



Plastic Drawdown: A rapid assessment tool for developing national responses to plastic pollution when data availability is limited, as demonstrated in the Maldives

Jo Royle^{a,3}, Ben Jack^{a,3}, Hannah Parris^{a,3,1}, Tim Elliott^b, Arturo Castillo Castillo^c,
Shenali Kalawana^a, Hawwa Nashfa^{d,2}, Lucy C. Woodall^{e,f,3,*}

^a Common Seas, Bristol, United Kingdom

^b Eunomia Research & Consulting Ltd, Bristol, United Kingdom

^c Faculty of Natural Sciences, Centre for Environmental Policy, Imperial College, London, United Kingdom

^d Ministry of Environment, Government of Maldives, Maldives

^e Department of Zoology, University of Oxford, Oxford, United Kingdom

^f Nektan, Begbroke Science Park, United Kingdom

ARTICLE INFO

Keywords:

Marine plastic
Data-limited
Stakeholder engagement
Drawdown
Rapid assessment

ABSTRACT

Governments are increasingly supporting initiatives to address plastic pollution, but efforts are largely opportunistic or driven by national socio-political priorities. There is an urgent need to move away from piecemeal single product instruments (e.g. single use plastic bag taxes or plastic straw bans) to deliver system-wide strategies that minimise the most pervasive sources of plastic pollution. Developing a common understanding of a jurisdiction's plastic waste stream and the solutions available to decision-makers is vital to build consensus across stakeholders and to align on an evidence-based portfolio of priority instruments.

This paper presents the Plastic Drawdown framework as a boundary-spanning tool to quickly create a coherent, relevant, and credible analysis and visualisation for stakeholders of plastic waste, leakage hotspots and minimisation opportunities. Using a new plastic waste modelling framework with a consultative structure, Plastic Drawdown explores plastic waste and leakage over a ten-year period and assesses impacts of policy instruments on this projection. Plastic Drawdown is adaptable to the data poor environment typical of many countries and designed as a rapid assessment tool to support the decision making of governments operating in a highly resource-constrained context.

The Maldives is used as a case study to show the utility of the tool, where it highlighted strategies with the potential to reduce leakage of plastic waste into the marine environment by up to 85% by 2030. Plastic Drawdown built the case for phasing out single-use plastic waste across the Maldives and supported the Government's decision to set ambitious targets, as announced at the United Nations General Assembly in 2019.

1. Introduction

Over the last six decades plastic production has rapidly increased (Geyer et al., 2017). Plastic pollution in the ocean and wider environment, is now recognised as a global ecological, social and economic crisis (Law, 2017). This has prompted a global response that is reflected in the development of national and international targets (e.g. UNEA

Resolutions 3/6, 4/6 and 4/9).

The many diffuse sources of plastic pollution, and the diversity of impacts it has across its lifecycle – from production, to use and disposal – makes tackling plastic a complex societal challenge closely linked to many others e.g. climate change (Stoett and Vince, 2019; Ford et al., 2022) soil contamination (Bläsing and Amelung, 2018) and perturbations of aquatic environments (Horton et al., 2017). Effective responses

* Corresponding author at: 11a Mansfield Road, Oxford OX1 3SZ, United Kingdom.

E-mail address: lucy.woodall@zoo.ox.ac.uk (L.C. Woodall).

¹ Now at the Centre for Atmospheric Sciences, University of Cambridge, Cambridge, United Kingdom.

² Now at Common Seas, Bristol, United Kingdom.

³ All contributed equally to this paper.

<https://doi.org/10.1016/j.gloenvcha.2021.102442>

Received 2 July 2021; Received in revised form 26 October 2021; Accepted 3 December 2021

Available online 16 December 2021

0959-3780/© 2021 The Authors.

Published by Elsevier Ltd.

This is an open access article under the CC BY-NC-ND license

(<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

require decision makers to navigate multiple dimensions (e.g. political, economic and cultural) to develop a strategically aligned suite of system instruments (Karasik et al., 2020), which take into account the specific context and operate at multiple scales (Lau et al., 2020). Critical to this process is the production of credible baseline data to create useable knowledge to facilitate inclusive and equitable consultation and establish a common understanding of the challenges and opportunities across stakeholders.

Global analysis of plastic waste generation and leakage using ‘top down’ approaches conducted remotely by international institutes or agencies, have been instrumental in placing plastic pollution in the global consciousness, illustrating the scale of the challenge and building consensus that action is needed (e.g. Jambeck et al., 2015). Whilst governments’ responses to plastic waste and leakage minimisation have increased over the last five years (Xanthos and Walker, 2017; UNEP, 2018; Karasik et al., 2020), today’s commitments and actions are falling far short of the action required to reduce plastic leakage at a global level (Borrelle et al., 2020; Lau et al., 2020).

Global-scale analysis does not provide sufficient detail for decision-makers to enact effective policy instruments across smaller geographic scales (i.e. country-wide), particularly for countries where plastic production, consumption and waste data are limited. To provide information required for national or sub-national level decision making, detailed tools for assessing the sources and pathways of plastic leakage have been developed (World Bank, 2021). To-date these have provided useful detailed analyses for authorities in specific situations, however, many of these approaches are resource and time intensive, which can make them unsuitable in situations where budgets are limited and rapid action is required. In response, rapid assessment approaches for generating plastic waste and litter data have been developed (e.g. Boucher et al., 2020; Turrell, 2020), but have yet to incorporate analysis of the potential impact of policy instrument options, which is key for policy-makers and managers.

Our paper presents a rapid assessment approach to evaluate national plastic waste generation and pollution, and analyses the potential effectiveness of different policy instruments in reducing waste leakage into aquatic environments. It is designed to support evidence-based decision-making by national governments, and to be adaptable for use in geographies where data are limited.

