

# Environmental Challenges

## Economic Damage of Plastic Pollution: An Integrated Assessment Across Territories

--Manuscript Draft--

<b>Manuscript Number:</b>	ENVC-D-26-00297
<b>Full Title:</b>	Economic Damage of Plastic Pollution: An Integrated Assessment Across Territories
<b>Article Type:</b>	Full Length Article
<b>Keywords:</b>	Plastic waste; pollution; environmental accounting; damage cost analysis
<b>Abstract:</b>	<p>Environmental externalities, such as the ecological and health effects of plastic pollution, are often overlooked in typical economic assessments, where it is expected that by 2050, the amount of plastic in the ocean will exceed that of fish. The total damage cost due to plastic waste was systematically evaluated using damage cost analyses across multiple environmental domains, including terrestrial/land impacts, freshwater/wadi impacts, coastal/marine impacts, and atmospheric/human exposure impacts. Total damage costs due to plastic leakage were \$2.69M in 2022, decreasing to \$1.10M under a high-stringency policy by 2050, indicating significant cost savings. The reduction in plastic leakage from 34,988 to 14,370 tons/year is associated with a nearly 60% decrease in damage costs. Plastic leakage to land contributes the highest economic burden, reducing from \$1.14M to \$0.47M, while plastic leakage to freshwater decreases from \$0.87M to \$0.36M. Plastic leakage to coastal and marine costs \$0.66M to \$0.27M, and atmospheric/human exposure costs drop from \$0.023M to \$0.009M. The effectiveness of high-stringency policies, as evidenced by scenario analysis and sensitivity analysis, was demonstrated by a reduction in plastic leakage rates from 5.6% to 2.3%, supporting a rationale for stringent plastic management policies. Further, the marginal damage of plastic leakage into the environment is <math>\approx</math> \$76.8/ton. The research presented here advances theoretical understanding of integrating externalities and provides local governments, policymakers, businesses, and stakeholders with practical insights. To fill this gap, this study develops an integrated damage cost assessment framework to quantitatively evaluate the marginal harm caused by plastic pollution emissions. This framework can be used for future research and policy initiatives in a society more concerned with sustainability</p>

# Economic Damage of Plastic Pollution: An Integrated Assessment Across Territories

## ABSTRACT

Environmental externalities, such as the ecological and health effects of plastic pollution, are often overlooked in typical economic assessments, where it is expected that by 2050, the amount of plastic in the ocean will exceed that of fish. The total damage cost due to plastic waste was systematically evaluated using damage cost analyses across multiple environmental domains, including terrestrial/land impacts, freshwater/wadi impacts, coastal/marine impacts, and atmospheric/human exposure impacts. Total damage costs due to plastic leakage were \$2.69M in 2022, decreasing to \$1.10M under a high-stringency policy by 2050, indicating significant cost savings. The reduction in plastic leakage from 34,988 to 14,370 tons/year is associated with a nearly 60% decrease in damage costs. Plastic leakage to land contributes the highest economic burden, reducing from \$1.14M to \$0.47M, while plastic leakage to freshwater decreases from \$0.87M to \$0.36M. Plastic leakage to coastal and marine costs \$0.66M to \$0.27M, and atmospheric/human exposure costs drop from \$0.023M to \$0.009M. The effectiveness of high-stringency policies, as evidenced by scenario analysis and sensitivity analysis, was demonstrated by a reduction in plastic leakage rates from 5.6% to 2.3%, supporting a rationale for stringent plastic management policies. Further, the marginal damage of plastic leakage into the environment is  $\approx$  \$76.8/ton. The research presented here advances theoretical understanding of integrating externalities and provides local governments, policymakers, businesses, and stakeholders with practical insights. To fill this gap, this study develops an integrated damage cost assessment framework to quantitatively evaluate the marginal harm caused by plastic pollution emissions. This framework can be used for future research and policy initiatives in a society more concerned with sustainability.

**Keywords:** *Plastic waste, pollution, environmental accounting, damage cost analysis*

## 1.0 Introduction

The rapid growth in production and consumption, along with ineffective waste management, has resulted in plastic pollution, which has become one of the significant environmental concerns of the twenty-first century (Maheshwari & Banerjee, 2025; Jones & Pathak, 2025). After use, the product is recycled, burned, or disposed of in landfills. All these operations are hazardous to the environment at various stages of the product life cycle (Nzama et al., 2022). Recycling is not very popular; incineration causes air pollution and contributes to greenhouse gas emissions; and landfilling pollutes soil and water, mainly with microplastics. Plastic waste has entered the world, settling in land and water bodies, and the environmental crisis it has brought is beyond national boundaries (Marks et al., 2020). Plastic pollution is particularly hazardous because it is irreversible and has both environmental and social impacts (Abahussain et al., 2025). The plastic pollution severely affects marine and freshwater ecosystems, biodiversity, and food webs negatively by obstructing food uptake, covering organisms, and eliminating habitats (Gerbersdorf et al., 2011; Thrift et al., 2023; Tekman et al., 2022). In addition to ecological damage, plastic pollution is now affecting human health, with microplastics observed in food, drinking water, and even the human body itself, raising questions about the long-term health consequences due to plastic leaked to the environment (Ziani et al., 2023).

1  
2  
3  
4 Governments have increasingly responded to environmental challenges through regulations to  
5 improve air and water quality and reduce pollution intensity, particularly in areas with high  
6 pollution levels (Li & Wang, 2025; Shan & Ji, 2024). Nonetheless, such regulations are likely to  
7 affect firms' production decisions. Even though the aim of such regulations is not to increase firms'  
8 production costs or lower their productivity, there will still be effects. In Oman, environmental  
9 governance has been achieved through the adoption of international climate change agreements  
10 and the enactment of laws on waste management, chemicals, and environmental permitting. Even  
11 with the work done in environmental sustainability, Oman continues to face challenges, as  
12 evidenced by its low score on the Environmental Performance Index (EPI), ranking 149 out of 180  
13 countries (Yale, 2022). The structural problem with the traditional economic and accounting  
14 system also indicates these issues, as it is ineffective at addressing environmental externalities.  
15 The traditional national and company accounting framework treats environmental degradation,  
16 e.g., plastic pollution, as a set of expected fringe or external costs and underestimates the cost-  
17 effective costs of industrial processes (Nguyen et al., 2016). The problem of plastic pollution  
18 shows that the environmental or damage costs are not visible may be profound, long-term, and  
19 deeply disturbing to society. This has been a weakness and, therefore, the need to integrate total  
20 damage cost due to plastic waste enable easier decision-making and the implementation of more  
21 sustainable policies. Particularly in green accounting and Environmental Management Accounting  
22 (EMA), these methods have proven useful in addressing plastic pollution. Environmental  
23 accounting assists organizations in identifying, quantifying, and reporting environmental costs in  
24 an organized manner, enabling them to implement more effective and efficient regulatory  
25 compliance, enhance transparency, and engage in proactive environmental management  
26 (Schaltegger and Burritt, 2017). Environmental accounting enables organizations to pursue cleaner  
27 production, plastic reduction, and environmental responsibility rather than being forced to do so  
28 by regulatory pressure. In this way, empirical data exist on the applicability of environmental  
29 accounting to the management of plastic pollution. To illustrate this point, Nzama et al. (2022)  
30 found that the environmental information produced by the EMA is closely and significantly  
31 associated with plastic pollution management and the corporate strategy of food and beverage  
32 production organizations, in which products are packaged in plastic. Austin (2022) further argues  
33 that including environmental costs in accounting practices prompts companies to minimize the use  
34 of plastics in packaging and to instead use environmentally friendly materials. In its regulatory  
35 aspects, Saputra et al. (2021) argue that green accounting can complement government efforts to  
36 prohibit the use of disposable plastics, thereby promoting waste management in line with cultural  
37 and institutional factors.

38 Although such findings exist, the current literature also indicates gaps in the implementation of  
39 EMA, inconsistent disclosures, and the inability of the organizational strategies and real-life results  
40 to be closely tied in pollution control activities (Nzama, 2021; Wedantara et al., 2025). Moreover,  
41 cleanup exercises and awareness-raising programs, as important as they are in combating plastic  
42 pollution, cannot adequately address the volume of plastic waste in the environment without a  
43 more integrated accounting framework and governance system (Prata et al., 2019). These gaps  
44 illustrate the main issue the present research aims to address: the absence of research that quantifies  
45 the costs of plastic waste in terms of the harm caused by its spread across territories and that  
46 assesses its true environmental impact on society. Thus, damage costs due to plastic leaking into  
47 the environment are deemed essential. Effective actions are vital to mitigate these costs and protect  
48 both the environment and human well-being. The assumption is that a case study in Oman would  
49 be suitable, as Gulf nations are likely to face higher costs and environmental and health problems  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

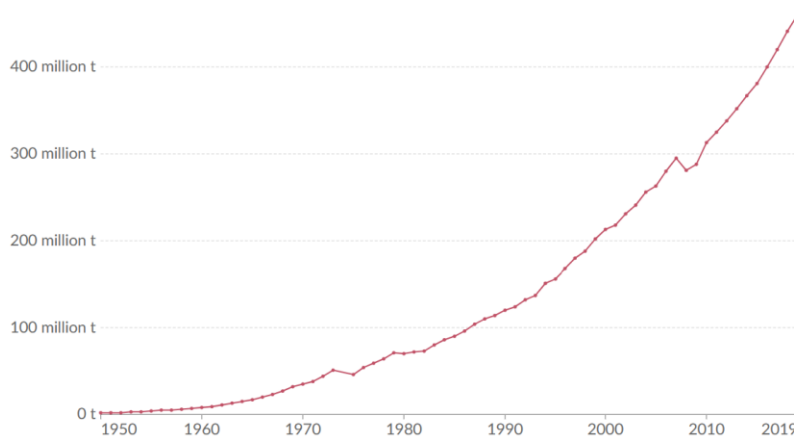
1  
2  
3  
4 due to the absence of more comprehensive solutions for plastic waste management (Al-Mutairi,  
5 2025). It is an urgent issue that should be considered when formulating long-term, broad  
6 management, given the evaluation of the costs of plastic pollution and the years of understanding  
7 regarding the Gulf countries.  
8

9 The structure of this research is as follows. Section 2 examines the concept of plastic pollution and  
10 its global significance. Section 3 presents Oman as a case study. Section 4 details the methods and  
11 measurement approaches for damage cost analysis. Section 5 reports the results, including scenario  
12 and sensitivity analysis. Section 6 introduces the framework for addressing plastic pollution.  
13 Section 7 presents the results and discussion and concludes with future research directions.  
14

## 15 16 **2.0 Plastic Pollution and Its Global Significance**

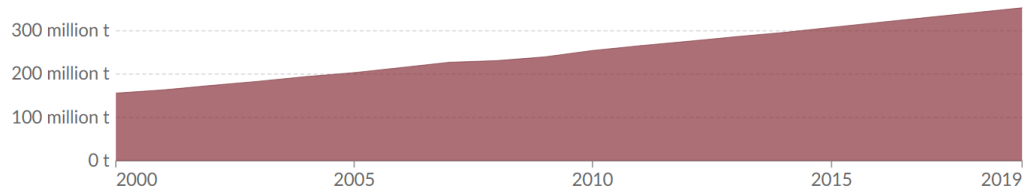
17  
18 Plastic pollution affects ecosystems, animals, and humans. Plastic waste disrupts ecological  
19 balance and destroys ecosystems (Islam, 2025). Plastic waste can release toxins into soil and water,  
20 affecting plants and animals (Govind & Nishitha, 2023). Plastics decompose over centuries,  
21 compounding the damage they cause. Since wildlife can ingest or become entangled in plastic,  
22 plastic pollution has the greatest negative impact on them. Damage, starvation, and death result  
23 from these conditions. Marine animals mistake plastic particles for food, thereby reaching higher  
24 trophic levels in the food chain. Ghost fishing gear continues to ensnare and kill marine life after  
25 disposal, destroying biodiversity and fisheries.  
26

27 To elaborate on the effectiveness of plastic in reducing pollution, the following are some statistics  
28 from Ritchie (2023). Figure 1 shows global plastics production from 2000 to 2019. We couldn't  
29 find world statistics until 2023. Current statistics show that production has almost linearly  
30 increased over time. Massive production reached 400 million tons in 2019. Also, Figure 2 shows  
31 that 75% of the four hundred million tons produced worldwide are wasted. Figure 3 shows that  
32 sixty million metric tons were unmanaged in 2019, in addition to the previous amount. Figure 4  
33 shows that 979.5 million metric tons are emitted to the Ocean, while Asia contributes 793.3 million  
34 tons.  
35  
36  
37

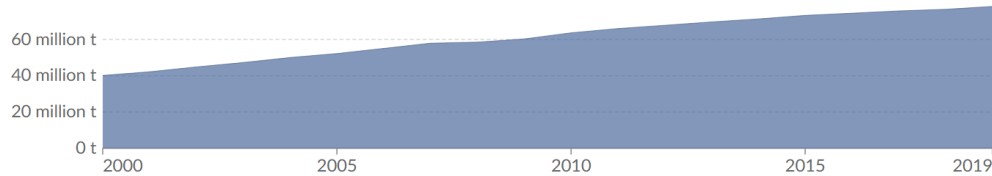


38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52 **Figure 1.** Global plastics production (Ritchie, 2023c)

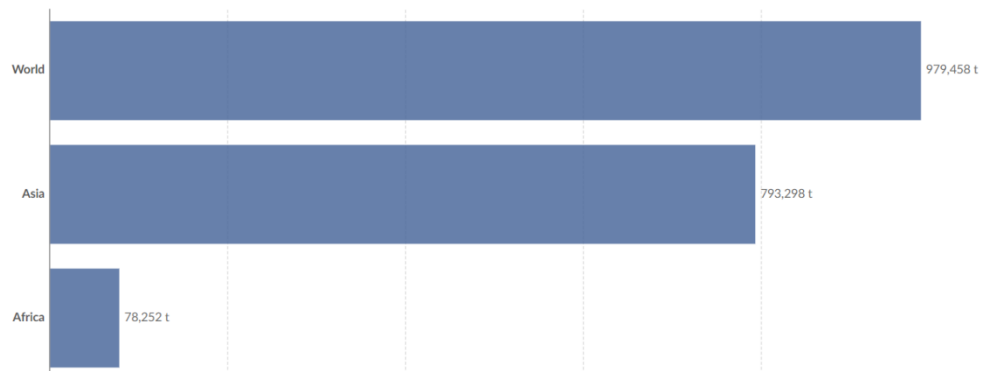
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65



**Figure 2.** Global wasted plastics



**Figure 3.** Unmanaged plastic waste (Ritchie, 2023c)



**Figure 4.** Plastic waste emitted into the Ocean (Ritchie, 2023c)

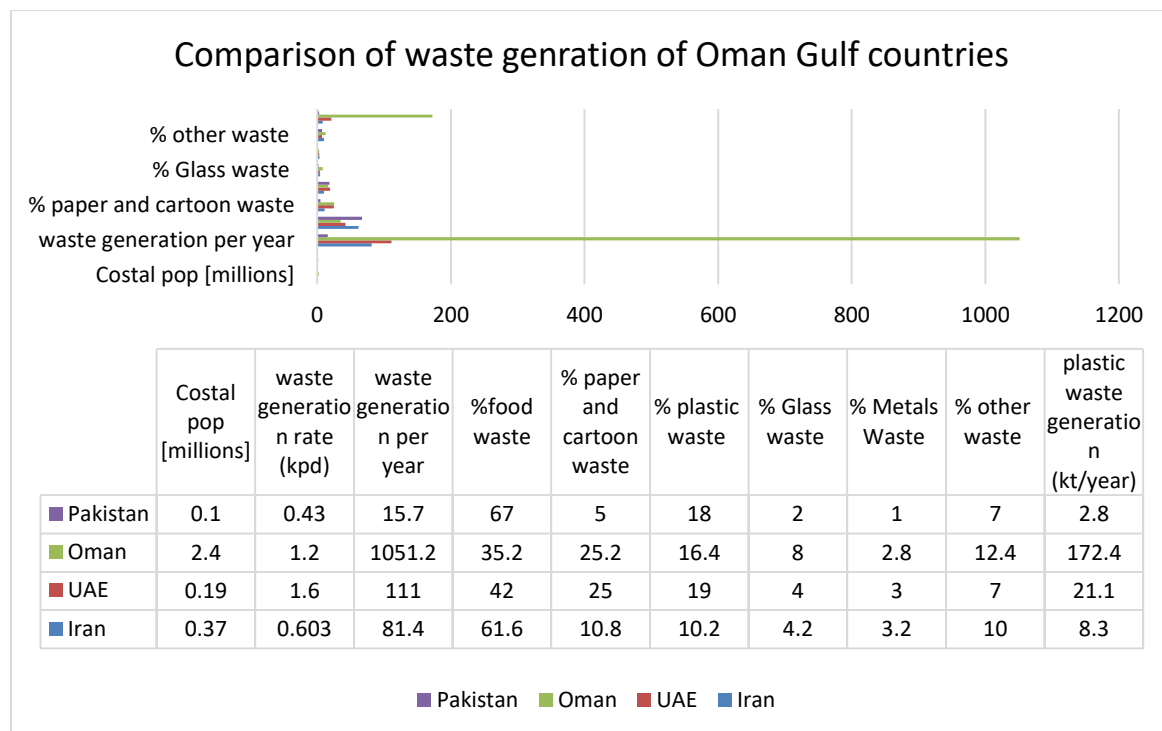
To address plastic pollution effectively, one should conduct comprehensive economic analyses based on cost-of-damage assessments. The assessments will examine the costs of plastic pollution degradation in a territorial context, raising awareness and enabling management activities in the environmental, social, and health realms. Clean-up expenditures used to reduce damage can offset the cost of medical treatment and the financial impact on affected industries. Plastic pollution has no solutions other than collective action on the local, national, and international levels. This ought to decrease production of plastics, improve management of waste, and augment alternatives to green.

