Tons/Year

~ An average of 330 tonnes of rubbish are brought to Thilafushi every day, most of \
which are from MalÃƒÂ©.
Source: \
https://globalvoicesonline.org/2014/10/24/theres-an-island-made-of-toxic-tr\
ash-rising-out-of-the-sea-in-the-maldives/

|

Total tourism revenues= INTEG (

+Annual tourist spending,

0)

~ Rufiyaa

~ The accumulation of revenues since simulation start.

|

Kilos of waste per tourist per day=

3.5

~ kg/tourist/day

~ Each tourist of Maledives generates 3.5 kg of garbage per day.
Source: \
http://www.welt.de/vermischtes/article131144033/Im-tuerkisblauen-Wasser-ein\
e-Insel-aus-Muell.html

|

Waste per inhabitant in Maldives=

1.2

~ kg/person/day

~ Each inhabitant of Maledives generates 1.2 kg of garbage per day. Source: \
http://www.welt.de/vermischtes/article131144033/Im-tuerkisblauen-Wasser-ein\
e-Insel-aus-Muell.html

|

```
Population in Maldives= INTEG (
	Maldives Population growth,
	  152143)
	~ people
	~ 394.000 people in 2014
	  Source: \
	  http://www.welt.de/vermischtes/article131144033/Im-tuerkisblauen-Wasser-ein\
	  e-Insel-aus-Muell.html
	|

********************************************************
	.Control
********************************************************~
	  Simulation Control Parameters
	|

FINAL TIME  = 2050
	~ Year
	~ The final time for the simulation.
	|

INITIAL TIME  = 1979
	~ Year
	~ The initial time for the simulation.
	|

SAVEPER  = 1
	~ Year [0,?]
	~ The frequency with which output is stored.
	|

TIME STEP  = 0.015625
```

~ Year [0,?]

~ The time step for the simulation.

|