Methods for creating useable and credible knowledge have long-been applied to a range of environmental problems (Clark et al., 2016a). In this study, we apply key insights from this literature to create a new plastic waste modelling framework, Plastic Drawdown (PD), to act as a ‘boundary spanning’ tool (Bednarek et al., 2018). PD brings together the best available information on plastic waste generation, and models waste flows to quantify the proportion that is captured by waste management infrastructure and what leaks into the aquatic environment. Then, drawing on insights from a global analysis of plastic policies, PD presents the potential reductions in plastic leakage that can be achieved by different policy instruments. Visualisations of all steps of this analysis are shared with government and stakeholder representatives to facilitate their understanding of the magnitude and type of plastic waste and leakage, and help them to identify and prioritise system-wide mitigating measures.

The PD approach tackles several existing challenges. First, it recognises the limited availability of reliable waste data in many geographies and the need to gather dispersed data and sources. Secondly, it provides quantitative analyses that are policy focused and time bound, producing clear expectations of instrument outcomes. Thirdly, PD delivers results as simple visual outputs, so that all actors can participate in meaningful discussions without requiring technical interpreters (Cash et al., 2003; Van Kerkhoff and Lebel, 2015). Collectively, these elements engender improved trust and legitimacy of the results to end users (Clark et al., 2016b), and as a result speed up implementation of context-specific policy instruments that are especially hard to develop for complex socio-ecological ‘wicked’ problems (Addison et al., 2013).

In this paper, with the objective of demonstrating the PD framework as a useful rapid assessment tool for developing a system wide policy response to plastic pollution in countries with limited available data, we first describe the PD framework, then demonstrate its value by using a case study of the Maldives, for which waste data are limited, but where Plastic Drawdown provided evidence to enable the Government to announce and implement an ambitious Plastic Phase Out Commitment (Hawwa, 2020).

2. Methods

2.1. Conceptual framework

As a boundary spanning tool, PD provides a comprehensive analysis of data on plastic waste flows and the effects of policy instruments to reduce leakage into aquatic environments. By consolidating the available evidence, it builds a common understanding of the problem across government and other stakeholders who hold key responsibilities across the plastic life cycle (the **Engagement Group**) and through culturally appropriate methods, most often consultative workshops, supports them to prioritise instruments with the best chance to successfully combat plastic pollution in their jurisdiction (Fig. 1). PD includes three analysis steps:

1. **Baseline Calculations** to describe the amount of plastic from different waste sources that leaks into aquatic environments, and what drives this leakage.
2. **Business as Usual (BaU)** projection of how the quantity and composition of plastic waste and leakage will evolve over the time horizon.
3. **Policy Analysis and Visualisation** of the instruments that could have the greatest potential impact on reducing plastic waste leakage, considering the plastic waste composition and leakage characteristics of the jurisdiction.

Jurisdiction specific data are gathered, collated and analysed in a step-wise manner in the PD model to create a jurisdiction-specific assessment of the current and projected plastic waste generation and leakage (analysis process steps 1 + 2), then combined with policy data to indicate which instruments could have most impact on reducing plastic waste leakage, as presented in BaU (step 3). Outputs of each step are presented as figures and are used during consensus building and policy planning with the Engagement Group. Then the Engagement Group uses the PD assessment to create scenarios reflecting national priorities, which are used as the basis for strategy development and the establishment of a national action plan.

2.2. Analysis process

The jurisdiction-specific PD assessment uses a system map (SM 1). The map is a template used in order to produce a repeatable and robust method to analyse the plastic waste flow, tracking it from **source nodes** (inputs) to **end nodes** (final destinations). The waste follows **flow pathways** through **intermediate nodes**, which represent the physical waste management infrastructure. Transmission factors represent the relative amount of plastic waste directed along each flow pathway and are specific to each case study (see 2.3.1). Together, these elements characterise the relationship between waste generation, the waste management infrastructure, and waste leakage into the aquatic environment.

Plastic flows are characterised by algorithms implemented in spreadsheet workbooks (SM 2) that follow the three analysis steps presented in Fig. 2 and the following section.