### 3.0 Plastic Pollution in the Sultanate of Oman

The Sultanate of Oman, situated along the southern coast of the Arabian Peninsula, is the clearest example of how tenuous the link is between economic growth and environmental sustainability. The natural history of Oman is complex, shaped by its deserts, mountains, and long coastline along the Arabian Sea. The oil and natural gas industries have benefited the economy in recent decades. Oman is a very interesting case study of plastic pollution and its effects, as the country is economically thriving and its environment is also relevant. A serious issue for Oman's economic sectors is plastic pollution. The oil and gas industry also produces plastic byproducts, and it is a major industry in Oman. This is because these polymers are employed in packaging, building, and consumer goods. Plastic pollution is an environmental issue, particularly in coastal and urban

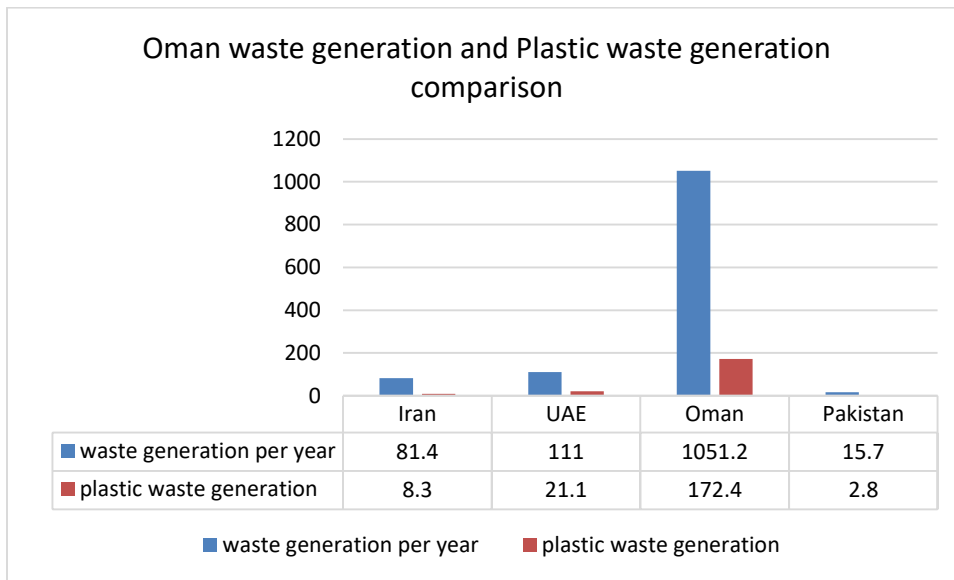
regions. Tourism and fishing are also affected by plastic pollution. The beautiful seashores and rich marine life of the country appeal to tourists worldwide, but this is threatened by plastic waste along its shores. Plastics cause death to animals and destroy aquatic life, threatening the lives of citizens living along the coast.

Comparing Oman with its Gulf neighbors in relation to population, waste generation rate (kilograms per person per day-Kpd), waste generation (kilo tons/year-kt/year), percentage of food waste, percentage of paper and carton waste, plastic waste generation (kt/year), percentage of plastic waste, and percentage of wasted metals are given in Figure 5, that compares waste production indicators for four countries bordering the Gulf of Oman: Pakistan, Oman, the United Arab Emirates (UAE), and Iran. These countries have coastal populations (coastal pop) in the millions, ranging from 0.1 million in Pakistan to 2.4 million in Oman. The creation of wastes is reported in kilograms per day (kpd) and total wastes per year in kilotons (kt/year) of 1kg/day and 15.7 kt/year, respectively, showing significant differences between countries, where Oman creates the highest number of wastes per year of 1051.2 kt/year, and Pakistan the lowest of 15.7 kt/year. Different waste streams are decomposed by percentage of total waste; Oman records a very high percentage of paper and carton waste (25.2%), compared with 5% in Pakistan. The percentages of plastic waste are similar, with the UAE leading at 19 % and Iran trailing at 10.2 %. Glass waste percentages are highest in Oman at 8 % and in Pakistan at 2 %. Metals and other waste also show variability, with Oman having the highest rate at 12.4% and Pakistan the lowest at 7%. Additionally, the plastic waste generation in kilotons per year is provided, with Oman again leading significantly at 172.4 kt/year, whereas Pakistan has the lowest amount at 2.8 kt/year. Therefore, there are considerable differences in waste generation and composition among the Gulf countries, reflecting varied consumption patterns and possibly different waste management policies.



**Figure 5.** Oman Vs. Gulf neighbours

Figure 6 illustrates the differences between total and plastic waste generation in Oman compared to Iran, the UAE, and Pakistan. Specifically, it presents a comparative analysis of waste generation, including plastic waste, among these four countries. Oman exhibits the highest total annual waste generation at 1051.2 kt/year, substantially exceeding the values reported for the other nations. This trend is also evident in plastic waste generation, with Oman leading at 172.4 kt/year. In contrast, Iran and Pakistan report significantly lower waste generation rates, with Iran producing 81.4 kt/year of total waste and 8.3 kt/year of plastic waste, and Pakistan generating 15.7 kt/year of total waste and 2.8 kt/year of plastic waste. The UAE occupies an intermediate position, generating 111 kt/year of total waste and 21.1 kt/year of plastic waste. The data in Figure 6 further indicate a relationship between total waste and plastic waste generation across these countries, although Oman's values are disproportionately high.



**Figure 6.** Oman Waste Generation and Plastic Waste Generation Comparison

Figure 7 projects the quantities of mismanaged plastic waste and potential marine debris from four countries, Pakistan, Oman, the UAE, and Iran, in the year 2030. It is divided into categories that estimate the percentages of mismanaged plastic waste that may end up as marine debris: 15%, 25%, and 40%.

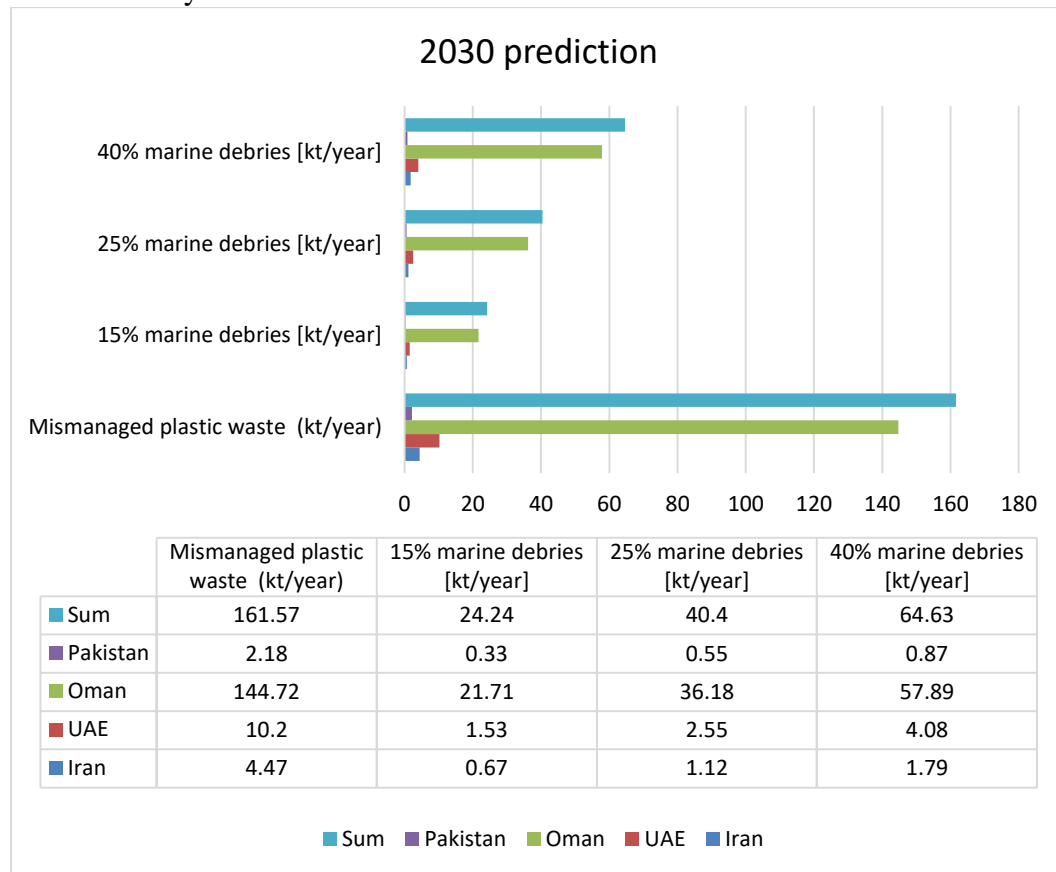
According to Figure 7, Oman is projected to have the highest amount of mismanaged plastic waste, with an estimated 144.72 kilotons (kt) per year. This is a large figure, particularly when converted to marine garbage: 21.71 kt/year at 15 percent, 36.18 kt/year at 25 percent, and 57.89 kt/year at 40 percent.

The number for Pakistan is the lowest among the four cases, with an estimated managed misdirected plastic waste of 2.18 kt/year. Marine waste in Pakistan is estimated to range from 0.33kt/year at 15% to 0.87 kt/year at 40%.

In the UAE and Iran, the quantities of mismanaged plastic waste are moderate (10.2 kt/year and 4.47 kt/year, respectively). In line with this, their potential contributions to marine waste are also moderate, with figures for the UAE ranging from 15 % to 40 %, and for Iran from 15 % to 40 %.

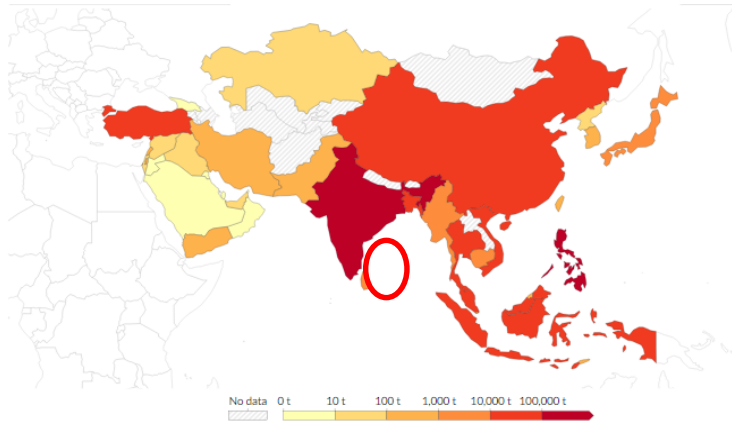
The total amount of improperly handled plastic waste of all the 4 countries is 161.57 kt/year, which may possibly result in 24.24 kt/year of marine debris at the 15% level, 40.4 kt/year at the 25% level, as well as 64.63 kt/year at the maximum estimated 40% level.

These estimates highlight the dramatic effects on the marine environment from poorly managed plastic waste, particularly since an increasing proportion is washed up as debris in our seas. The statistics highlight the importance of better waste management practices to avoid plastic pollution in ocean ecosystems.

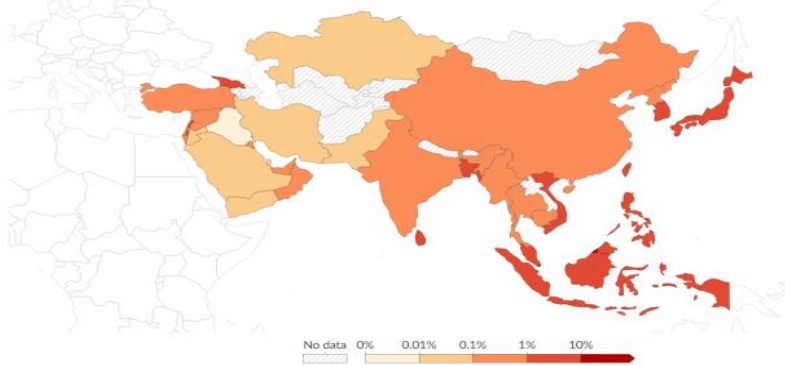


**Figure 7.** 2030 prediction

To look more deeply into Oman's plastic waste, Figure 8 shows the amount of plastic waste emitted into the ocean each year in Asia. It is almost one ton per year. Although Oman is not comparable to other Asian countries, its area is small relative to other countries. Oman also borders Yemen, Saudi Arabia, and the UAE. As can be seen, Yemeni and Emirati waste is significant and may also flow into Oman. Also, due to the small area, the probability of throwing waste into the Ocean is relatively high compared to neighboring countries shown that 0.11% (refer Figure 9). At the same time, no waste trade is identified in Oman.



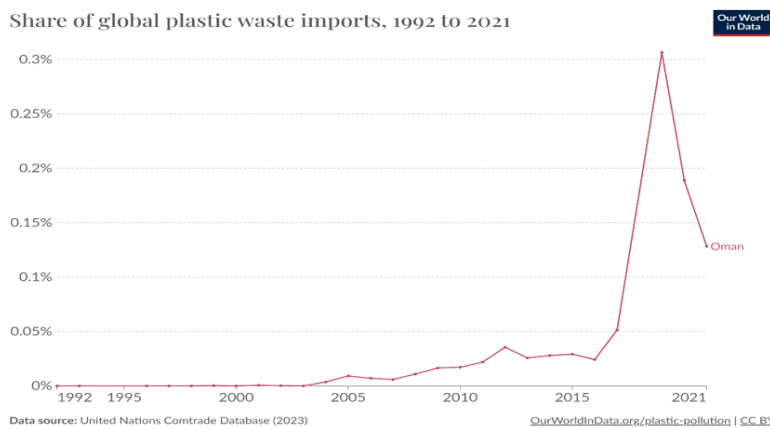
**Figure 8.** Oman waste emitted in the Ocean



**Figure 9.** Probability of emitting plastic waste into the Ocean

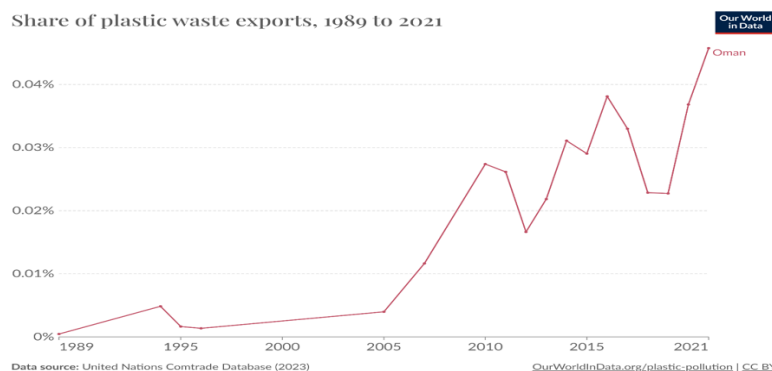
The case study of Oman highlights the complexity of addressing plastic pollution amid economic development. It shows that we need a more sophisticated approach that balances environmental protection and economic growth. It is believed that damage cost analysis due to plastic waste is an essential precaution to go for sustainable methods in businesses that are key to the country's growth.

Figure 10. Oman's Share of global plastic waste imports, 1992 to 2021, and Figure 11. Oman's Share of global plastic waste exports (1989 to 2021) shows Oman's Share of global waste (Meijer et al., 2021).



**Figure 10.** Oman's Share of global plastic waste imports, 1992 to 2021

Source: (ourworldindata, 2023)



**Figure 11.** Oman's Share of global plastic waste exports, 1989 to 2021 (ourworldindata, 2023)

#### 4.0 Methods and measurements

This study estimates the economic damages from plastic pollution using a damage-cost approach conversant by contingent valuation principles (Zambrano-Monserrate & Ruano, 2020). Contingent valuation is a widely used non-market valuation method for assigning monetary values to environmental impacts, including pollution (Hanemann, 1994). Using data from various international secondary data sources, including peer-reviewed articles, the total damage cost of plastic pollution will be estimated. In addition, the number of plastics leaked into the environment will be estimated using a universally accepted leakage rate due to a lack of country-specific data. The leaked plastics will be allocated to different environmental domains using universally accepted sectoral allocation factors. Damage costs will be estimated based on the amount of leaked plastic in each domain and standardized unit damage cost factors. This will enable monetizing the damage costs of plastic pollution. In addition, a scenario analysis has been carried out to estimate the effects of different waste management cost scenarios across plastic management policy stringency levels.

As such, the measurement of the variables in Table 1 and the annualized benchmark costs for waste management solutions are shown in Table 2 below:

**Table 1.** Measurement

Details	Abbreviation/Equation	Tons/year	%	\$	Ref	
Total municipal solid waste	MSW	2,989,467	-	-	Umar (2022)	
Plastic share of MSW	PR	-	20.9%	-	Zafar (2018)	
Plastic leakage rate	(LR)	-	5.6%	-	OECD (2025)	
<i>Plastic leaked into the environment</i>					Calculated	
<i>Territorial allocation (ai)</i>						
Terrestrial / Land Impacts	(PLE_t)	-	50%	42.38%	-	Holzbecher et al. (2025)
Freshwater / Wadi	(PLE_f)	-	38%	32.21%	-	Ghayebzadeh et al., (2020)
Coastal / Marine Impacts	(PLE_c)	-	28.98%	24.56%	-	Al-Tarshi et al. (2024)

Atmospheric / Human Exposure Impacts	(PLE_a)	-	1%	0.85%	-	Jones (2023)
<i>weight</i>			1.1798	100%	-	
Plastic waste management cost	(PWC)				76.8\$	OECD (2022) Assumed mid-case: \$76.8/ton; For scenario (Ref Table 2)

**Table 2.** Annualized Benchmark Costs for Waste Management Solutions

Waste Management Solution	Annual Cost Range (\$/tonne/year)	Median \$/tonne/year
Mixed waste collection and transfer	40.7 – 86.4	63.55
Source-separated waste collection and transfer	29.9 – 86.4	58.15
Sorting station for clean recyclables	48.8 – 103.9	76.35
<i>Plastics recycling facility*</i>	54.8 – 98.8	76.8
Mechanical biological treatment for mixed waste	60.4 – 91.5	75.95
Incineration with energy recovery	89.8 – 149.1	119.45
Landfilling	28.5 – 33.6	31.05
Litter collection	1,000 – 2,000	1500

*Note:* Operating costs include personnel, energy and fuel, consumables, administration, taxes, and insurance. Maintenance costs comprise maintenance and repair, spare parts, and services. Depreciation and interest payments are included. For the Global Plastics Outlook analysis, median estimates were used globally for all treatment methods except recycling, where high estimates were applied to reflect ambitious recycling targets.

*Source:* Adapted from OECD (2022, Table 7.1), based on UNEP & ISWA (2015), Pfaff-Simoneit (2013), Soós, Whiteman & Gavgas (2020), and WRAP (2021).

\* *Used as proxy for Oman*

Plastic waste leakage for 2022 is reported in Table 3 (adapted from OECD, 2025, Table 1.2). Oman-specific leakage is not available; hence, the global average of 5.6% (Ref. Table 3) is used as a proxy for the plastic leakage rate to the environment.

**Table 3.** Plastic leakage rate (environment)

Country / Region	2022 Baseline (%)	2050 Baseline (%)	2050 High Stringency (%)	Reduction in Volume (Mt)
Thailand	6.8	1.4	0.2	0.1
Rest of ASEAN – HIC & UMIC	12.0	7.9	0.1	0.8
Indonesia	18.3	17.1	0.2	3.1
Rest of ASEAN – LMIC	17.4	10.7	0.2	3.0
Japan	0.3	0.2	0.2	0.01
Korea	0.3	0.2	0.2	<0.01
China	6.4	4.4	0.3	6.6
ASEAN average	14.2	10.9	0.2	7.0
APT average	7.4	5.8	0.3	13.6
OECD average	1.1	0.5	0.2	0.9

Non-OECD average	9.5	7.6	3.5	23.3
Global average*	5.6	5.1	2.3	24.2

Note: The reduction in volume shows the difference between the projected levels in the High Stringency and Baseline scenarios in 2050. Leakage rates are not assumed to be eliminated for countries outside the APT in this scenario; rather a moderate reduction is projected outside the APT. Rest of ASEAN – LMIC includes Cambodia, Lao PDR, Myanmar, Philippines, Viet Nam; Rest of ASEAN – HIC & UMIC includes Brunei Darussalam, Malaysia, Singapore. Source: OECD ENV-Linkages model

Source: Adapted from (OECD, 2025, Table 1.2), OECD ENV-Linkages model.

\* Used as proxy for Oman

## 5.0 Results and Discussion

*Calculation of total plastic waste per year:*

$$PW = MSW \times PR \quad (1)$$

Where,

PW = Plastic share of MSW (tons year<sup>-1</sup>)

MSW = Total municipal solid waste (tons year<sup>-1</sup>)

PR = Plastic share of MSW

$$PW = 2,989,467 * 0.209 \approx 624,798.60 \text{ t/yr}$$

*Calculation of plastic leaked into the environment (Total and Territorial level calculation):*

$$PL = PW \times LR \quad (2)$$

Where,

PL = Plastic leaked into the environment (tons/year)

PW = Plastic share of MSW (tons year<sup>-1</sup>)

LR = Plastic leakage rate (5%)

$$= 624,798.60 \text{ t/yr} * 0.056 \approx 34,988.72 \text{ t/y}$$

*Calculation of plastic leaked into the environment (Territorial Level-Terrestrial / Land Impacts):*

$$PLE_t = PL \times \alpha_i \quad (2a)$$

$$PLE_f = PL \times \alpha_i \quad (2b)$$

$$PLE_e = PL \times \alpha_i \quad (2c)$$

$$PLE_a = PL \times \alpha_i \quad (2d)$$

Constraint:

$$\sum_{i=1}^n \alpha_i = 1$$

Where,

PLE<sub>t</sub> = Plastic leaked into Terrestrial / Land Impacts

PLE<sub>f</sub> = Plastic leaked into Freshwater / Wadi

PLE<sub>e</sub> = Plastic leaked into Coastal / Marine Impacts

PLE<sub>a</sub> = Plastic leaked into Atmospheric / Human Exposure Impacts

PL = Plastic leaked into the environment (tons/year)

α<sub>i</sub> = Sectoral allocation factor (i.e., 42.38%, 32.21%, 24.56%, 0.0085%, ref Table 1)

Calculation:

$$PLE_t = 34,988.72 \text{ t/y} * 0.4238 \approx 14,828.24 \text{ t/y}$$

$$PLE_f = 34,988.72 \text{ t/y} * 0.3221 \approx 11,269.46 \text{ t/y}$$

1  
2  
3  
4  $PLE_e = 34,988.72 \text{ t/y} * 0.2456 \approx 8,594.45 \text{ t/y}$

5  $PLE_a = 34,988.72 \text{ t/y} * 0.85 \approx 296.56 \text{ t/y}$

6 Thus, the annual plastic leaked to environment (base line year 2022) in Oman is  $\approx 34,989 \text{ t/y}$  which  
7 includes Terrestrial / Land Impacts  $14,828.24 \text{ t/y}$ ; Freshwater / Wadi impact  $11,269.46 \text{ t/y}$ ; Coastal  
8 / Marine Impacts  $8,594.45 \text{ t/y}$ ; and Atmospheric / Human Exposure Impacts  $296.56 \text{ t/y}$ . The  
9 highest annual plastic leaked to environment is in the Terrestrial / Land and lowest is in the  
10 Atmospheric / Human Exposure.  
11  
12

13  
14 *Calculation of damage cost (in \$) due to plastic leaked into the environment (Total and*  
15 *Territorial level calculation):*

16  $DC_i = PLE_i \times DC_i$  (3)

17 Where,

18  $DC_i =$  Sector specific damage cost per year

19 Calculation:

20  $DC_l = 14,828.24 \text{ t/y} * 76.8 \approx 1,138,809 \text{ \$}$

21  $DC_f = 11,269.46 \text{ t/y} * 76.8 \approx 865,495 \text{ \$}$

22  $DC_e = 8,594.45 \text{ t/y} * 76.8 \approx 660,054 \text{ \$}$

23  $DC_a = 296.56 \text{ t/y} * 76.8 \approx 22,776 \text{ \$}$

24  
25  
26  
27 Total Damage cost:  $DC_{total} \approx \sum_i DC_i$  (4)

28  $1,138,809 + 865,495 + 660,054 + 22,776 \approx 2,687,134 \text{ \$}$

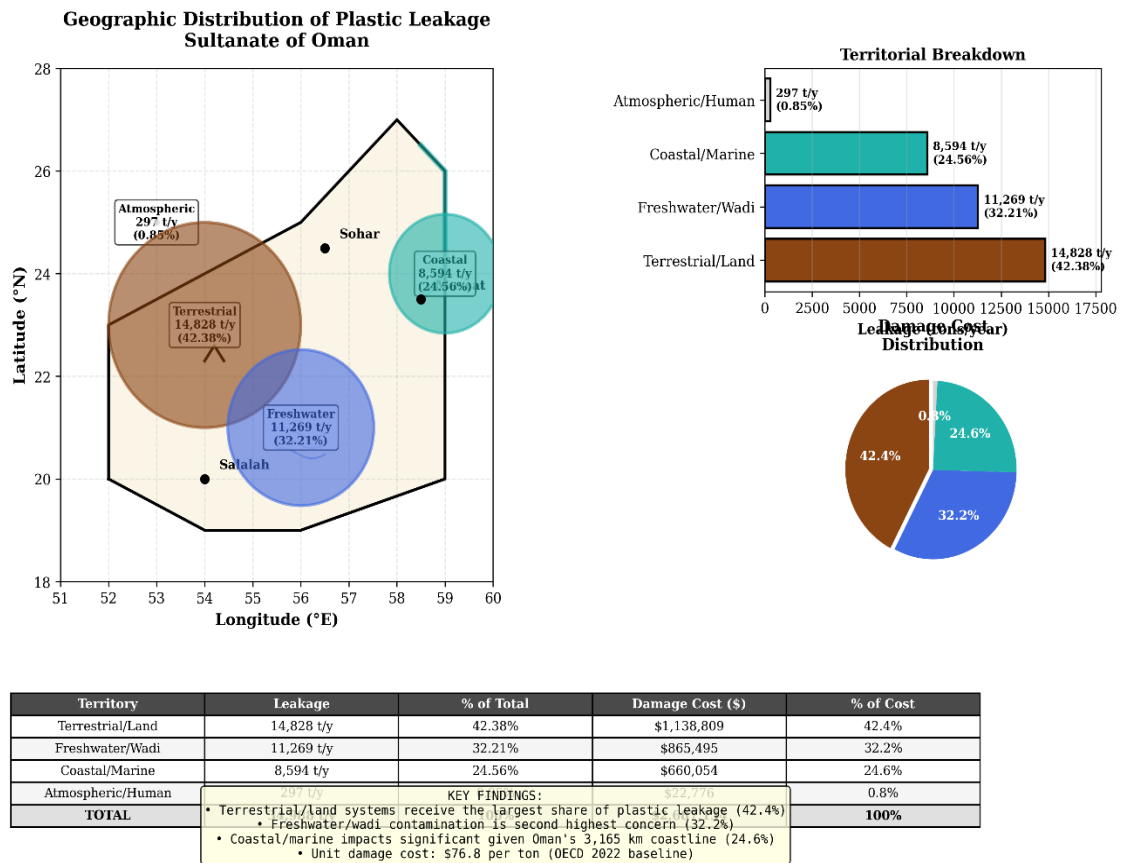
29  
30  
31 Thus, the annual damage cost of plastic pollution (baseline year 2022) in Oman is  $\approx 2,687,134 \text{ \$}$ ,  
32 which includes Terrestrial / Land Impacts at  $1,138,809 \text{ \$}$ ; Freshwater / Wadi Impact at  $865,495 \text{ \$}$ ;  
33 Coastal / Marine Impacts at  $660,054 \text{ \$}$ ; and Atmospheric / Human Exposure Impacts at  $22,776 \text{ \$}$ .  
34 The highest annual damage cost from plastic pollution is in Terrestrial / Land Impacts, and the  
35 lowest is in Atmospheric / Human Exposure Impacts.

36 Thus, on an assumption of linear damages, the marginal damage of plastic leakage is estimated as  
37 the ratio of total damage cost to total plastic leaked into the environment ( $2,687,134 \text{ USD} /$   
38  $34,988.72 \text{ t/year}$ ), yielding  $\approx 76.8 \text{ \$/ton}$ .  
39  
40  
41

### 42 **5.1 Baseline Damage Cost Assessment (2022)**

43 When the damage cost methodology is systematically applied to the Oman plastic waste data, one  
44 can obtain comprehensive estimates of environmental damage across four territorial areas.  
45 According to 2022 statistics, the total amount of municipal solid waste generated was  $2,989,467$   
46 tons annually, of which  $624,799$  tons ( $20.9 \%$ ) was plastic waste (Zafar, 2018). Using the global  
47 average leakage rate of  $5.6$  (OECD, 2025) to represent Oman, we estimate that  $34,989$  tons of  
48 plastic leak into the environment each year.

49 The territorial allocation of this leakage, illustrated geographically in Figure 12, reveals significant  
50 variation across environmental domains.  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65



**Figure 12.** Spatial distribution of plastic leakage across environmental territories in Oman (2022).

In Figure 12 provides geographic context by using proportionally sized numbers to indicate annual leakage volumes. The most significant share (14,828 t/y, 42.4%) is attributed to terrestrial/land systems, which are associated with the prevalence of land-based waste management infrastructure and terrestrial pollution pathways in Oman's arid environment. Freshwater/wadi pollution accounts for 11269 t/y (32.2%), suggesting a high impact in freshwater/wadi. 8,594 t/y (24.6%) reaches coastal/marine environments, which is substantial given Oman's 3,165 km coastline. Pathways of atmospheric/human exposure 297 t/y (0.8%). Absolute quantities are presented in a bar chart (upper right); proportional distribution is depicted in a pie chart (lower right); extensive statistics are presented in a summary table 4.

**Table 4.** Damage Cost Distribution by Environmental Territory (2022)

Territory	Leakage (tons/year)	Leakage (%)	Unit Cost (\$/ton)	Annual Damage (\$)
Terrestrial/Land	14,828	42.38%	76.8	1,138,809
Freshwater/Wadi	11,269	32.21%	76.8	865,495
Coastal/Marine	8,594	24.56%	76.8	660,054
Atmospheric/Human	297	0.85%	76.8	22,776

TOTAL	34,989	100%	76.8	2,687,134
-------	--------	------	------	-----------

Note: Damage costs calculated as:  $Damage\ Cost = Leakage\ Volume \times Unit\ Damage\ Cost$ . Proportional distribution remains constant across physical and economic metrics due to uniform unit cost application.

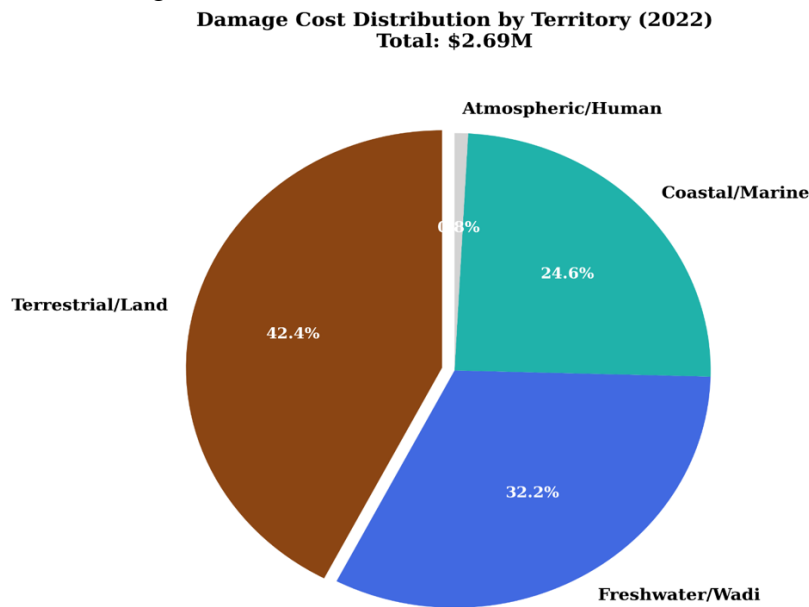
The terrestrial and land systems account for the largest share, 42.4%, reflecting both the prevalence of land-based waste management systems and the use of terrestrial pollution pathways in the Omani arid environment. It is possible to explain the concentration of plastic leakage in terrestrial systems by several factors: the lack of recycling facilities, the reliance on landfilling as the primary method of waste disposal, and the longevity of plastic compounds under desert climate conditions, where natural decomposition is low.

With the water shortage in Oman, the freshwater and wadi systems contribute 32.2%, which carry the accumulated plastic trash from land into wadi systems. This level of contamination is a major environmental and human health issue, given that wadis are the main source of freshwater in Oman and support diverse ecological systems.

Ocean and marine ecosystems receive 24.6%, which is alarming given that Oman has 3165 kilometers of coastline and relies heavily on the sea through fishing activities and tourism. This high coastal distribution is indicative of direct disposal, riverine/wadi delivery to the coast, and wind-driven transport of land-based plastic debris.

Atmospheric transport and direct human pathways of exposure 0.8%, are emerging issues, as the literature increasingly reports airborne transport of microplastics, particularly in arid regions with strong wind patterns, and potential human health effects from pollutant exposure.

The economic burden induced by monetizing these physical flows using a unit damage cost is shown in Figure 13.