2.2.1. Step 1: Baseline calculations

PD analyses the simplified flow and leakage of different foci plastic

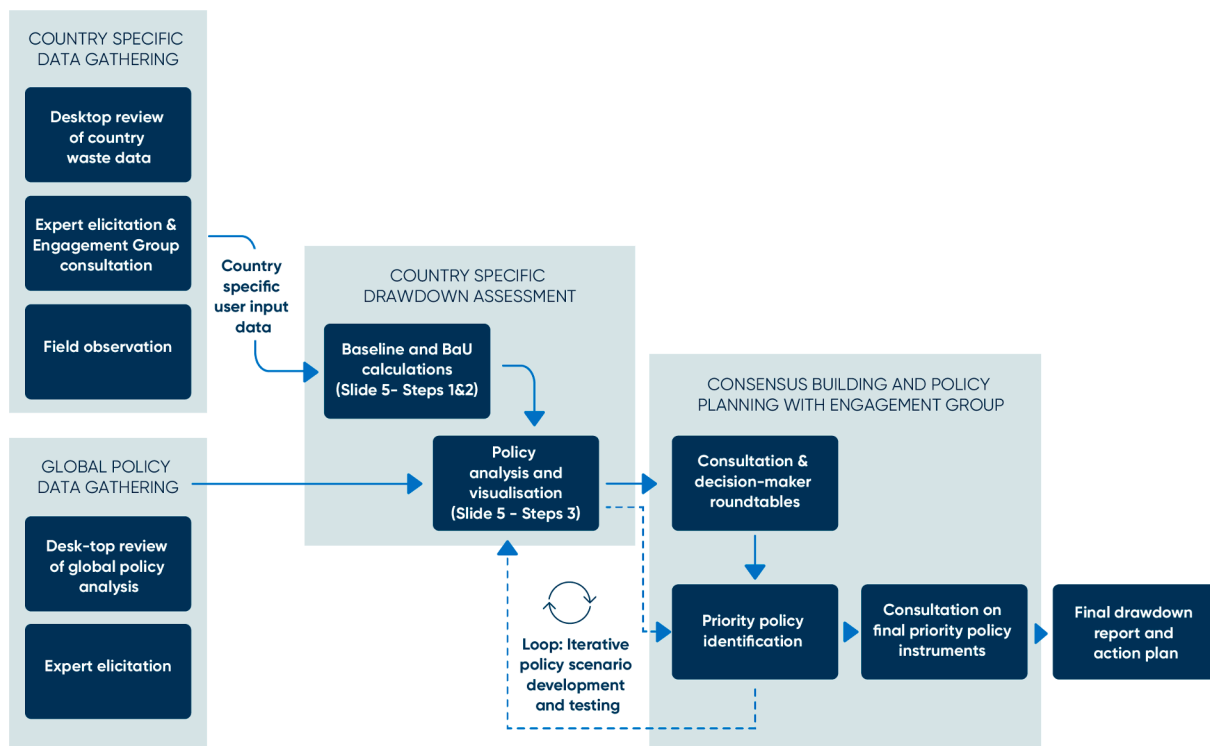


Fig. 1. Plastic Drawdown (PD) framework as a boundary spanning tool between plastic pollution knowledge and policy design.

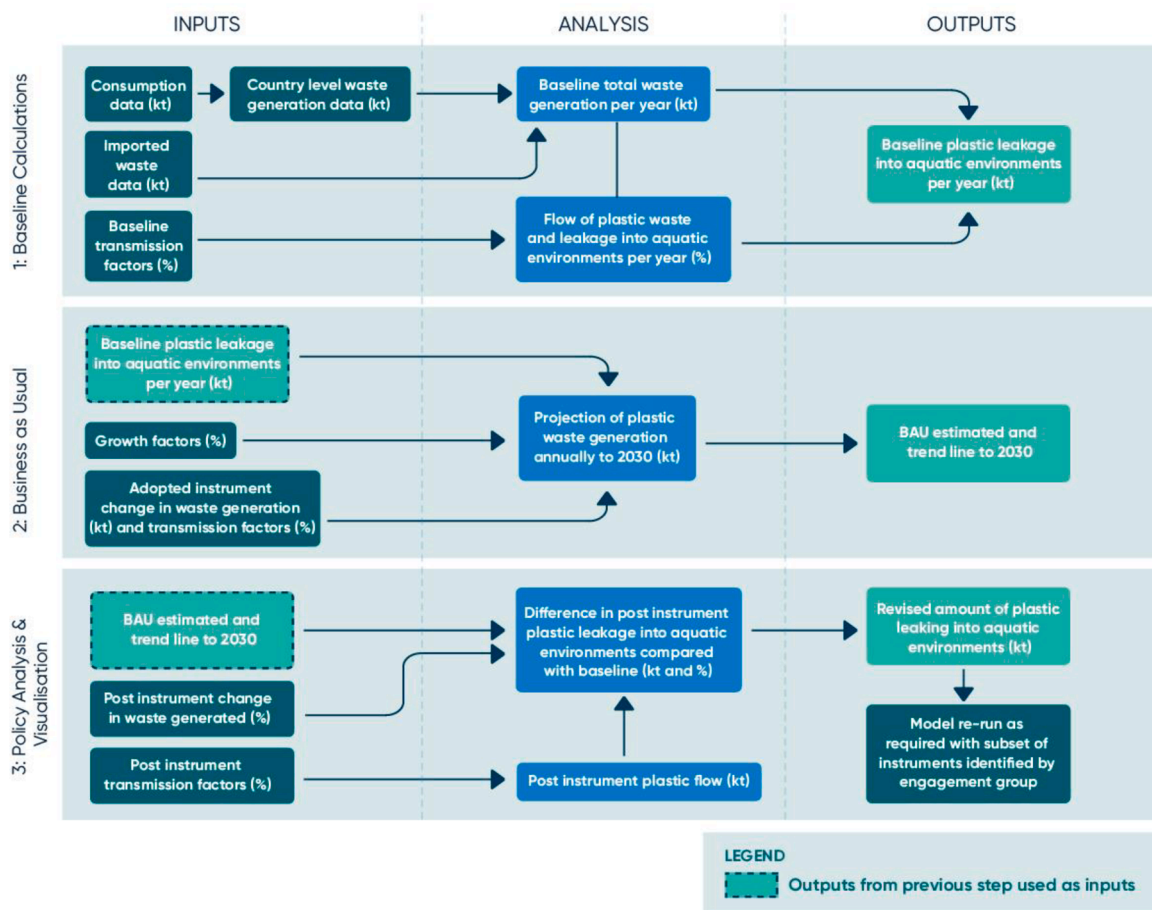


Fig. 2. Three steps of the Plastic Drawdown analysis 1: Baseline Calculations, 2: Business as Usual, 3: Policy Analysis and Visualisation. The dark green boxes show inputs, blue boxes show analysis and light green show outputs. The dashed border indicates how the outputs of one step become the inputs to the next.

items (SM 3) rather than polymers. This recognises that managing pollution often requires a focus on specific items, their value chains, and the human behaviours associated with use and disposal; and this is reflected in most policy responses across the world (Karasik et al., 2020).

PD combines national consumption and waste assessments with imported waste estimates to derive total plastic waste generated (2.3.1). Transmission factors are then applied to reflect contextual conditions (e.g. waste management infrastructure, policies and consumer behaviour) and direct waste along flow pathways into one of five end node categories (landfill, exported, incinerated, leakage into the terrestrial environment or leakage into the watercourse). The total amount and composition of plastic waste that leaks into the marine environment is the sum of all aquatic environment nodes.

2.2.2. Step 2: BaU projection

A projection of changes in leakage for the period to 2030 is made by applying socio-economic and demographic growth factors to baseline waste generation estimates for each plastic item (2.3.2). In addition, the impact of policy instruments already adopted and with an implementation timetable, are also incorporated into the business as usual (BAU) projection. The effect of policy instruments is calculated according to expected reductions in waste generated (e.g. in response to upstream instruments, such as item bans) or changes to the transmission factors for relevant plastic items (e.g. reflecting improved plastic waste management) (2.3.3).

2.2.3. Step 3: Policy analysis and visualisation

Firstly, PD estimates the impact of 18 waste and leakage reduction policy instruments that could all be implemented today by a national government (SM 4). These were identified through workshops with industry and academic representatives during the development of PD (Common Seas, 2019a). Instruments range from upstream measures to reduce plastic production and waste generation, to downstream measures to improve waste management systems and the capture of plastic litter before it reaches the marine environment. Policies focused on the recovery of plastic from the ocean are not included, to emphasise the need for preventing plastic reaching the ocean in the first place. Each policy instrument may target specific plastic items, or a range of items (SM 5). For example, a policy to introduce water refill schemes reduces the number of single use plastic (SUP) beverage bottles and caps, whereas a policy to increase provision of solid waste collection is applied to all macroplastic items within municipal solid waste. To indicate the potential effect that each instrument will have, each can be presented based on a 'pessimistic', 'central' or 'optimistic' assessment of situation. A set of key principles, drawn from a global literature, describe which instrument design parameters or enabling factors must be present to achieve the most optimistic effect. This supports the Engagement Group to consider the political, economic and socio-cultural capacity to implement policy within their jurisdiction.

Secondly, subsets of these policy instruments of interest to the Engagement Group are identified, adapted as needed to align with local priorities, and applied over different timeframes as specific test scenarios. The potential effectiveness of these instruments is modelled against the BAU in the same manner as calculated for adopted policy instruments (described in step 2). Any instruments applied within the same year are ordered to account for sequence-dependency effects. Policy instrument effects are visualised with the BAU by a stacked area graph (colloquially, 'wedge diagram'). This provides an effective illustration of the potential projected impact of individual, and combinations of policy instruments (scenarios).

2.3. Data inputs

Across all inputs, data were compiled according to a set of data collection principles. Data mining first prioritised time-relevant data for the focus plastic item, within the jurisdiction of interest and from a

reliable source. Where data were unavailable for a focus item, alternative items or groups of items were used, where the nature and behaviour related to leakage was similar. Where jurisdiction level data were unavailable, regional level data were apportioned to the jurisdiction level, or available data from an analogous jurisdiction (with similar geo-demographic characteristics and in the same World Bank income category) were used. Preference was given to the most recent data available, with data from the last 5–10 years also used where more recent information was unavailable.

Data from recognised sources and national databases were used when available. Where these data were not available, estimates from peer reviewed literature, media reports (referencing original sources) and waste and sanitation data from the countries in question were utilised. Where published data could not be found, field observations were made and the Engagement Group and other experts identified through stakeholder mapping (Expert Group) were consulted, to make assumptions based on their knowledge, e.g. of waste management and littering behaviours.

2.3.1. Step 1: Baseline calculations

A long list of focus macroplastic items was determined during the development of PD from beach litter reports (e.g. International Coastal Cleanup data) and consultation. From this, a short list of 23 items was created, which comprised ca.95% of all identifiable beach litter items (including single use food and beverage items, sanitary products, construction plastics and fishing gear). Secondly, microplastics for which sufficient data exist to estimate waste generation were also included (tyre and brake dust, clothing fibres, pellets, micro-beads). This resulted in 28 foci items (23 macroplastic and 5 microplastic) (SM 3).

To ensure the context of the study nation is captured, foci plastic items are checked against the local dominant litter items identified through desk-top research and early Engagement Group dialogues. PD also explicitly documents an 'other plastic' category, which is calculated by i) estimating the total plastic fraction in municipal solid waste, and ii) subtracting the total weight of the explicitly identified plastic items.

Waste generation data are gathered from diverse sources including published reports, market data, trade data, waste-management planning documents, local traders and Expert Group opinion. To allow comparability, when waste generation is provided as frequency data, they are converted into weight using standard values (SM 6).

Transmission factors, used to determine the waste throughput level at specific nodes, are established by either i) using existing studies and data of relevance to the transmission factors (e.g. waste-water treatment or solid waste management systems), ii) consulting the Expert Group using a semi-structured interview (SM 7), or iii) making field observations.

2.3.2. Step 2: BaU projection

Waste and subsequent leakage growth rates for each plastic item are projected forward from the baseline year using growth forecasts and backwards from regression of historic rates between 2010 and 2018.

2.3.3. Step 3: Policy analysis and visualisation

Waste generation inputs and transmission factors are amended for each item according to policy instruments applied within the PD model. For each policy, the timeframe and immediacy of effect can be adjusted by the Engagement Group, and changes can be based on either a 'pessimistic', 'central' or 'optimistic' assessment.