**Figure 13.** Annual damage cost distribution by environmental territory (2022).

Pie chart represents a proportional distribution of total annual damage of \$2.69M between four areas: terrestrial/land, which accounts the greatest at 1.14M, (42.4%, brown) freshwater/wadi,

which accounts the least at 0.87M (32.2%, blue), coastal/marine which accounts 0.66M (24.6%, teal), and atmospheric/human which accounts 0.02M (0.8%, gray). The proportions resemble physical leakage distribution as the unit cost of damage, which is applied uniformly (OECD 2022 baseline).

The pattern of damages is accurately reflected in the leakage pattern, with terrestrial impacts causing \$1,138,809 in annual damages (42.4%), freshwater contamination causing \$865,495 (32.2%), coastal/marine degradation causing 660,054 (24.6%), and atmospheric/human exposure causing 22,776 (0.8%) of the damage costs. This proportionality between physical flows and economic destruction arises because unit damage costs are applied uniformly across territories, given a constant marginal damage per ton of leaked plastic in all environmental destinations.

These initial estimates indicate several vital lessons. To begin with, a high concentration of damage in terrestrial and freshwater systems, combined with other costs, accounts for 74.6% of total costs (2.00M out of 2.69M), indicating that policy interventions that promote land-based waste management and freshwater protection would yield the greatest payoff. Second, the marginal damage of plastic leakage, defined as the total damage divided by the total leakage, is 76.8/ton, which can serve as a useful reference point for assessing the economic efficiency of prevention measures. Any intervention with a cost under 76.8/ton of plastic leakage avoided will create a positive net economic value, without accounting for non-market benefits, such as ecosystem services, biodiversity protection, and human health.

Third, the apparently minor atmospheric/human exposure pathway, though accounting for less than 1% of the damage, amounts to close to \$23,000 in annual expenses. This number, however small compared to other ways, warrants cautionary actions as the research on the health effects of microplastics continues to develop, and the impact of greater harm on health with time is better comprehended.

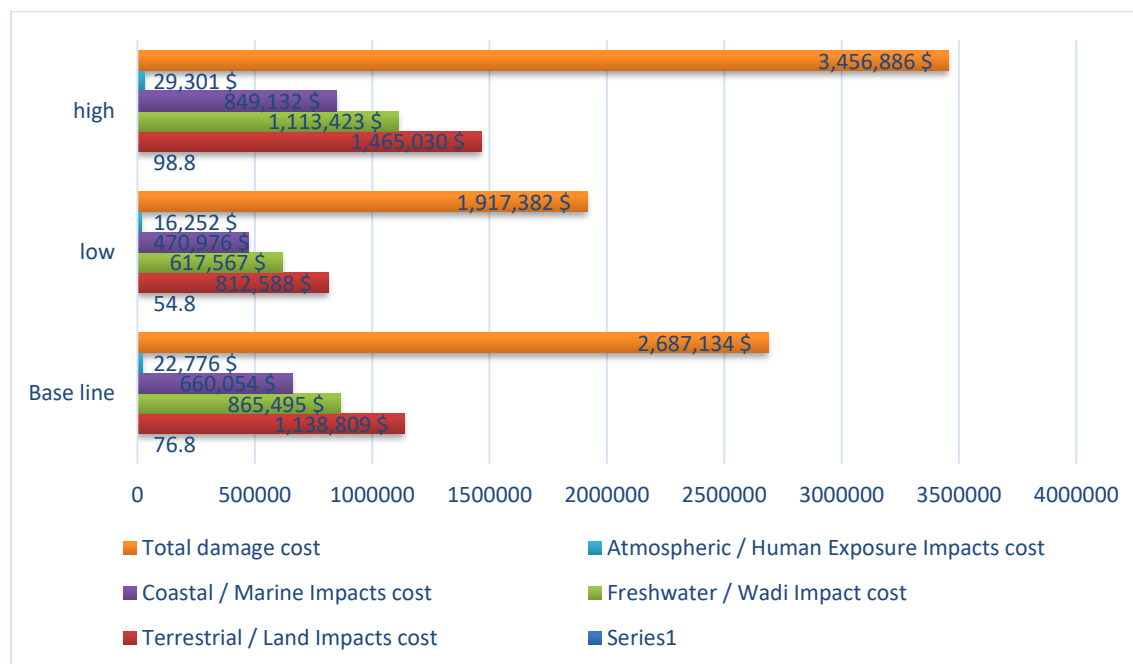
### 5.2 Damage cost due to plastic leakage- Scenario analysis

Based on the costs for Waste Management Solutions, the baseline, low, and high values were calculated in Table 5 & Figure 14, Annualized Benchmark Costs for Waste Management Solutions. The scenarios are considered to have annual cost ranges of 54.8\$ and 98.8\$ (per ton/year) for low and high, respectively.

**Table 5.** Damage cost scenario analysis

Scenario	Base line	low	high
Costs for Waste Management Solutions	76.8	54.8	98.8
Plastic leakage rate (environment) (%)	5.6%	5.6%	5.6%
Terrestrial / Land Impacts	14,828.24 t/y	14,828.24 t/y	14,828.24 t/y
Freshwater / Wadi	11,269.46 t/y	11,269.46 t/y	11,269.46 t/y
Coastal / Marine Impacts	8,594.45 t/y	8,594.45 t/y	8,594.45 t/y
Atmospheric / Human Exposure Impacts	296.56 t/y	296.56 t/y	296.56 t/y
<b>Total Plastic leaked into environment</b>	<b>34,988.72 t/y</b>	<b>34,988.72 t/y</b>	<b>34,988.72 t/y</b>
Terrestrial / Land Impacts cost	1,138,809 \$	812,588 \$	1,465,030 \$
Freshwater / Wadi Impact cost	865,495 \$	617,567 \$	1,113,423 \$
Coastal / Marine Impacts cost	660,054 \$	470,976 \$	849,132 \$
Atmospheric / Human Exposure Impacts cost	22,776 \$	16,252 \$	29,301 \$

<b>Total damage cost</b>	<b>2,687,134 \$</b>	<b>1,917,382 \$</b>	<b>3,456,886 \$</b>
--------------------------	---------------------	---------------------	---------------------



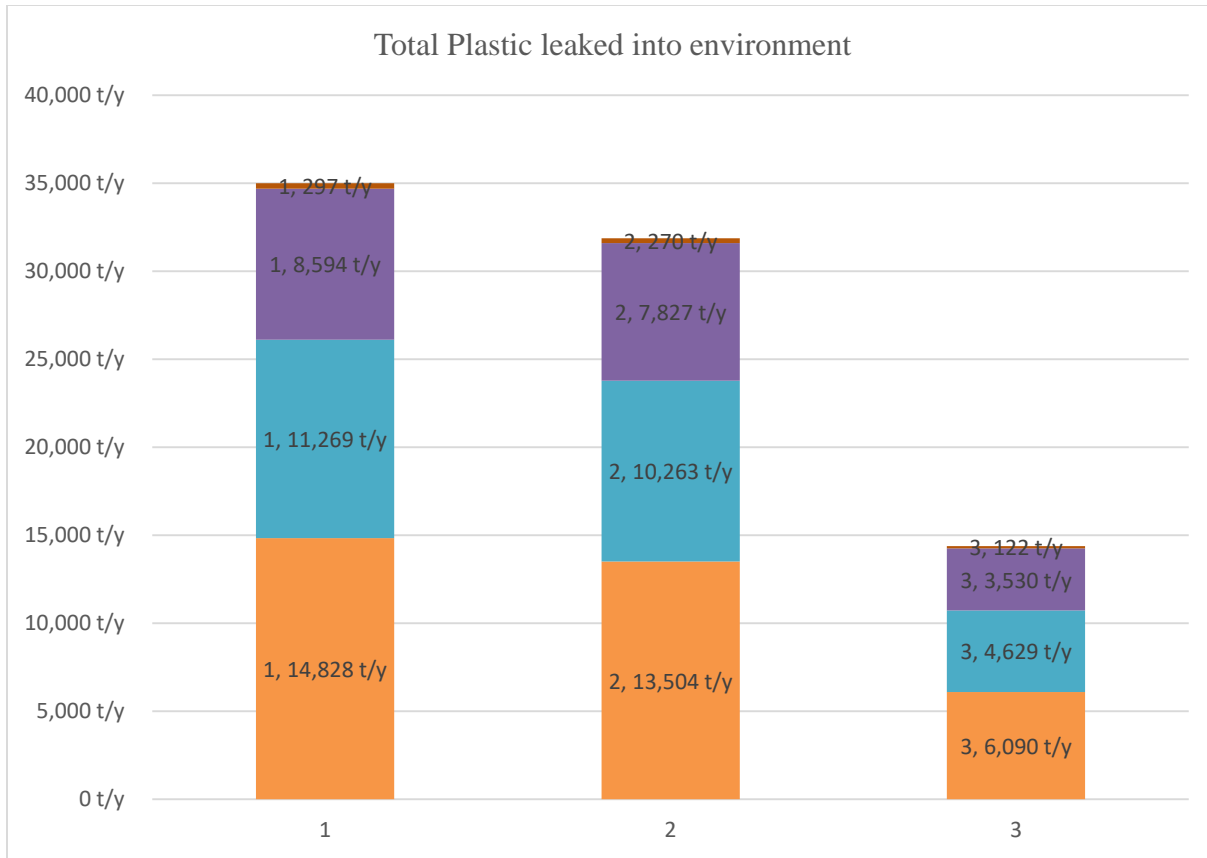
**Figure 14.** Damage cost- Scenario analysis

**Scenario analysis based on Plastic leakage rate (Total Plastic leaked into environment)**

Total plastic leaked into the environment is calculated based on three scenarios, which start from the baseline value, ie, actual observed leakage in the year 2022, then scenarios for business-as-usual projection for 2050, and aggressive policy scenario projection for 2050, as shown in Table 6 & Figure 15.

**Table 6.** Scenario analysis based on Plastic leakage rate (Total Plastic leaked into environment)

Scenario	2022 Baseline (%)	2050 Baseline (%)	2050 High Stringency (%)
Plastic leakage rate (environment) (%)	5.6%	5.1%	2.3%
Costs for Waste Management Solutions	76.80 \$	76.80 \$	76.80 \$
Plastic leakage rate (environment) (%)	5.6%	5.1%	2.3%
Terrestrial / Land Impacts	14,828 t/y	13,504 t/y	6,090 t/y
Freshwater / Wadi	11,269 t/y	10,263 t/y	4,629 t/y
Coastal / Marine Impacts	8,594 t/y	7,827 t/y	3,530 t/y
Atmospheric / Human Exposure Impacts	297 t/y	270 t/y	122 t/y
<b>Total Plastic leaked into environment</b>	<b>34,989 t/y</b>	<b>31,865 t/y</b>	<b>14,370 t/y</b>



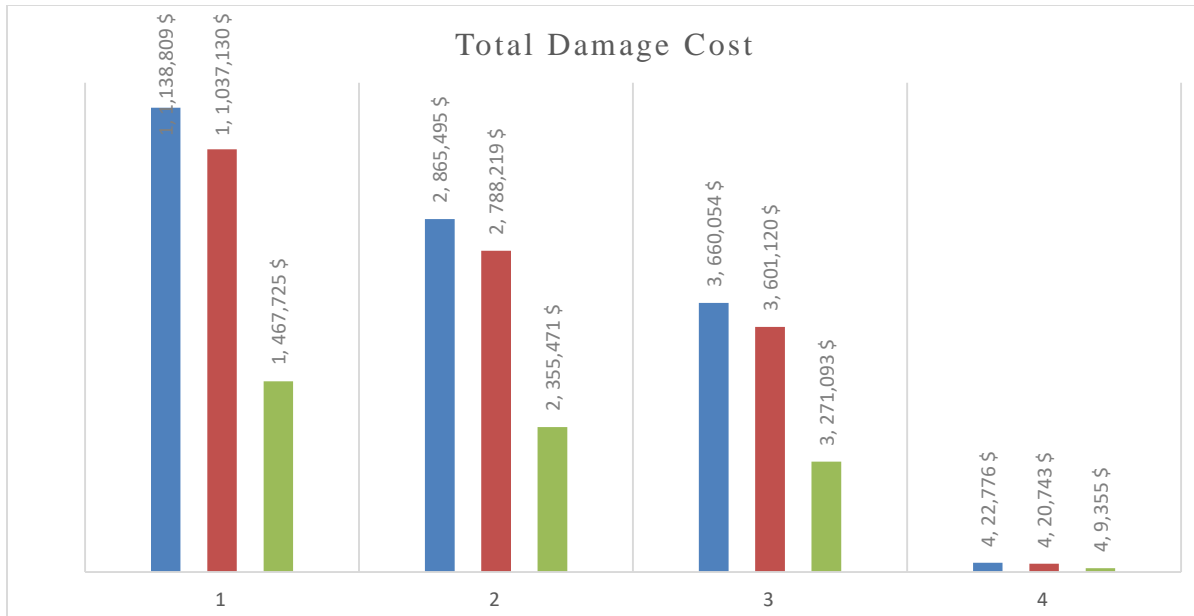
**Figure 15.** Scenario analysis based on Plastic leakage rate (Total Plastic leaked into environment)

**5.3 Scenario analysis based on Plastic leakage rate (Total damage cost)**

Of the three scenarios, total damage costs are calculated, which start from the baseline value, i.e., actual observed leakage in the year 2022, then scenarios for business-as-usual projection for 2050, and aggressive policy scenario projection for 2050, as shown in Table 7 & Figure 16.

**Table 7.** Scenario analysis based on Plastic leakage rate (Total damage cost)

Scenario	2022 Baseline (%)	2050 Baseline (%)	2050 High Stringency (%)
Plastic leakage rate (environment) (%)	<b>5.6%</b>	<b>5.1%</b>	<b>2.3%</b>
Terrestrial / Land Impacts cost	1,138,809 \$	1,037,130 \$	467,725 \$
Freshwater / Wadi Impact cost	865,495 \$	788,219 \$	355,471 \$
Coastal / Marine Impacts cost	660,054 \$	601,120 \$	271,093 \$
Atmospheric / Human Exposure Impacts cost	22,776 \$	20,743 \$	9,355 \$
<b>Total damage cost</b>	<b>2,687,134 \$</b>	<b>2,447,211 \$</b>	<b>1,103,644 \$</b>



**Figure 16.** Scenario analysis based on Plastic leakage rate (Total damage cost)

As per the three scenarios using OECD (2025) estimates of plastic leakage rates across three levels of regulatory stringency, their economic implications are given in Figure 17, and the quantitative comparisons are in detail in Table 8.

The baseline case (2022) indicates a status quo of 5.6% plastic waste leakage into the environment, resulting in 34,989 tons of plastic emissions annually and causing 2.69 million in damage costs. This baseline will indicate current waste management levels, infrastructure capacity, and regulatory standards in Oman.

According to a business-as-usual expectation to 2050, slight enhancements to waste management infrastructure, with an increased population requiring more services and technological advancements in recycling, as well as minor improvements in policy, reduce the leakage rate to 5.1 %, or 31,865 tons per year, and the damage to 2.45 million. This is a 9% reduction in costs (240,000\$ per year) that can be achieved without significant policy changes through a gradual, organic process. But even this small step does not cover the most significant part of plastic pollution harm.

A high-stringency policy scenario is an intense contrast of the high-stringency policy, showing how radical change through a comprehensive intervention can be achieved. Through ambitious waste reduction goals, compulsory recycling and the Extended Producer Responsibility (EPR) programs, circular economy tool, tax on consumption of virgin plastic, and heavy investment in waste management systems, the leakage rate may reduce to 2.3%, which is half the current rate and 55% lower than the business-as-usual (2050) forecast. This would limit environmental contamination to 14,370 t/y, reducing the annual cost of damage to 1.10M \$.

The economic impact of the policy shift is a 59% reduction in the annual economic damage avoided, totaling 1.58M\$. This annual benefit of 1.58M\$ serves as a reference point for measuring policy costs. Provided that implementation costs of high-stringency measures (such as investment in infrastructure, regulation enforcement, and educational campaigns to the population and economic incentives) are lower than this level, the policies can be associated with positive net economic value even without taking into account high-order non-market benefits like biodiversity

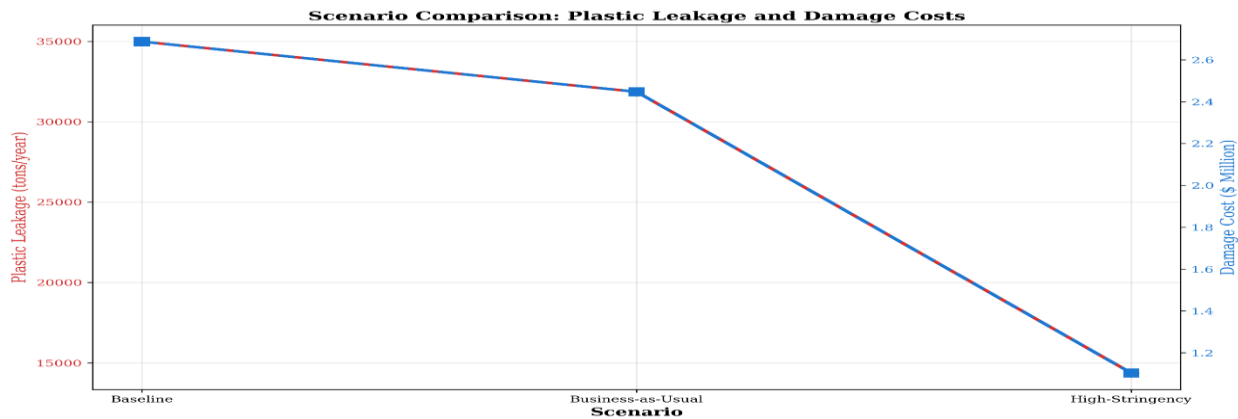
protection, ecosystem service provision, improved public health outcomes, and tourism attractiveness.