2.3.4. Data reliability

PD uses a systematic assessment (SM 8) of data reliability. This is documented with the data and permits users to track the state of knowledge, evaluate outputs and create priorities for future research. Each input is scored from 1 to 3 to reflect its (subjective) reliability. Quality level 1 refers to information from official and/or peer reviewed datasets specific to the jurisdiction and published within the previous

three years. It also includes evidence from technical specialists, managers or researchers operating within the jurisdiction with in-depth knowledge of the jurisdiction. Inputs with quality level 2 are data from older published sources and/or non-peer reviewed grey literature. They are also data apportioned from analogous jurisdiction data sets and/or evidence from members of the Engagement and Expert Groups. When local evidence does not exist, estimates and assumptions based on non-jurisdiction specific specialist opinion is used and considered quality level 3.

3. Case study: Maldives

3.1. Background

The PD framework was implemented in the Maldives in September 2019 by the invitation of Maldives' Government. Maldives is an upper-middle income nation in the Indian Ocean with a mixed economy dominated by tourism (24.5% of GDP) and fisheries (18%) (National Bureau of Statistics, 2020). It controls a large exclusive economic zone (923,000 km²) and comprises 347 inhabited islands of which 132 are resort-only islands.

With a small population (450,000 people), dispersed island geography and considerable distance from global recycling markets, effective waste management has been a challenge to the Maldives for several decades (Ministry of Environment, 2019). Waste management infrastructure centres around the non-engineered landfill located near the capital Malé on the island of Thilafushi. Waste is collected from Malé and resort islands and transferred by vessel to Thilafushi. Waste is also collected from some geographically central community islands, and while some of the organic waste is managed at the island level, many communities lack adequate infrastructure to store the remaining waste prior to transportation to Thilafushi, or lack resources to transport the waste to Thilafushi. This leads to extensive burning of waste on beachfronts and dumping on land, both activities result in leakage of waste into the marine environment (Ministry of Environment, 2019). Burning also occurs at Thilafushi to ensure sufficient landfill capacity (Asian Development Bank, 2018).

Plastic waste leakage into the marine environment, represents an important socio-economic burden (Rodríguez et al., 2020). It is a threat to Maldives as a high-end tourist destination with a perceived pristine environment and impacts fisheries through mechanisms such as propeller entanglement and damage to gear (Nash, 1992). Plastic waste therefore could impinge directly on GDP through tourism and fisheries.

3.2. Plastic Drawdown implementation

3.2.1. Step 1: Baseline calculations

A review of data completed prior to field work provided an initial picture of the use of foci plastic items in the economy and how they were managed at end of life, both within, and outside of, formal waste management systems. This was updated and supplemented with data collected from Maldives Customs (provided confidentially) and through meetings with the Engagement (SM 9) and Expert Groups. No alterations were needed to the list of foci plastic items.

The amount of waste of each type was estimated from customs import data and market research (SM 10). In two cases, where item counts were unavailable for the Maldives, figures were taken from data previously collected from Indonesia. The Indonesia dataset was considered appropriate to use as a proxy for the Maldives, as Indonesia is an island nation with similar income level (Asian Development Bank, 2020a), and within the same broad geographic region. Indonesian figures were apportioned according to the most recent purchasing power parity and population estimates for Maldives. Data provided as item counts were then converted into weights (SM 6). Transmission factors were estimated using data on waste infrastructure and systems (SM 11).

Maldivians categorise their country across three distinct

geographies: urban Maldives (mostly Greater Malé area), inhabited rural islands and island resorts (Ministry of Environment, 2019). To calculate waste generation levels for each of these three territory categories, the following proportions were applied to the estimated total of waste generation: urban areas (49%), resorts (20%) and rural islands (31%) (Ministry of Environment, 2019). Demographic, waste management and economic Maldives-specific data (SM 12) were used to inform growth rates of plastic waste item generation and leakage over the timeframe modelled.

3.2.2. Step 2: BaU projection

Waste generation growth rates (SM 13) used to construct the BAU trajectory were based on historical data and market forecasts. Where available, market forecasts for individual items were sourced from commercial providers of data. No plastic policy instruments had been adopted in the Maldives at the time of analysis, so none were incorporated in the BAU estimates.

3.2.3. Step 3: Policy analysis and visualisation

The potential for the 18 PD policy instruments to reduce plastic waste generation and leakage was calculated (Common Sea, 2019a). Graphical outputs from steps 1–3 (e.g. SM 14) were reviewed by the Engagement Group to identify priority policy instruments to target key polluting plastic items and leakage sources. Analysis revealed SUP bottles contributed the most to waste and leakage, and the Engagement Group identified this item type as a priority. As a consequence, a policy instrument to ban and/or tax SUP bottles within three use categories (water bottles, other beverage bottles, other SUP bottles, e.g. household cleaning products) was added to the PD analysis.

Five policy scenarios were developed, which cumulatively added different policy instruments (Table 1). Scenarios 1–4 focused on specific SUP products and scenario 5 incorporated SUP-focused instruments alongside improved collection, transportation, storage and final disposal of solid waste (SM 15).

Each policy instrument was modelled to start in 2021 and the timeframe for each policy to reach full effect was adjusted to reflect the financial and technical complexity of implementation. For example, implementing an SUP item ban or tax, is estimated to take two years to allow for appropriate public engagement and for the required legislation to be passed. By contrast, large scale infrastructure changes are predicted to take 10 years.

3.3. Results and discussion

3.3.1. Step 1: Baseline calculations






3.3.1.1. Waste generation. Projections from 2019 suggest Maldives would produce 22.1 kt of plastic waste in 2020, which is 7.5% of total municipal solid waste. Of this, approximately 8.8 kt is identifiable as the foci plastic items and the rest, 13.3 kt tonnes of plastics (60%), is identified as 'other plastic'. The large relative proportion of this category highlights the value of research to further disaggregate the fraction.

The relative proportion of plastic waste in the Maldives is congruent with that of analogous countries such as Sri Lanka (5.9%) and Fiji (7.9%) (Lebreton and Andradý, 2019). The proportion of 'other plastic' in the waste stream is relatively large. This is in part because the foci items within PD do not account for all types of plastic that contribute to plastic waste, and due to the inherent limitations within the available waste data used to calculate total and item-specific plastic waste generation. Although the exact composition of 'other plastic' waste is unknown, this category includes industrial plastic waste, business to business waste, as well as household waste items (e.g. toys, appliances and textiles).

The largest individual category of foci items is SUP beverage bottles (21% of all plastic). Expert judgement indicated that these bottles primarily contained water. Bottled water is common across all Maldives

Table 1

List of policy scenarios identified by stakeholder and government representatives during the consultative process, and their associated mapped policy instruments within Plastic Drawdown. SUP = single use plastic.

Scenario Number	Policy Scenario	Policy Instruments				
		Phase out of SUP bottles	Taxes on specified items	Item bans	Increase provision of solid waste collection	Improve storage and management of waste
1	Reduction of SUP water bottles 	X				
2	Reduction of SUP beverage bottles 	X				
3	Reduction of all SUP bottles 	X				
4	Reduction of all SUP bottles and taxes or ban on SUP items for which there are alternatives 	X	X	X		
5	Reduction of all SUP bottles, bans and taxes on other SUP items and improved waste collection, transport and storage 	X	X	X	X	X

reflecting a preference for the taste of bottled water over tap and the reliance on bottled water by those who have limited access to potable water. The proportion of SUP bottles within total plastic waste generated is much higher than the global average of 6% (Lau et al., 2020) but is similar to the analogous nation of Indonesia (20%, Common Seas, 2019b). Other identifiable SUP items include diapers (4%), grocery bags (4%), other types of plastic bottles (e.g. cleaning products) (3%) and food wrappers (2%).

While the overall contribution made by the Maldives to the global plastic waste crisis is relatively small, per capita the amount is substantially higher than the European Union (0.03 kg person⁻¹ day⁻¹). Urban areas, rural areas and resort islands contributed 10.8 kt, 6.8 kt and 4.4 kt to total plastic waste generation respectively. Although in absolute terms the resort islands contribute less plastic waste than urban and rural areas, resort islands generate almost twice as much plastic waste per capita compared to Maldivians (tourists 0.50 kg person⁻¹ day⁻¹ and Maldivian residents 0.26 kg person⁻¹ day⁻¹).

3.3.1.2. Leakage. Approximately 1.6 kt of plastic waste (7% of the total plastic waste generated) is estimated to enter the marine environment from the Maldives in 2020. The national landfill site Thilafushi is the major leakage source, comprising approximately 62% of all plastic escapes within the country. This is primarily due to relatively poor waste retention at the landfill site. This is a well-known problem and there are currently active projects to improve management and end open burning at Thilafushi (Ministry of Environment and Energy, 2018).

Dialogue with island community leaders and resort operators reported a practice of (illegal) waste dumping at sea from vessels that transport waste from rural and resort islands to Thilafushi. Further research is required into this practice and its contribution to overall plastic leakage, but conservative estimates from PD analysis suggest that it contributes up to 21% of the national leakage total.

Analysis of the baseline results showed that, of the total plastic waste entering the aquatic environment, 12% originated from land based littering. This comprises plastic waste that is dumped because there are no

formal management options, and littered waste. This is particularly significant on rural islands where there are limited formal waste management facilities.

Notably, the relative contribution of SUP beverage bottles to the total amount of plastic entering the marine environment increases from 28% at baseline to 33% by 2030, suggesting that action on these items could result in an important decrease of plastic waste entering the marine environment.

3.3.2. Step 2: BAU projection

Total annual plastic waste generation in the Maldives under a BAU scenario is projected to increase approximately 39%, from 22.1 kt to 30.7 kt between 2020 and 2030. In line with the increase of waste, PD analysis suggests that an additional 22 kt of plastic will leak into the marine environment from the Maldives over this ten-year period in the absence of any policy instruments. Analysis also reveals that the top six polluting plastic items will remain the same between 2020 and 2030 (although the exact order differs between years), highlighting the long-term relevance and likely effectiveness of instruments that have direct consequences on these items.

The analysis assumes that the proportion of plastic waste sent to, and remaining in, landfill (93% of collected waste, with 7% assumed to leak into the environment) remains constant throughout the 10 years to 2030. Under this premise, PD estimates that approximately 8.3 kt of additional landfill capacity is needed for plastic alone, in order to manage the waste entering landfill for the period 2020–2030. This is an increment of almost 40% over 10 years. If this additional landfill capacity is not developed, then plastic leakage rates are likely to grow and/or levels of informal burning and associated CO₂ and other toxic emissions would increase. Maldives is a highly land-constrained environment therefore providing additional landfill capacity is not straight-forward and not a long-term and sustainable solution for waste (Tammemagi, 2000). Instead, waste-to-energy facilities are being proposed by the Maldives government, and one is under development (Asian Development Bank, 2020b).

3.3.3. Step 3: Policy analysis and visualisation

Using the five different policy scenarios (Table 1), identified by the local Maldivian Engagement Group, PD estimated that approximately 13.5 kt of plastic waste leakage could be prevented over the 10-year period 2020–30. This would reduce leakage into the marine environment to approximately 0.4 kt per year in 2030 (Fig. 3), a 61% reduction in leakage compared to the BAU projections. Potential reductions increase over time; with 51% less plastic leakage by 2022 and 85% by 2030, these figures broadly align with global analysis of plastic waste leakage (Lau et al., 2020). PD analysis suggests that substantial reductions in plastic leakage in the Maldives can be achieved through a relatively small number of carefully selected policies, thereby focusing limited resources and attention where it can be most effective.