Importantly, the proportional cuts are equal in all the territories (around 59% of the total plastic leakage is through the terrestrial, freshwater, coastal, and atmospheric channels), and thus it is believed that globally uniform policies that aim to reduce the total leakage of plastics will yield equal payoffs across all areas i.e. there will not be a situation where one area would benefit at the expense of another.

**Table 8.** Scenario Comparison: Plastic Leakage and Damage Costs (2022-2050)

Scenario	Year	Leakage Rate (%)	Total Leakage (t/y)	Terrestrial (t/y)	Freshwater (t/y)	Coastal (t/y)	Atmospheric (t/y)	Total Damage (\$M/y)
Baseline	2022	5.6	34,989	14,828	11,269	8,594	297	2.69
Business-as-Usual	2050	5.1	31,865	13,504	10,263	7,827	270	2.45
High-Stringency	2050	2.3	14,370	6,090	4,629	3,530	122	1.1
Change (Baseline → High-Stringency)	-	-58.90%	-20,619	-8,738	-6,640	-5,064	-175	-1.58
Relative Reduction	-	-	59.00%	58.90%	58.90%	59.00%	58.90%	59.00%

*Note: High-Stringency scenario based on OECD (2025) Global Plastics Outlook projections assuming comprehensive policy implementation including extended producer responsibility, circular economy incentives, consumption reduction targets, and enhanced waste management infrastructure. Territorial distribution maintains constant proportional allocation (42.38%, 32.21%, 24.56%, 0.85%) across all scenarios.*



**Figure 17.** Scenario comparison of plastic leakage rates and associated damage costs (2022-2050).

The three curves in the dual-axis line graph are 2022 Baseline (5.6% leakage, 34,989 t/y, 2.69M\$ annual damage, red), 2050 Business-as-Usual (5.1% leakage, 31,865 t/y, 2.45M\$, orange), and 2050 High-Stringency Policy (2.3% leakage, 14,370 t/y, 1.10M \$, green). A high-stringency scenario delivers a 59% damage reduction, with a total annual damage reduction of 1.58M\$, under an extensive policy. A very close relation between leakage rate and damage costs is demonstrated by the linear trend line.

#### 5.4 Sensitivity Analysis

Because there is inherent uncertainty in unit damage cost estimates, particularly when using international benchmarks as proxies for local conditions, Table 9 measures the influence of different cost assumptions on damage estimates and Figure 18 presents a sensitivity analysis of the entire set of OECD (2022) waste management cost benchmarks.

**Table 9.** Sensitivity Analysis: Damage Costs Under Varying Unit Cost Assumptions

Territory	Leakage (t/y)	Low Cost (\$54.8/ton)	Baseline Cost (\$76.8/ton)	High Cost (\$98.8/ton)	Absolute Range (\$)	Relative Range (%)
Terrestrial/Land	14,828	\$812,588	\$1,138,809	\$1,465,030	\$652,442	±28.7%
Freshwater/Wadi	11,269	\$617,567	\$865,495	\$1,113,423	\$495,856	±28.7%
Coastal/Marine	8,594	\$470,976	\$660,054	\$849,132	\$378,156	±28.7%
Atmospheric/Human	297	\$16,252	\$22,776	\$29,301	\$13,049	±28.7%
TOTAL	34,989	\$1,917,382	\$2,687,134	\$3,456,886	\$1,539,504	±28.7%

*Note: Low scenario uses OECD (2022) lower bound for plastic recycling (\$54.8/ton); high scenario uses upper bound (\$98.8/ton). Baseline uses median value (\$76.8/ton). Percentage variation calculated as:  $[(High - Low) / (2 \times Baseline)] \times 100\%$ . Constant relative uncertainty across territories confirms proportional scaling of damage estimates.*

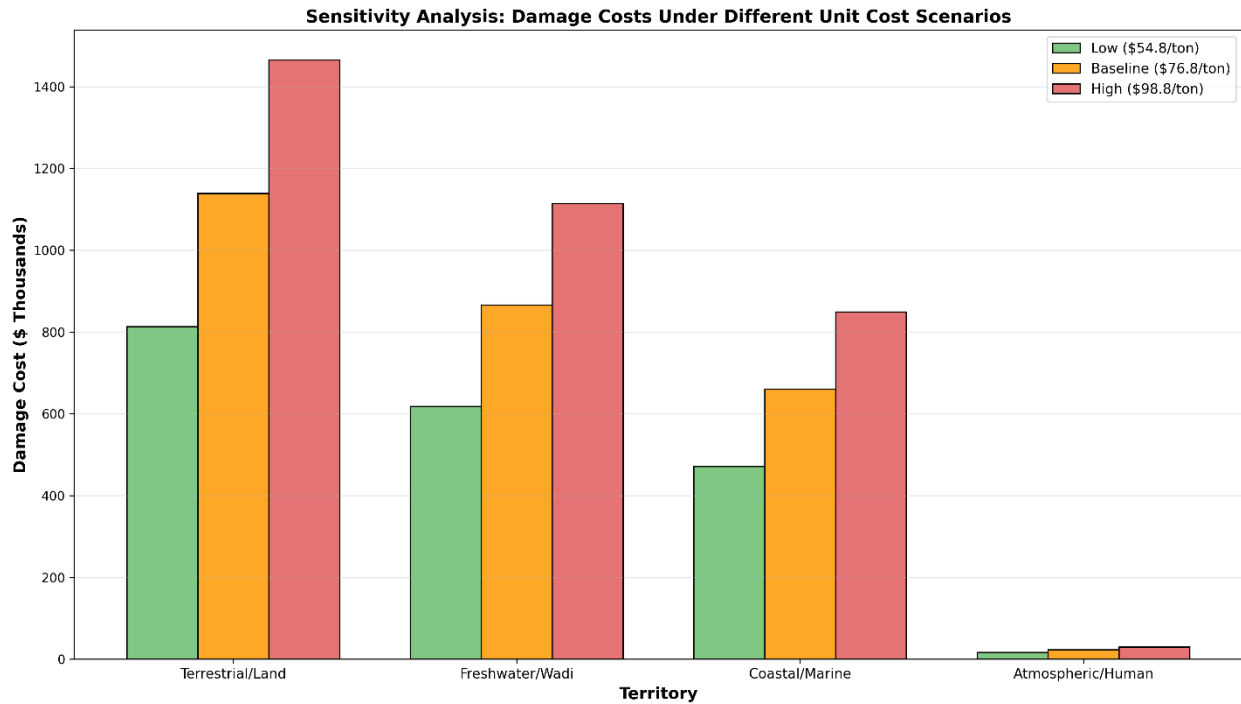
Based on Table 9, the low-cost scenario (54.8/ton) results in annual damages of 1917382, whereas the high-cost scenario (98.8/ton) yields 3456886 in annual damages. The midpoint of this range is our estimate of the lower and upper bounds of 2,687,134. The sensitivity analysis indicates moderate uncertainty (around the baseline estimate of about 29%) that can inform robust policy implications, while accounting for the inherent constraints of estimating damage costs.

Notably, the proportions of units of different territories do not change in cases of varying unit cost assumptions since proportional relationships are retained in the damage multiplicative form (Damage = Leakage × Unit Cost). Terrestrial impacts exhibit the largest change in variance (812,588 to 1,465,030t/y), due to the high volume of leakage into the domain (14,828 t/y) and the corresponding proportional increase in variance. Nonetheless, in percentage terms, all territories are approximately equal, with ±28.7% around the baseline estimates.

This constant proportional uncertainty has significant implications for policy prioritization. The economic significance of the territorial effects is unaltered across the full possible range of unit costs: terrestrial systems are always the most important source of damage (42.4%), followed by

1  
2  
3  
4 freshwater (32.2%), coastal (24.6%), and atmospheric (0.8%). Territorial targeting policy priorities  
5 are thus resistant to uncertainty in unit costs.  
6

7 The sensitivity analysis indicates that, even under the most conservative (low-cost) scenario,  
8 annual damages exceed \$1.9 million, and under the high-cost scenario, damages may approach  
9 \$3.5 million. The 80% (-29% to +29%) range shows moderate sensitivity to unit cost assumptions,  
10 without creating overly wide bounds, indicating the ability to make informed policy decisions. The  
11 analysis proves that, despite the unit cost in question, plastic pollution in Oman creates  
12 considerable economic losses, which number millions of dollars each year, which is the reason  
13 why much policy attention and investment in the mitigation effort should be paid to it.  
14  
15



43  
44  
45  
46  
47  
48  
49  
50  
51  
52

**Figure 18.** Sensitivity analysis of damage costs by territory under alternative unit cost assumptions.

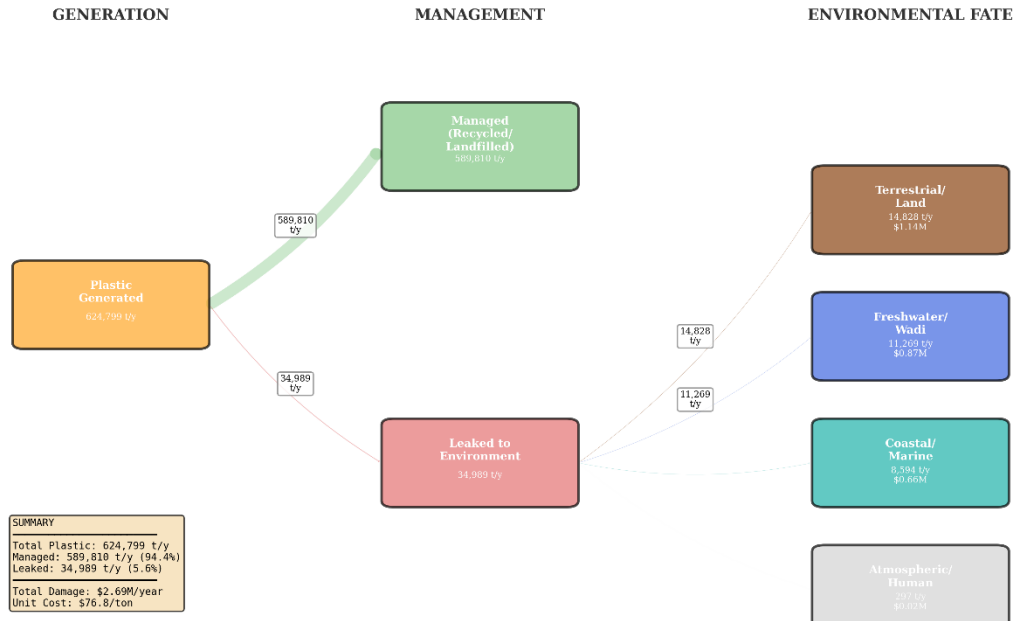
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

The bar chart is grouped by waste management cost range, as provided by the OECD (2022): low costs (green bars; 54.8/ton), medium costs (orange bars; 76.8/ton), and high costs (red bars; 98.8/ton). The minimum and maximum damage estimates are 1.92M and 3.46M, respectively, with a middle point value at 2.69M. The maximum absolute variance is observed in terrestrial and freshwater effects, which account for a large portion of the total leakage. The proportions of the territories are fixed at 42.4, 32.2, 24.6, and 0.8 in all the cost cases, which is the multiplicative structure of the damage function.

### 5.5 Flow Analysis and Material Balance

Figure 19 provides a comprehensive visualization of plastic waste flows from generation through environmental fate, offering an integrated view of the material balance and associated economic costs.

Plastic Waste Flow and Damage Costs in Oman (2022)



**Figure 19.** Plastic waste flow and damage costs in Oman (2022).

Sankey-style diagram shows all paths between generation ( 624,799 t/y, orange) and management (589,810 t/y managed/recycled/landfilled, green; 34,989 t/y leaked to environment, red) to environmental fate over four territories (terrestrial 14,828 t/y/\$1.14M brown, freshwater 11,269 t/y/\$0.87M blue, coastal 8,594 t/y/\$0.65M teal, atmospheric 297 t/y/\$0.22M grey). Flow labels indicate quantities by the sizes of boxes. The summary box (lower left) presents key statistics: 94.4% of plastic waste has been managed, 5.6% leaks into the environment, and total damage is \$2.69M/year at a unit cost of \$76.8/ton.

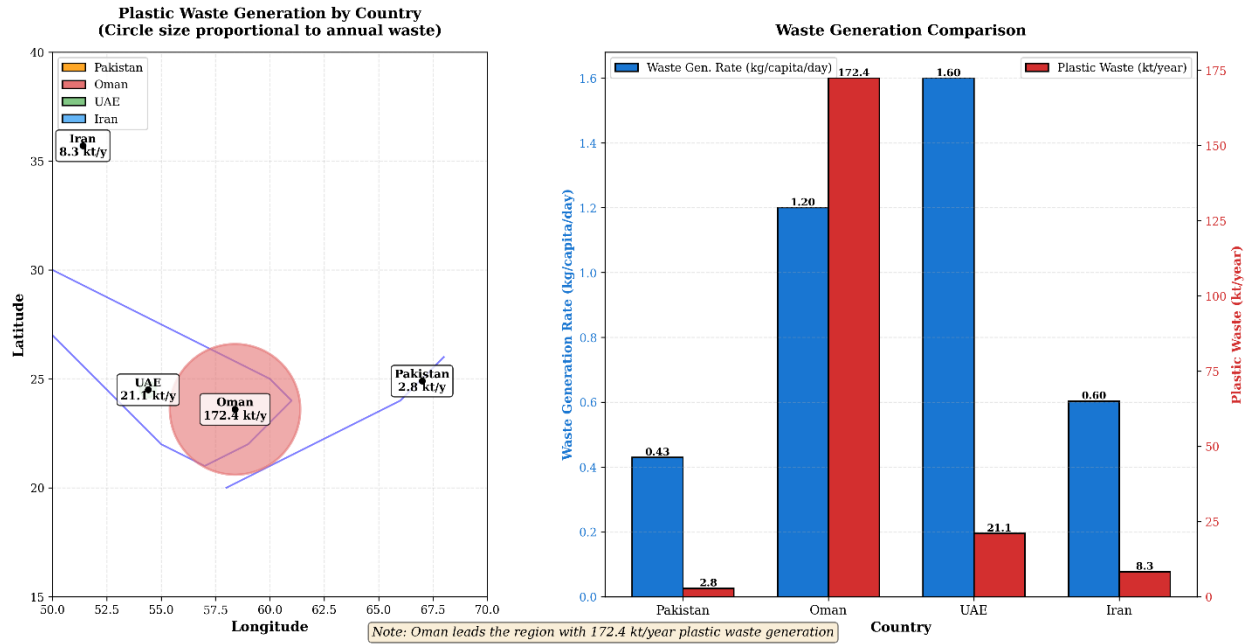
In the flow diagram, it is apparent that of the 624,799 t/y of plastic waste generated in Oman each year, 94.4% (589,810 tons) is properly disposed of through recycling, landfilling, or incineration, and 5.6% (34,989 tons) is released into the environment. Although it accounts for the highest percentage of plastic waste, this rate of management causes significant environmental pollution and related destruction.

All pathways yield proportional damage costs, and the four territories together yield economic damages of \$2.69 million per unit, at a unit cost of \$76.8 per ton.

This systems-level viewpoint reveals the effectiveness of current waste management facilities in capturing the bulk of plastic waste, while highlighting the remaining 5.6% leakage, which causes significant environmental and economic damage. Even small percentage-point decreases in the leakage rate will result in considerable absolute decreases in environmental pollution and economic losses, highlighting the strong leverage that better waste management habits have.

**5.6 Regional Context and Comparative Analysis**

To situate Oman's plastic pollution challenge within the broader Gulf region, Figures 20 and 21 present comparative analyses with neighbouring countries, while Table 10 summarizes key regional indicators.



**Figure 20.** Gulf regional plastic waste generation comparison.

Left side: stylized map with the size of circles being equal to the annual plastic waste production: Oman (172.4 kt/y, or the largest red circle), UAE (21.1 kt/y), Iran (8.3 kt/y, and Pakistan (2.8 kt/y in coastal areas). The column on the right presents a grouped bar chart of waste generation rates (kg/capita/day; blue bars) and absolute volumes of plastic waste (kt/year; red bars). The note shows that Oman leads the region in per capita plastic waste generation (1.20 kg/capita/day) and in absolute volumes (172.4 kt/y).