The relative contribution of each policy instrument to plastic pollution reduction changes across the timeframe of the analysis (Fig. 4). Overall, the policies that contribute most to reducing plastic leakage are initiatives that address the use and disposal of all types of SUP bottles (scenario 3). This scenario reduces plastic leakage by 6.9 kt from the 2020–2030 BAU trajectory, and would achieve 51% of the total amount of potential leakage reductions possible. The largest effect is likely within 3–4 years. Improved waste management could, by 2030, provide a similar contribution to all plastic leakage reduction (~5 kt over 10 years) but most of this takes place at the end of the period because of the time required to finance and implement new infrastructure. Therefore, this combination of policy instruments has the potential for greater impact past 2030.

The priority policy instruments identified by the Engagement Group do not target fishing gear or microplastics which are on the list of foci items. Although these pollutants contribute a relatively small proportion of plastic waste leakage, they do present specific challenges. Fishing gear pollution is highly impactful on marine life, with ghost fishing effects being widely documented (Gilman et al., 2016). Due to their size, microplastics are considered to pose different threats to those of macroplastic items (Bucci et al., 2020). To reduce both microplastic and fishing gear environmental leakage, specific policy instruments are required (Eriksen et al., 2018).

3.3.4. Impact of PD in the Maldives

PD provided evidence and a framework for Maldives government decision-makers to act. The outcomes of PD analysis and Engagement Group consultation were presented as a confidential white paper ‘Maldives plastic phase-out strategy’ to the Government. A target to phase-out single-use plastic by 2023, was announced at United Nations General Assembly by the Maldives President in 2019 and this was

directly informed by the evidence generated, policy guidance and action plan derived from PD. The plan was endorsed by cabinet and contained a holistic portfolio of policy instruments, including import bans, tariffs and deposit-return schemes, as well as increased provision for education, data collection and alternative materials. The first step was the ratification of the 18th Amendment Bill to the Export-Import act of the Maldives (Act No. 31/79) in December 2020 to ban importation of some SUP items. At the same time, several island resorts and community organisations have undertaken specific actions to reduce the use of plastics and improve waste management under the Namoonaa Baa initiative in partnership with the Clean Blue Alliance (Outlook, 2020).

4. Discussion

Using a relatively straightforward modelling framework, simple visualisations and cost-effective data collection strategies, PD produced a clear picture of the current plastic waste and leakage in the Maldives, estimated how this would change by 2030 and demonstrated the potential impact of specific policy instruments. The evidence, action plan and convening generated from PD resulted in policy commitments and subsequent action by the Government, which are expected to result in a substantial reduction of plastic waste leaking into aquatic environments in the Maldives.

The PD methodology is an intentionally straightforward process that encourages the full engagement of stakeholders from across the plastics value chain, to include national and local Government, waste management, plastic producers, private sector and academic stakeholders with varied technical literacy. Simplifying a system is commonly used in other modelling environments (e.g. ecological and oceanographic models), where it is important to capture main patterns and processes within complex systems (May and Oster, 1976). Whereas overreliance on technical accuracy can introduce prohibitive costs and delays in producing useable results, especially in data-limited situations (National Research Council, 2005).

PD provides a transparent process to identify and consolidate data from varied sources and data pedigrees. By providing a single comprehensive analysis of the plastic pollution problem and solutions, backed by credible data, the PD analysis facilitates consultation and consensus building between decision makers. PD presents data through simple visualisations, which is recognised as a powerful tool to engage diverse, non-technical audiences with complex research, in order to facilitate co-design of the research itself and of the policy responses to it (Otten et al., 2015). As demonstrated in the Maldives, visualising different potential policy effects as the stacked area graph (Fig. 3) provided an intuitive

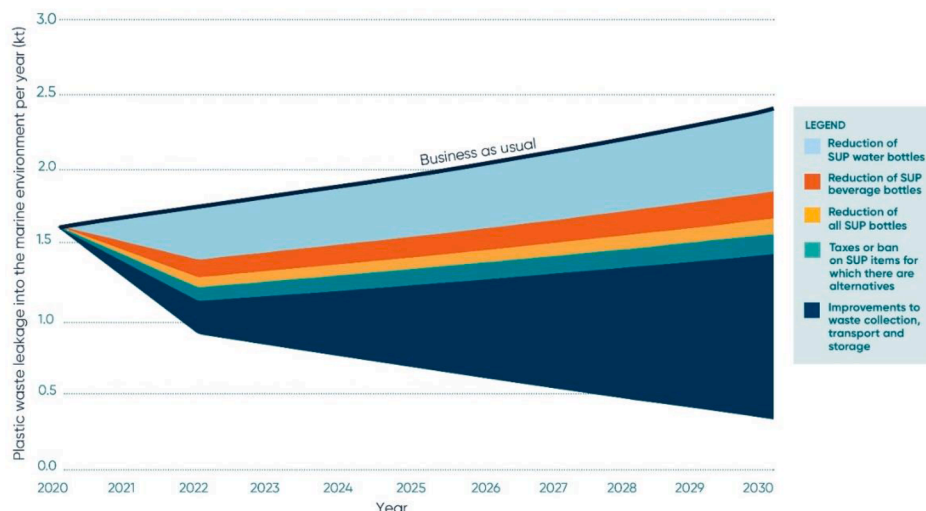


Fig. 3. The potential impact of scenario 5 developed by the Engagement Group to reduce plastic leakage using the intermediate assessment. SUP = Single use plastic.