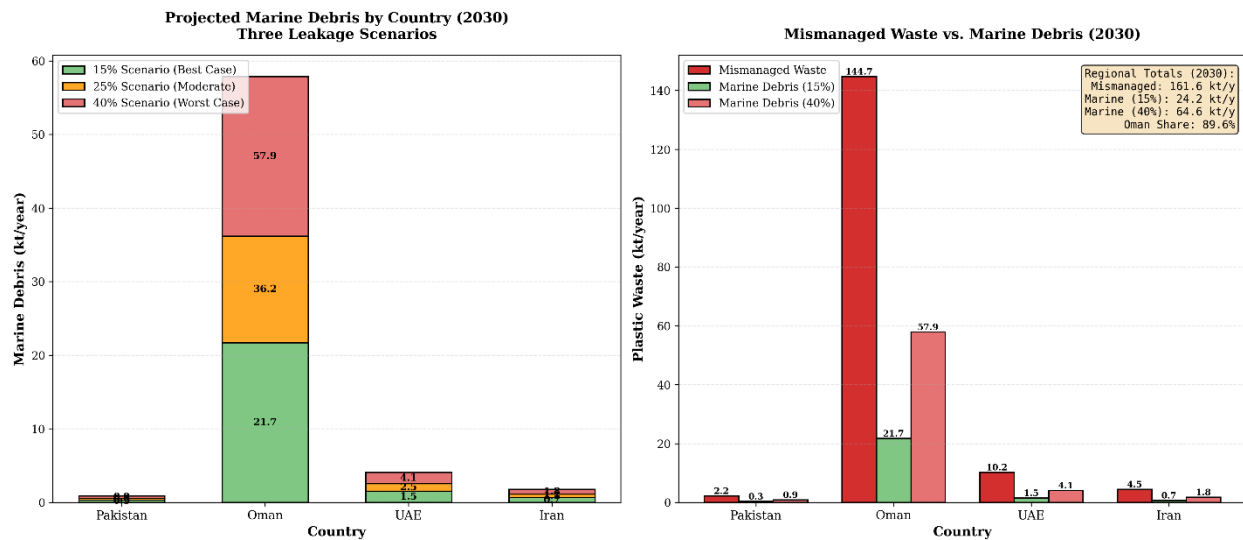
**Table 10.** Gulf Region Plastic Waste Generation Comparison

Country	Coastal Pop. (M)	Waste Rate (kg/capita/day)	Total Waste (kt/y)	Plastic (%)	Plastic Waste (kt/y)	Mismanaged 2030 (kt/y)	Marine Debris Potential (kt/y)
Pakistan	0.1	0.43	15.7	18.00%	2.8	2.2	0.3 - 0.9
Oman	2.4	1.2	1,051.20	16.40%	172.4	144.7	21.7 - 57.9
UAE	0.19	1.6	111	19.00%	21.1	10.2	1.5 - 4.1
Iran	0.37	0.6	81.4	10.20%	8.3	4.5	0.7 - 1.8
Regional Total	3.06	-	1,259.30	-	204.6	161.6	24.2 - 64.6

Note: Coastal population represents population within 50km of coast. Marine debris potential calculated under three scenarios: 15% (best case), 25% (moderate), and 40% (worst case) of mismanaged waste entering marine environment. Oman's contribution represents 84.3% of total plastic waste and 89.6% of mismanaged waste in sampled Gulf region.

The regional analysis (Table 10) shows that Oman has an unreasonably high rate of plastic waste production compared to other Gulf countries. With 2.4 million inhabitants, the coastal city is larger than the sampled portions of neighboring countries, and Oman produces 172.4 thousand tons of plastic waste, accounting for 84.3% of the total plastic waste of the countries analyzed. The waste

allowance rate of 1.20 kg/capita/day falls between 0.43 in Pakistan and 1.60 in the UAE; however, due to the larger population base, the absolute amounts are significantly higher. Importantly, Figure 21 estimates that without any meaningful policy action, Oman's contribution to marine debris in 2030 may range from 21.7 to 57.9 thousand t/y, under different leakage conditions (15% to 40% of mishandled waste to marine environments). This is about 90% of the total estimated marine waste in the four countries under analysis, with Oman having a disproportionate influence in the region.



**Figure 21.** Projected marine debris by country (2030) under three leakage scenarios.

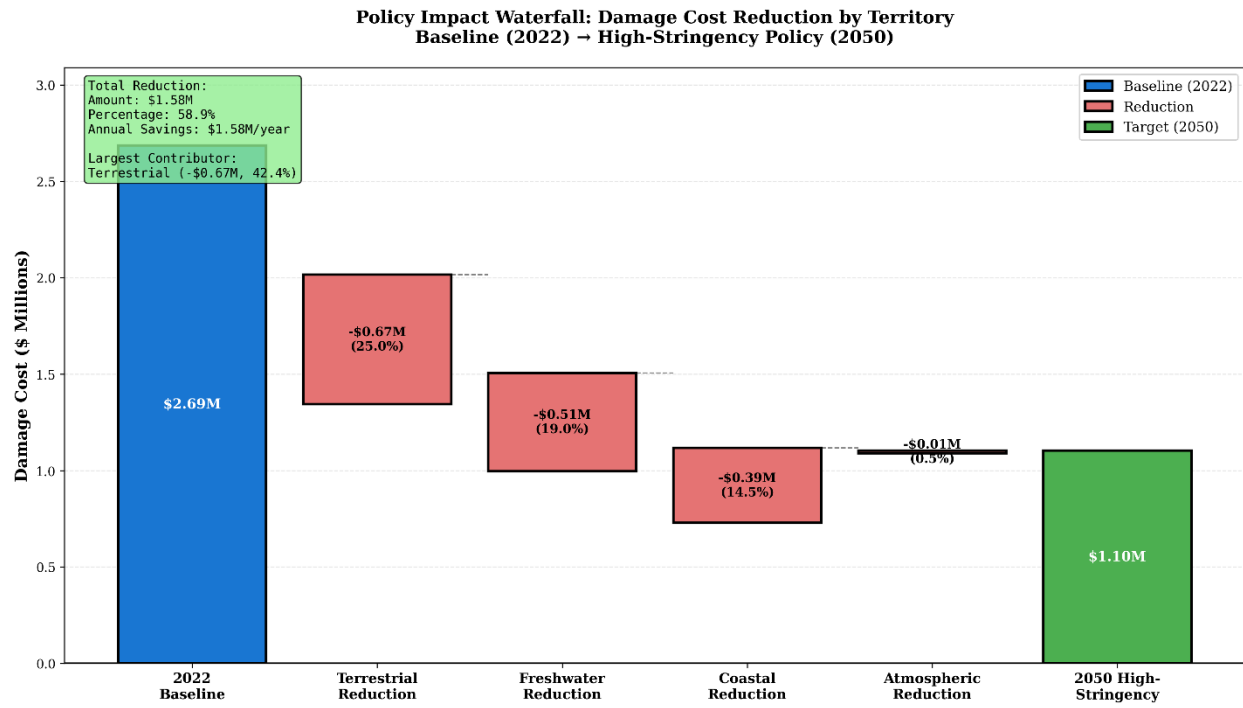
The left panel shows a stacked bar chart: Oman accounts for 21.7 kt/y (15% scenario, green), 36.2 kt/y (25% orange), and 57.9 kt/y (40% red), representing about 90% of global marine trash. The right panel is a comparison of mismanaged waste (red bars, left axis) and marine debris results (15% green and 40% red bars, right axis). The text box shows the regional totals: 161.6 kt/y of mismanaged waste could result in marine garbage of 24.2-64.6 kt/y. Oman: 89.6% of the regional mismanaged plastic.

This leadership in plastic production and waste management in the region is indicative of Oman's economic growth, consumption patterns, and available waste management infrastructure. Although the nation has been working to modernize waste services, the dynamism of plastic consumption, driven by rising incomes, urbanization, and the use of single-use plastics, has been growing faster than infrastructure development.

The regional comparison would have two major uses. First, it situates Oman in the context of the proposed challenge, not as a local issue but as a regionally significant one regarding shared marine resources in the Arabian Sea and the Gulf of Oman. Second, it outlines opportunities for regional collaboration to address plastic pollution, including joint investments in infrastructure, the sharing of information on policy best practices, and joint regulation of waste management principles across the Gulf region.

### 5.7 Policy Impact Decomposition

Figure 22 breaks down the total cost reduction (1.58M\$) associated with high-stringency policies into territorial components by undertaking a waterfall analysis, which, as further explained in Table 11, supports the breakdown of the overall cost-reduction components.



**Figure 22.** Policy impact waterfall: damage cost reduction by territory from baseline (2022) to high-stringency scenario (2050).

The Figure 22, commences with the original damage of the terrestrial at \$2.69M (blue bar, left), followed by subsequent damage -terrestrial -\$0.67M (25.0%, red), freshwater -\$0.51M (19.0%, red), coastal -\$0.39M, (14.5), atmospheric -\$0.01M (0.5), and culminates with target damage of \$1.10M (green bar, right). The summary (top left) shows that the total reduction is \$1.58M (58.9%), with the largest contribution from terrestrial (-0.67M, 42.4% of the total reduction). Intermediate stages with cumulative reductions are linked by dashed lines.

**Table 11.** Policy Impact Decomposition: Territorial Contributions to Damage Reduction

Component	Baseline 2022 (\$)	High-Stringency 2050 (\$)	Absolute Reduction (\$)	% of Total Reduction	% of Baseline
<b>Terrestrial/Land</b>	1,138,809	467,725	-671,084	42.40%	-58.90%
<b>Freshwater/Wadi</b>	865,495	355,471	-510,024	32.20%	-58.90%
<b>Coastal/Marine</b>	660,054	271,093	-388,961	24.60%	-58.90%
<b>Atmospheric/Human</b>	22,776	9,355	-13,421	0.80%	-58.90%
<b>TOTAL</b>	2,687,134	1,103,644	-1,583,490	100%	-58.90%

*Note: Reductions calculated as (Baseline 2022 - High-Stringency 2050). Percentage contributions to total reduction show terrestrial/land contributing largest absolute savings (-\$671,084), followed by freshwater (-\$510,024), coastal (-\$388,961), and atmospheric (-\$13,421). Uniform 58.9% reduction across territories reflects proportional scaling of leakage reduction from 5.6% to 2.3%.*

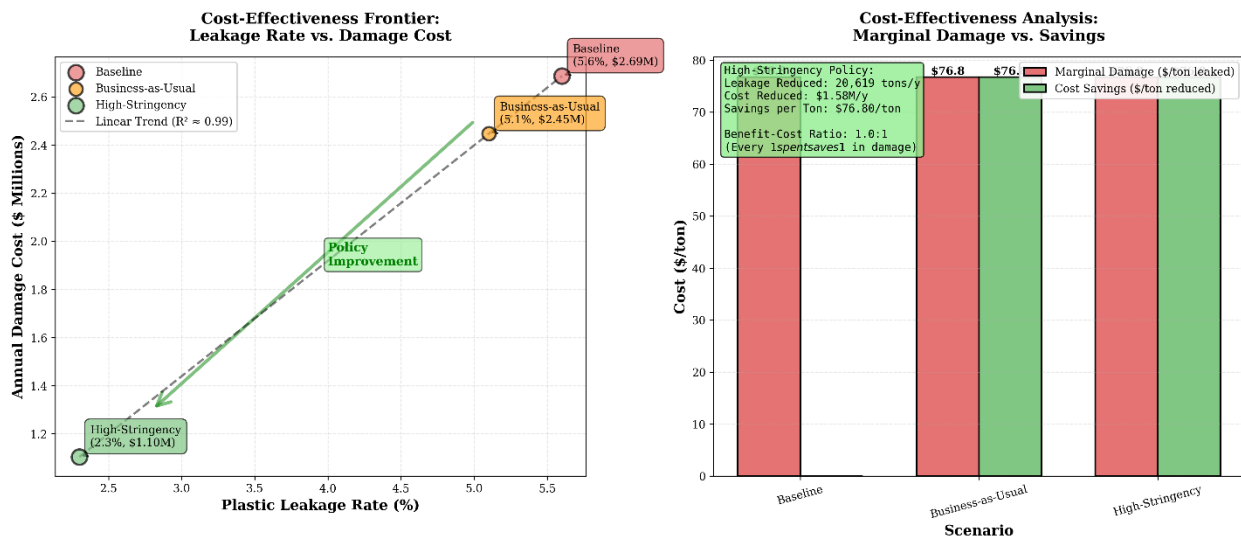
The waterfall breakdown shows that terrestrial / land impacts make the highest contribution to the total potential cost savings 671,084\$ yearly, or 42.4 % of the maximum reduction potential. Freshwater systems provide an additional potential savings of 510,024\$ (32.2%), with coastal/marine systems second at 388,961\$ (24.6%) and atmospheric pathways third at 13,421\$ (0.8%).

The equality of percentage change in territories (58.9% of all domains) is due to the proportionality of the modeled policy intervention: the high-stringency policies decrease aggregate plastic leakage by 5.6% to 2.3% (58.9% reduction), and the percentage change is uniformly applied to all the pathways of the environment, as indicated by the coefficients of territorial allocation. There are policies that might have disproportionately high benefits for pathways, such as enhanced coastal cleanup, which would selectively alleviate marine effects, whereas enhanced landfill administration would selectively enhance terrestrial systems. However, the overall effect of extensive policy packages can reasonably be modeled as proportionate decreases.

Based on policy prioritization, decomposition indicates that the policies that involve intervention in terrestrial and freshwater systems have the highest absolute economic payoffs. Nevertheless, the large proportional significance of coastal/marine systems to the Oman economy (via tourism and fisheries) and atmospheric/human pathways to the health of the population can perhaps justify policy response which is not strictly limited to what pure economic damage indices would indicate, especially when it comes to the benefits of the ecosystem which may be difficult to quantify, including ecosystem services, biodiversity protection, and long-run health.

### 5.8 Cost-Effectiveness Analysis

Figure 23 combines the cost-effectiveness of the policy interventions in the form of both the association between the leakage rates and the damage costs (on the left panel) and the cost savings per ton of plastic leakage avoided (on the right panel).



**Figure 23.** Cost-effectiveness analysis of plastic pollution reduction policies.

Figure 23 (left) illustrates the cost-effectiveness frontier: in three cases (Baseline, 5.6%, 2.69M\$, red; Business-as-Usual, 5.1%, 2.45M\$, orange), a scatter plot of leakage rate (x-axis) against annual damage cost (y-axis) is shown. A strong correlation is shown by the linear trend line (dotted

1  
2  
3  
4 gray). The green arrow labeled "Policy Improvement" indicates the best direction. The right panel  
5 shows a bar chart comparing marginal damage (ones leaked, red bars) and cost savings (ones  
6 reduced, green bars) for each scenario. High-Stringency benefits (text box, upper left): 20,619 t/y  
7 saved, \$1.58M savings, 76.80/t savings, benefit-cost ratio 1:1 (each dollar spent on prevention will  
8 save one dollar in damages, non-market benefits omitted).  
9

10 The cost-effectiveness frontier (left panel) shows a near-perfect linear association between plastic  
11 leakage rates and economic damages, supporting the theoretical forecasts under the assumption of  
12 constant marginal damages. This linearity suggests that a 1% decrease in the leakage rate does not  
13 reduce economic returns at any of the ranges studied. In the high-stringency case, shown in the  
14 lower-left of the frontier, is an economically optimal path of policy enhancement, one that reduces  
15 environmental contamination and economic losses simultaneously.  
16

17 The right panel measures cost-effectiveness in marginal cost-damage and cost savings per ton. The  
18 unit damage assumption is that the marginal damage will be a constant amount of 76.8\$/t,  
19 regardless of the situation. More to the point, the cost savings realized under leakage prevention  
20 also approximate the same figure of about 76.8\$/t in both the business-as-usual and the high-  
21 stringency scenario, which shows that prevented leakage prevents damage with a value equal to  
22 the unit cost.  
23  
24

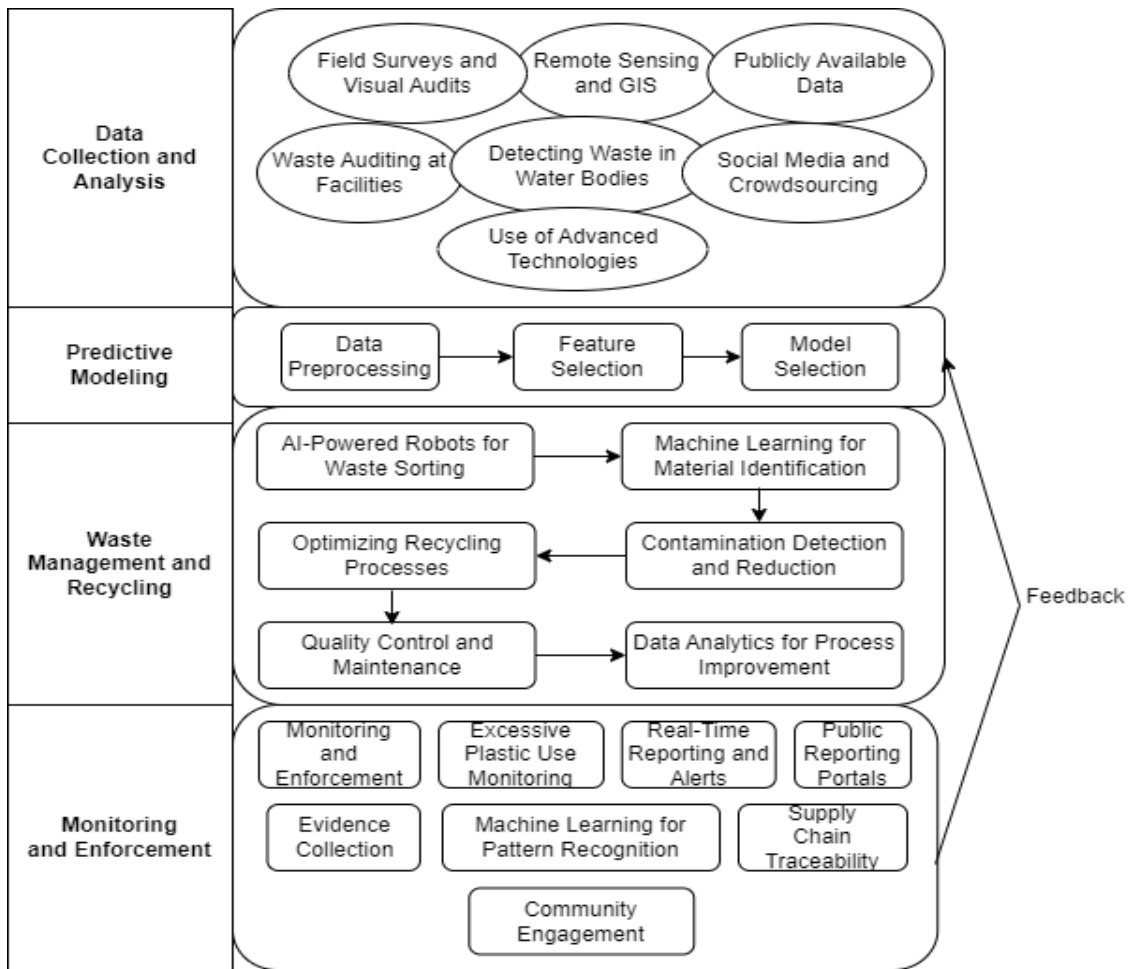
25 The outcome of this analysis is a crucial policy implication, namely, any less expensive prevention  
26 policy below the cost of 76.8\$/t of plastic leakage prevented creates economic value. The  
27 implication is that even expensive, widespread interventions can be economically justified given  
28 the total benefits to society.  
29  
30

## 31 **6.0 Plastic Pollution Framework**

32 Given emerging concerns about plastic waste entering the environment and the importance of  
33 plastic management, we propose a plastic pollution framework. To quantitatively capture the  
34 damages of plastic pollution, an overall, diverse evaluation method should be applied to encompass  
35 both tangible and intangible costs incurred by society and the environment. We also offered an  
36 elaborate outline on this type of procedure. The initial stage relies on strict data collection and  
37 analysis, as illustrated in Figure 24. This basic level not only helps understand the extent of the  
38 issue and its implications but also lays a foundation for successful interventions and policy design.  
39 On-site plastic waste will have to be measured using Visual Audits and Field Surveys. Surveys are  
40 one of the methods specialists use to identify, clean, and estimate plastic waste. These programs  
41 emphasize waste disposal techniques and the locations of plastic waste. Using remote Sensing and  
42 Geographic Information Systems (GIS), an aerial view is provided for large, inaccessible regions.  
43 Plastic pollution in rural and marine areas can be mapped using GIS and satellite imagery. A  
44 combination of these technologies demonstrates the failure of traditional surveying tools. Also, the  
45 public can work with the data. Datasets on plastic consumption, recycling, and waste generation  
46 are prevalent across governmental, non-governmental, and organizational levels. These  
47 repositories provide a macro perspective on the trajectory of plastic waste and are essential for  
48 policy development and strategic planning.  
49

50 Mobile phones and social media have transformed the role of everyone in data collection. Tracking  
51 of social media and crowdsourcing of waste by people. Starting with illegal dumping areas and  
52 moving to water pollution from plastics, digital information displays the current state of plastic  
53 waste in real time. Plastic waste is also generated in large quantities by industry. Therefore, facility  
54 waste audits are significant. Facility waste breakdowns will also be detailed to define the types of  
55 plastic and how they are discarded, recycled, or mitigated. Cost optimization may be possible in  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

waste management and environmental compliance audits. Finally, there is improved management and detection of waste in the new era. There exist modern sensors, drones, and IoT. Large dump sites can be surveyed by drones to ensure compliance and proper waste processing. Strategic waste container sensors also have Fullness alarms that improve collection routes. Hence, the plastic waste issue can be solved by gathering and interpreting data through a prismatic approach. Integrating technological advances with the conventional approaches, the concerned parties would be able to come up with practical approaches to deal with this urgent environmental issue.



**Figure 24.** Plastic waste framework

Predictive modeling provides insight into future waste disposal using data. This stage identifies potential waste paths, hazards, and illegal dumping sites. First, data preprocessing cleans raw data for use with complex models. The feature selection guide assists the model in narrowing down to the important variables. Finally, model selection refers to the process of selecting the optimal machine learning or statistical model for the data and problem at hand.

The most significant is the action-phase forecast. It promotes viability and innovation. Waste sorting has taken on a new dimension with the emergence of AI-powered robots that ensure accurate sorting. Machine learning can also be used to speed up waste sorting by improving material identification. Process optimization facilitates effective recycling and ensures maximum resource savings. Under Contamination Detection and Reduction, contamination control is achieved through monitoring the recycling process to ensure contamination does not occur. Quality

1  
2  
3  
4 Control and Maintenance provide a guarantee of perfection in operations by checking against  
5 standards and the condition of the equipment. The last stage is Data Analytics to Process  
6 Improvement, which enhances waste management through data mining.

7 Environmental issues such as recycling and waste management are essential, especially regarding  
8 plastic waste. Waste-collection robots powered by artificial intelligence (AI) are among the biggest  
9 strides toward addressing this issue. These AI robots can differentiate between plastics. Waste  
10 management centers will be revolutionized, with the accuracy and speed of the machines enabling  
11 them to categorize reusable plastic.

12 The significance of machine learning in object identification cannot be overstated. Recycling  
13 should be done with appropriate labeling of plastics, since they come in a wide variety, such as  
14 Polyethylene Terephthalate (PET) and High-Density Polyethylene (HDPE). The solution is  
15 machine learning models trained on large-scale datasets. They can identify plastics by their  
16 manufacturing techniques, thereby informing recycling or disposal decisions.

17 Recycling is intelligent but complex. Plastics are divided into various types; therefore, the  
18 recycling process differs for each type. These are operations that should be streamlined. The  
19 optimization of the processes will focus on transforming most of the waste plastic into usable  
20 materials. This also minimizes the environmental effect of plastic. Recycling also has issues. Over  
21 time, food, liquids, and other contaminants degrade plastics. These toxins must be extracted from  
22 the recycling stream before reuse. Present-day pollution monitoring and remediation practices  
23 address this. These systems guarantee the quality of recycling.

24 Special consideration should be paid to the techniques and tools of plastic waste management.  
25 Quality machinery should be checked, serviced, and repaired on-site. The efficiency of operations  
26 will enable the use of recycled plastic to meet the requirements. Lastly, any plastic waste  
27 management is factual. The presence of these data on recycling and pickup rates proves the  
28 effectiveness of the processes. These data can be analyzed to inform stakeholders about sustainable  
29 ways to deal with plastic waste.

30 Waste management does not end at collection, sorting, and re-use. The technology involves  
31 implementing waste-disposal measures and monitoring them. Make sure that those people and  
32 organizations who do not wear them receive punishment. The evidence gathered is of importance  
33 to the enforcement agencies. Breakers of the rule are tried based on convincing evidence. The  
34 cases deter recidivism and make a person feel punished.

35 Compared to the previous forms of surveillance, technology has increased the fabric of  
36 surveillance. These advances have been pioneered by machine learning, which identifies patterns.  
37 Machine learning on big data can be used to combat common malpractices, such as unlawful  
38 dumping. The data will allow the agencies to avoid the escalation of violations and to identify  
39 areas that require greater attention.

40 Management of waste begins with waste generation. This is done during the supply chain tracking.  
41 Governmental organizations could ensure a seamless chain of accountability by accounting for  
42 waste generation and disposal. Supervision helps prevent unlawful distortions, uphold good  
43 behavior, and punish offenders.

44 Excessive use of plastics impacts waste management. The systems track a business's use of excess  
45 plastics and prompt it to use more sustainable materials. Messages and live reporting are very  
46 crucial in the modern globalized world. Such systems are considered automatic warnings about  
47 threats to garbage, violations, or emergency zones.

48 Lastly, people should be involved in complete waste control. Published channels enable  
49 individuals to communicate their concerns and misconduct, and to provide feedback on waste.  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 These platforms make accountability and participation easier, and waste management is a local  
5 problem.

6 Interrelationships enable feedback, which is a way to achieve continuous improvement. It transfers  
7 its experience in the earlier processes to new strategies and approaches. This renders its waste  
8 management reactive and adaptive.

9  
10 Without the project's facilitation, the community cannot sustain any waste management project.  
11 This layer puts waste initiatives and community stakeholders in a better position to establish a  
12 mutually beneficial relationship. The proposal to involve the masses is not only about  
13 disseminating information where it will be read, but also about holding people accountable to one  
14 another. Waste-reduction campaigns are more effective when the community is informed,  
15 engaged, and interested. The reason is that everyone is more committed and responsible.  
16  
17  
18

## 19 **7.0 Conclusions and future research directions**

20

21 This study presents the quantification of plastic pollution using a damage cost analysis and the  
22 contingent valuation method to estimate damage costs across territorial sectors. The findings  
23 indicate that the economic impact of plastic pollution in Oman is substantial, with an estimated  
24 overall damage cost of 2.69M\$ in 2022. This shows that plastic pollution is not only an  
25 environmental issue but also an economic one, supporting claims in the environmental accounting  
26 literature that mainstream economic systems are poor at accounting for environmental  
27 externalities. The impacts of plastic pollution on land and terrestrial environments are very high;  
28 this is why they account for a larger share of overall damage costs. There is an implication that  
29 land leakage is the main channel through which plastic pollution causes economic and  
30 environmental expenses in Oman. This has been observed in previous studies, which have  
31 identified land mismanagement in plastic waste management as the major contributor to pollution  
32 in freshwater and marine environments (Mihai and Pop, 2025). The vulnerability of Oman's  
33 delicate freshwater resources to plastic pollution is also demonstrated by the high cost of damage  
34 when they are contaminated. Economic damages from sea are not as significant as those on land.  
35 Given that Oman has a long coastline and depends on marine resources, these results indirectly  
36 show the long-run economic losses that plastic pollution could have on biodiversity and economic  
37 diversification. Their consideration is less beneficial to the economy, which is why they are fewer  
38 in the results; however, its substance that human exposure to atmospheric pollutants and  
39 microplastics can have considerable consequences for human health. The results of the scenario  
40 and sensitivity analysis provide strong evidence of the economic feasibility of the highly rigid  
41 policies on plastic management. According to the outputs, in a very strict case where plastic  
42 leakage rates are reduced to 2.3% of the existing platform's 5.6%, the cumulative damage cost may  
43 decrease by almost 60% by 2050 with high stringent policies. It means that policy measures can  
44 have a significant economic and environmental impact by prioritizing reducing plastic leakage and  
45 maximizing recycling rates. According to damage cost analysis, the findings highlight the  
46 significance of external cost measures in the process of making economic decisions. Besides that,  
47 the sensitivity of total damage costs to the cost assumptions of waste management is also a factor  
48 that underscores the significance of the efficiency of resource allocation across alternative waste  
49 treatment options. For example, investments in modern recycling plants and collection systems  
50 may not be economically justified in the short term, but they may appear economically justified  
51 when the environmental benefits they prevent are considered. These results also align with the  
52 concept of green and environmental management accounting, which promotes the internalization  
53 of environmental costs to encourage more sustainable production and consumption patterns  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 (Safkaur et al., 2025). The research suggests that damage cost analysis is an effective tool for  
5 influencing national strategies for managing plastics in Gulf countries and around the world. This  
6 research can inform policymakers, regulators, and businesses in implementing stronger regulations  
7 on the use of plastics, advancing the circular economy, and supporting sustainability-oriented  
8 investments by quantifying the costs of plastic-related damage at the territorial scale. Moreover,  
9 the plastic waste management system proposed in this study aims to reduce plastic pollution.  
10  
11

### 12 **7.1 Summary findings as a damage cost analysis of plastic waste**

14 From the above, the following summarized research contributions can be arrived at

- 15 ○ Total damage cost as a metric: The total damage cost amounted to \$2.69M in 2022,  
16 reducing to \$1.10M under 2050 high-stringency, showing enormous cost savings.
- 17 ○ Plastic leakage and economic loss: Reduction of plastic leakage from 34,988 t/y to 14,370  
18 t/y under 2050 high-stringency, correlates with almost 60% decrease in total damage costs.
- 19 ○ Dominated impacts: Leakage to land contributes \$1.14M to \$0.47M highlight terrestrial  
20 importance regarding economic and ecological burden.
- 21 ○ Substantial impacts: Wadi/freshwater leakage accounts for \$0.87M to \$0.36M,  
22 highlighting substantial interventions on economic and ecological burden.
- 23 ○ Average impacts: Coastal/Marine leakage accounts for \$0.66M to \$0.27M, highlighting  
24 average interventions on economic and ecological burden.
- 25 ○ Least impacts: Though smaller, Atmospheric/Human exposure leakage accounts for  
26 \$0.023M to \$0.009M, highlighting the least interventions on economic and ecological  
27 burden.
- 28 ○ The marginal damage of plastic leakage into the environment is  $\approx 76.8$  \$/ton.
- 29 ○ Efficiency of high-stringency policies: Plastic leakage to the environment and its reduction  
30 rate from 5.6% to 2.3% confirms economic rationale and leads to stringent plastic  
31 management policies.  
32  
33  
34  
35

36 There are weaknesses in this study. To begin with, it relies on secondary data and on cost-of-  
37 damage estimates derived from the available literature, given the lack of country-specific valuation  
38 data. This means that global averages and proxies might have been used in certain cases and,  
39 therefore, do not fully reflect the reality of the local environment and socio-economic conditions.  
40 Second, the damage cost analysis is premised on assumptions, and this can underestimate the  
41 effects on ecosystems, sustainability, and social well-being.  
42  
43

44 The study has significant implications for policymakers, regulators, the business community, and  
45 environmental managers. From a policy perspective, the costs of damage in this case are estimated,  
46 and this study provides a robust economic justification for strengthening policies on plastic waste,  
47 developing a state-of-the-art waste management framework, and encouraging recycling and a  
48 circular economy. The results of the current research indicate that the beneficial impact of  
49 preventive measures would be long-term, encompassing economic, environmental, and human  
50 health protection. From the perspective of the government and local authorities, the results of this  
51 research indicate that the government should prioritize establishing land-based waste management  
52 plants, as land-based leakage is the most harmful environmental source. Actions addressing  
53 freshwater and wadi systems are also required, as these systems are of high economic importance.  
54 For coastal management and tourism authorities, marine plastic pollution must be minimized to  
55 preserve biodiversity and maintain economic returns from tourism. Business and economic  
56 viewpoint: This study ascertains the relevance of environmental and sustainability accounting to  
57 decision-making. Economic analysis: Environmental externalities can inform businesses' more  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 appropriate decisions regarding packaging materials, waste disposal, and compliance with new  
5 environmental regulations. Theoretically, the study will provide new insights into the principles of  
6 contingent evaluation for the management of plastic waste based on the cost of damage.

7 The primary data, localized damage cost coefficients, and sector-specific valuation methods can  
8 be used to address future constraints. It would also be a good idea to analyze changes in plastic  
9 leaks and damage, and the policy's long-term success. Additional studies may also aim to expand  
10 the given framework to incorporate the principles of firm-level environmental accounting,  
11 behavioral responses to policy regulations, and the impact of technological innovation on waste  
12 treatment. One of the most important fields to study in the future is the implementation of the  
13 proposed plastic waste framework.  
14  
15  
16

## 17 **References**

- 18  
19 Abahussain, A. A., Nasr, F. A., bin Jumah, A., Saravanan, P., Kumar, N. S., Al-Zharani, M., ... &  
20 Tamizhdurai, P. (2025). Toxic threats from plastic waste: human health impacts,  
21 challenges, and policy solutions. *RSC advances*, *15*(48), 40761-40788.  
22  
23 Abbasi, T., & Abbasi, S. A. (2012). Is the use of renewable energy sources an answer to the  
24 problems of global warming and pollution? *Critical Reviews in Environmental Science and*  
25 *Technology*, *42*(2), 99-154.  
26  
27 Abraham, K. G., & Mackie, C. (2005). Panel to Study the Design of Nonmarket Accounts,  
28 National Research Council, Beyond the Market: Designing Nonmarket Accounts for the  
29 United States.  
30  
31 Agustia, D., Sawarjuwono, T., & Dianawati, W. (2019). The mediating effect of environmental  
32 management accounting on green innovation: firm value relationship. *International*  
33 *Journal of Energy Economics and Policy*, *9*(2), 299-306.  
34  
35 Al-Mutairi, K. A. (2025). Anthropocene Imprints on the Persian Gulf (arabian Gulf): a  
36 Comprehensive Review of Pollution and Conservation Challenges. *Applied Ecology and*  
37 *Environmental Research*, *23*(5), 9167-9196.  
38  
39 Al-Tarshi, M., Dobretsov, S., & Gallardo, W. (2024). Marine litter and microplastic pollution in  
40 mangrove sediments in the Sea of Oman. *Marine Pollution Bulletin*, *201*, 116132.  
41  
42 Atkinson, G. (2018). Cost-benefit Analysis and the environment: further developments and policy  
43 use. (*No Title*).  
44  
45 De Haan, M. and Keuning, S.J. (1996). Taking the environment into account: the NAMEA  
46 approach”, *Review of income and wealth*, Vol. 42 No. 2, pp. 131-148.  
47  
48 Eskander, S. M., & Fankhauser, S. (2020). Reduction in greenhouse gas emissions from national  
49 climate legislation. *Nature Climate Change*, *10*(8), 750-756.  
50  
51 Gerbersdorf, S. U., Hollert, H., Brinkmann, M., Wieprecht, S., Schüttrumpf, H., & Manz, W.  
52 (2011). Anthropogenic pollutants affect ecosystem services of freshwater sediments: the  
53 need for a “triad plus x” approach. *Journal of Soils and Sediments*, *11*, 1099-1114.  
54  
55 Ghayebzadeh, M., Taghipour, H., & Aslani, H. (2020). Estimation of plastic waste inputs from  
56 land into the Persian Gulf and the Gulf of Oman: An environmental disaster, scientific and  
57 social concerns. *Science of the Total Environment*, *733*, 138942.  
58  
59 Govind, A., & Nishitha, K. (2023). Plastic and its side Effects on Humans—A review article. *Asian*  
60 *Pacific Journal of Environment and Cancer*, *6*(1), 81-85.  
61  
62 Gray, W. B. (2015). Environmental regulations and business decisions. *IZA World of Labor*.  
63  
64 Hanemann, W. M. (1994). Valuing the environment through contingent valuation. *Journal of*  
65 *economic perspectives*, *8*(4), 19-43.

- 1  
2  
3  
4 Hassan, S. T., Wang, P., Khan, I., & Zhu, B. (2023). The impact of economic complexity,  
5 technology advancements, and nuclear energy consumption on the ecological footprint of  
6 the USA: Towards circular economy initiatives. *Gondwana Research*, *113*, 237-246.
- 7 Hecht, J. E. (1999). Environmental accounting. *Where we are now, where we are heading.*  
8 *Resources*, *135*, 14-17.
- 9  
10 Holzbecher, E., Ajaj, Y., & Martins, J. (2025). Plastic Pollution in Wadis: Investigation at a  
11 Hotspot in Wadi Hoqain, Oman. *The Open Environmental Research Journal*, *18*(1).
- 12 Index, E. S. (2005). Benchmarking national environmental stewardship. *Yale Center for*  
13 *Environmental Law and Policy*, *Yale University*.
- 14  
15 Islam, F. S. (2025). The Impact of Plastic Waste on Ecosystems and Human Health and Strategies  
16 for Managing It for A Sustainable Environment. *International Journal of Latest*  
17 *Technology in Engineering, Management & Applied Science*, *14*(3), 706-723.
- 18  
19 Jones, H., & Pathak, P. (2025). Plastic Utilization in the Modern Era: The Twenty-First Century.  
20 In *Plastic Footprint: Global Issues, Impacts and Solutions* (pp. 1-14). Singapore: Springer  
21 Nature Singapore.
- 22  
23 Jones, N., (2023). *Microplastics Are Filling the Skies. Will They Affect the Climate?* Yale  
24 Environment 360. Available at: [https://e360.yale.edu/features/plastic-waste-atmosphere-](https://e360.yale.edu/features/plastic-waste-atmosphere-climate-weather?utm)  
25 [climate-weather?utm](https://e360.yale.edu/features/plastic-waste-atmosphere-climate-weather?utm) (Accessed 11 January 2026).
- 26  
27 Karuppiah, K., Sankaranarayanan, B., & Ali, S. M. (2022). Evaluation of suppliers in the tannery  
28 industry based on energy accounting analysis: Implications for resource conservation in  
29 emerging economies. *International Journal of Sustainable Engineering*, *15*(1), 1-14.
- 30  
31 Kelsall, C. A. (2020). Ecological Management Accounting—Taking into Account Sustainability,  
32 Does Accounting Have Far to Travel?. *Sustainability*, *12*(21), 8854.
- 33  
34 Koohestani, K., Allahdadi, M. N., & Chaichitehrani, N. (2021). Oceanic Response to Tropical  
35 Cyclone Gonu (2007) in the Gulf of Oman and the Northern Arabian Sea: Estimating  
36 Depth of the Mixed Layer Using Satellite SST and Climatological Data. *Journal of Marine*  
*Science and Engineering*, *9*(11), 1244.
- 37  
38 Li, J., & Wang, X. (2025). Towards high-quality development: The complex role of environmental  
39 regulation. *PloS one*, *20*(2), e0312816.
- 40  
41 Maheshwari, A. K., & Banerjee, S. (2025). Consciousness and AI for Sustainable Development:  
42 A Case Study of Plastics. In *AI and Consciousness in Organizations and Society: A*  
*Diversity of Perspectives* (pp. 181-203). Cham: Springer Nature Switzerland.
- 43  
44 Marks, D., Miller, M. A., & Vassanadumrongdee, S. (2020). The geopolitical economy of  
45 Thailand's marine plastic pollution crisis. *Asia Pacific Viewpoint*, *61*(2), 266-282.
- 46  
47 Meijer, L. J., Van Emmerik, T., Van Der Ent, R., Schmidt, C., & Lebreton, L. (2021). More than  
48 1000 rivers account for 80% of global riverine plastic emissions into the Ocean. *Science*  
*Advances*, *7*(18), eaaz5803.
- 49  
50 Mihai, F. C., & Pop, V. (2025). Policy Implementation and Management of Microplastics  
51 in. *Handbook of Microplastic Pollution in the Environment: Monitoring and Treatment of*  
*Microplastics and Policy Perspectives*, 367.
- 52  
53 Moosa, I. A., & Ramiah, V. (2014). *The costs and benefits of environmental regulation*. Edward  
54 Elgar Publishing.
- 55  
56 Muller, N., Mendelsohn, R., & Nordhaus, W. (2009). Environmental accounting for pollution:  
57 Methods with an application to the United States economy. *Unpublished manuscript*.  
58 Retrieved from [http://nordhaus.econ.yale.edu/documents/Env\\_Accounts\\_052609.pdf](http://nordhaus.econ.yale.edu/documents/Env_Accounts_052609.pdf).
- 59  
60  
61  
62  
63  
64  
65

- 1  
2  
3  
4 Muller, N.Z., Mendelsohn, R. and Nordhaus, W. (2011). Environmental accounting for pollution  
5 in the United States economy”, *American Economic Review*, Vol. 101 No. 5, pp.1649-75.  
6 Muralikrishna, I. V., & Manickam, V. (2017). Environmental accounting. *Environmental*  
7 *management: Science and engineering for industry*, 113-134.  
8  
9 Nguyen, T. L. T., Laratte, B., Guillaume, B., & Hua, A. (2016). Quantifying environmental  
10 externalities with a view to internalizing them in the price of products, using different  
11 monetization models. *Resources, Conservation and Recycling*, 109, 13-23.  
12  
13 Nordhaus, W. D., & Tobin, J. (1972). Is economic growth obsolete?. In *Economic Growth (Fiftieth*  
14 *Anniversary Colloquium, V, National Bureau of Economic Research, New York, 1972)*.  
15  
16 Nzama, S., Olarewaju, O. M., Arise, O. A., & Ganiyu, I. (2022). Environmental Management  
17 Accounting (EMA) practices and plastic pollution control in selected food and beverage  
18 firms. *Cogent Business & Management*, 9(1), 2085368.  
19  
20 OECD (2022) *Global Plastics Outlook: Policy Scenarios to 2060*. OECD Publishing, Paris.  
21 Availableat:[https://www.oecd.org/content/dam/oecd/en/publications/reports/2022/06/global-plastics-outlook\\_f065ef59/aa1edf33-en.pdf](https://www.oecd.org/content/dam/oecd/en/publications/reports/2022/06/global-plastics-outlook_f065ef59/aa1edf33-en.pdf) (Accessed 11 January 2026)  
22  
23 OECD (2025) *Regional Plastics Outlook for Southeast and East Asia*. OECD Publishing, Paris.  
24 Availableat:[https://www.oecd.org/content/dam/oecd/en/publications/reports/2025/07/regional-plastics-outlook-for-southeast-and-east-asia\\_2e7d80a6/5a8ff43c-en.pdf](https://www.oecd.org/content/dam/oecd/en/publications/reports/2025/07/regional-plastics-outlook-for-southeast-and-east-asia_2e7d80a6/5a8ff43c-en.pdf) (Accessed  
25 11 January 2026).  
26  
27 Organisation for Economic Co-operation and Development (OECD). (2025). *Regional Plastics*  
28 *Outlook for Southeast and East Asia: Policy scenarios to halt plastic leakage to the*  
29 *environment* (Table 1.2). OECD ENV-Linkages model. Retrieved from  
30 [https://www.oecd.org/content/dam/oecd/en/publications/reports/2025/07/regional-](https://www.oecd.org/content/dam/oecd/en/publications/reports/2025/07/regional-plastics-outlook-for-southeast-and-east-asia_2e7d80a6/5a8ff43c-en.pdf)  
31 [plastics-outlook-for-southeast-and-east-asia\\_2e7d80a6/5a8ff43c-en.pdf](https://www.oecd.org/content/dam/oecd/en/publications/reports/2025/07/regional-plastics-outlook-for-southeast-and-east-asia_2e7d80a6/5a8ff43c-en.pdf)(Accessed 11  
32 January 2026).  
33  
34  
35 Ourworldindata , *Share of global mismanaged plastic waste*. (2013). Our World in Data.  
36 [https://ourworldindata.org/grapher/share-of-global-mismanaged-plastic-](https://ourworldindata.org/grapher/share-of-global-mismanaged-plastic-waste?tab=chart@ion=Asia&country=~OMN)  
37 [waste?tab=chart@ion=Asia&country=~OMN](https://ourworldindata.org/grapher/share-of-global-mismanaged-plastic-waste?tab=chart@ion=Asia&country=~OMN)  
38  
39 Pfaff-Simoneit, W. (2013), Entwicklung eines sektoralen Ansatzes zum Aufbau von nachhaltigen  
40 Abfallwirtschaftssystemen in Entwicklungsländern vor dem Hintergrund von Klimawandel  
41 und Ressourcenverknappung [In German]., Universität Rostock, Darmstadt/  
42 Rostock,[http://rosdok.uni-rostock.de/file/rosdok\\_disshab\\_0000000936/rosdok\\_derivate\\_0](http://rosdok.uni-rostock.de/file/rosdok_disshab_0000000936/rosdok_derivate_000005003/Dissertation_Pfaff-Simoneit_2013.pdf)  
43 [000005003/Dissertation\\_Pfaff-Simoneit\\_2013.pdf](http://rosdok.uni-rostock.de/file/rosdok_disshab_0000000936/rosdok_derivate_000005003/Dissertation_Pfaff-Simoneit_2013.pdf)(Accessed 11 January 2026).  
44  
45 Prata, J. C., Silva, A. L. P., Da Costa, J. P., Mouneyrac, C., Walker, T. R., Duarte, A. C., & Rocha-  
46 Santos, T. (2019). Solutions and integrated strategies for the control and mitigation of  
47 plastic and microplastic pollution. *International journal of environmental research and*  
48 *public health*, 16(13), 2411.  
49  
50 Ritchie, H. (2023, November 10). *Plastic pollution*. Our World in  
51 Data. <https://ourworldindata.org/plastic-pollution#research-writing>  
52  
53 Rounaghi, M.M. (2019). Economic Analysis of using green accounting and environmental  
54 accounting to identify environmental costs and sustainability indicators, *International*  
55 *Journal of Ethics and Systems*, Vol. 35 No. 4, pp. 504-512.  
56  
57 Safkaur, O., Pangayow, B., Hutajulu, H., & Hanasbe, L. (2025). The role of digital green  
58 accounting and environment performance on forest sustainable development goals: a case  
59 study on customary forest in Papua. *International Journal of Data and Network*  
60 *Science*, 9(3), 677-688.  
61  
62  
63  
64  
65

- 1  
2  
3  
4 Sapovadia, V. K. (2017). Importance of Aligning IFRS with SDGs. Available at SSRN 3042562.
- 5 Saputra, K. A. K., Manurung, D. T., Rachmawati, L., Siskawati, E., & Genta, F. K. (2021).  
6 Combining the concept of green accounting with the regulation of prohibition of disposable  
7 plastic use. *International Journal of Energy Economics and Policy*, 11(4), 84-90.
- 8  
9 Schaltegger, S., & Burritt, R. (2017). *Contemporary environmental accounting: issues, concepts and practice*. Routledge.
- 10  
11 Seetharaman, A., Ismail, M. and Saravanan, A.S. (2007), Environmental accounting as a tool for  
12 environmental management system, *Journal of Applied Sciences and Environmental*  
13 *Management*, Vol. 11 No. 2, pp. 137 - 145.
- 14  
15 Shan, C., & Ji, X. (2024). Environmental regulation and green technology innovation: an analysis  
16 of the government subsidy policy's role in driving corporate green  
17 transformation. *Industrial Engineering and Innovation Management*, 7(1), 39-46.
- 18  
19 Shen, N., Liao, H., Deng, R., & Wang, Q. (2019). Different types of environmental regulations  
20 and the heterogeneous influence on the environmental total factor productivity: empirical  
21 Analysis of China's industry. *Journal of Cleaner Production*, 211, 171-184.
- 22  
23 Smith, O., & Brisman, A. (2021). Plastic waste and the environmental crisis industry. *Critical*  
24 *Criminology*, 29, 289-309.
- 25  
26 Soós, R., A. Whiteman and G. Gavgas (2020), The cost of preventing ocean plastic pollution,  
27 OECD Environment Directorate, Working Party for Resource Productivity and Waste.
- 28  
29 Tekman, M. B., Walther, B., Peter, C., Gutow, L., & Bergmann, M. (2022). *Impacts of plastic*  
30 *pollution in the oceans on marine species, biodiversity and ecosystems*. WWF Germany.
- 31  
32 Thrift, E., Nouvellet, P., & Mathews, F. (2023). Plastic entanglement Poses a Potential Hazard to  
33 European Hedgehogs *Erinaceus europaeus* in Great Britain. *Animals*, 13(15), 2448.
- 34  
35 Umar, T. (2022). Greenhouse gas (GHG) emissions from municipal solid waste (MSW) in Oman.  
36 *International Journal of Social Ecology and Sustainable Development (IJSESD)*, 13(1), 1-  
37 26.
- 38  
39 UNEP and ISWA (2015), Global Waste Management Outlook, UN Environment Programme,  
40 <https://www.unep.org/resources/report/global-waste-management-outlook>. (Accessed 11  
41 January 2026).
- 42  
43 Vu-Quoc, L., Zhang, X. and Lesburg, L. (2000). A normal force-displacement model for  
44 contacting spheres accounting for plastic deformation: force-driven formulation, *J. Appl.*  
45 *Mech.*, Vol. 67 No. 2, pp. 363-371.
- 46  
47 WEDANTARA, I. B. R., DEWI, K. A. K., CONSTANTIA, P. S. D., & ARIAWAN, I. G. D.  
48 (2025). Analysis of the Impact of Plastic Pollution on Environmental Accounting and  
49 Implementation of Blue Economy in the Coastal Area of Serangan Beach, Bali. *Journal of*  
50 *Social Sciences and Cultural Study*, 2(3), 101-110.
- 51  
52 Welden, N. A. (2020). The environmental impacts of plastic pollution. In *Plastic Waste and*  
53 *Recycling* (pp. 195-222). Academic Press.
- 54  
55 WRAP (2021), Financial Cost of Packaging Litter – Phase 2 – Final Report, Prepared by Chiarina  
56 Darrah, Leyla Lugal, Paul Marsh, Kathryn Firth, Vera Lahme and Gemma Darwin.
- 57  
58 Yale Center for Environmental Law & Policy, *Environmental Performance Index /*  
59 *Environmental Performance Index*. (2022). [https://epi.yale.edu/epi-](https://epi.yale.edu/epi-results/2022/component/epi)  
60 [results/2022/component/epi](https://epi.yale.edu/epi-results/2022/component/epi)
- 61  
62 Zafar, S. (2018). *Solid waste management in Oman*. . EcoMENA. Available at:  
63 <https://www.ecomena.org/solid-waste-oman/> (Accessed 11 January 2026).  
64  
65

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

Zambrano-Monserrate, M. A., & Ruano, M. A. (2020). Estimating the damage cost of plastic waste in Galapagos Islands: A contingent valuation approach. *Marine Policy*, *117*, 103933.

Ziani, K., Ioniță-Mîndrican, C. B., Mititelu, M., Neacșu, S. M., Negrei, C., Moroșan, E., ... & Preda, O. T. (2023). Microplastics: a real global threat for environment and food safety: a state of the art review. *Nutrients*, *15*(3), 617.

### **Data Availability Statement**

The data that support the findings of this study are derived from publicly available secondary sources, which are cited within the manuscript. No new datasets were generated or analysed that contain personally identifiable information.