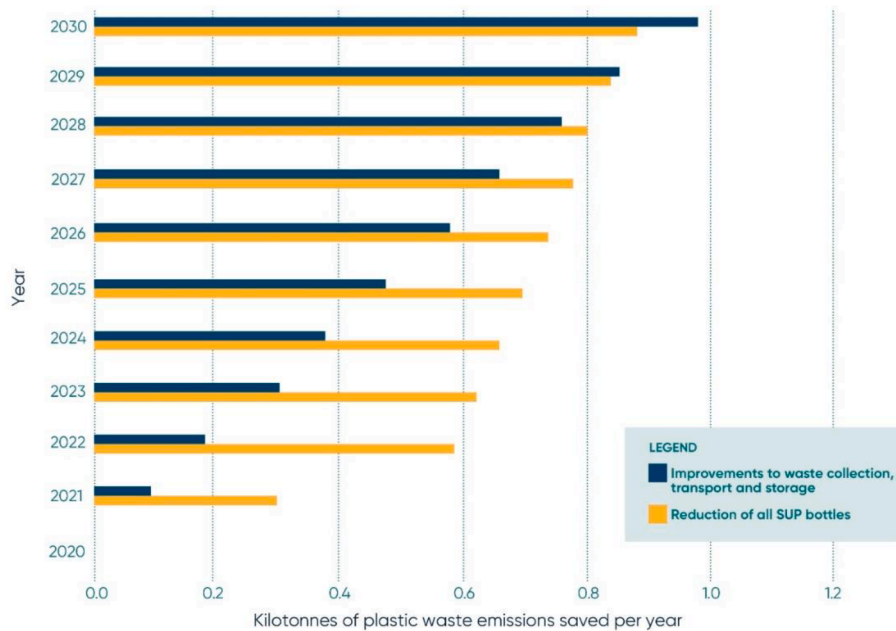


Fig. 4. Relative impact of policies with different focus on overall plastic waste leakage between 2020 and 2030.

way for decision makers to understand where the areas of greatest impact and priority lay. This is particularly important when technical literacy varies greatly between stakeholders (e.g. Nikas et al., 2017). This visualisation permitted PD to help develop a common conceptualization of the problem across the entire plastic value chain and waste management system, and between groups with different experiences and agendas (Dryzek, 1993). Accessible visualisations also provide transparency across process steps, from illustrating the challenge through to depicting the potential impact of policy instruments. This creates an opportunity for civic alignment (Shafir, 2013).

A key strength of PD was used was its ability to facilitate dialogue between members of the Engagement Group to tackle plastic leakage. Knowledge silos are widely recognised within Governments and organisations across the world (Ardichvili et al., 2003). Ultimately, by providing both a clear structure (in what can seem an overwhelmingly complex policy area), and data visualisation (to allow a wide group of stakeholders to engage), PD enabled effective collaboration between different stakeholders and the co-creation of an action plan that holds greater legitimacy; thus fulfilling the objectives of a boundary spanning tool (Cash et al., 2003). The power of this engagement-embedded approach was demonstrated in the Maldives where local actors had expertise in one component of the local plastics value chain, but no individual had a complete overview of the structure across all sectors. The PD framework documented the full plastic waste system, providing policymakers with knowledge to make decisions across institutional boundaries and scales. This approach is often considered as a leading indicator of good public policy making (Clark et al., 2016b).

Careful consideration of focal region for PD analysis is required. In the Maldives, the plastic life cycle of entire country was evaluated, but different island archetypes were identified, to capture differences in waste generation, waste management infrastructure and waste behaviours. The scale of available input data and jurisdiction of decision makers must match to permit the required analysis to be done, information to be shared and pathway to impact to be successful. For example, a large country may be best analysed at a sub-national level, with areas defined by factors such as geographic area or socio-economic archetype.

PD helped focus attention on a few key policy instruments that could result in 97% (13.5kt) of projected plastic leakage being avoided. This directed policymakers to the instruments that are likely to be most effective and provided message clarity to support wider stakeholder

engagement. Analysing national and sub-national regions separately also revealed that a diverse set of drivers were operating to generate plastic waste and plastic pollution across the Maldives. It revealed a high proportion of SUP water bottles in waste, almost four times as high as the global average, and was able to differentiate the patterns of waste and leakage across island types.

Application of PD in the Maldives demonstrates its potential to motivate a system-wide response to addressing plastic pollution, and inform a suite of policy instruments that target specific priority items within that geography. In this way PD can help to address some of the key limitations that have been identified within current policy making to address plastic pollution (Karasik et al., 2020, Lau et al., 2020).

Furthermore, PD can facilitate the holistic approach to understanding and reducing ocean pollution recommended by others (Jambeck et al., 2020; Lau et al., 2020), linking the reduction of plastic waste and leakage to solutions of other societal challenges. It highlights linkages between drivers of plastic waste and other public policy priorities, such as public health (e.g. provision of potable water) and climate change (e.g. waste incineration). In PD Maldives, SUP plastic water bottle policies were timed to align with initiatives to increase potable water systems on rural islands, to ensure that reducing SUP bottles would not undermine rural communities' access to drinkable water and that both actions contribute directly to SDG 6 and SDG 14 and indirectly to SDG11. This underscores the value of the PD process including the establishment and active participation of the Engagement Group, which incorporates a range of Government departments and perspectives. Diverse participation helps to breakdown internal silos and develop an integrated response to plastics, that aligns with other jurisdictional policy objectives.

PD can challenge the current understanding of policymakers or highlight the importance of factors currently out of the scope of policy discussions. For example, in Maldives it highlighted that dumping of waste from transport vessels was an important source of plastic leakage. Previously, although acknowledged by stakeholders, it remained outside the discussion of plastic mitigation because of a lack of structured evidence. Furthermore PD can also be used to monitor changes over time, by reassessing data input and the subsequent analyses when new data become available, and can inform further data collection efforts.

4.1. Outlook & future focus

As well as proven effectiveness in the Maldives, PD has been used in a variety of other contexts. This includes application in different countries, across a range of national income levels to support national action plans, assist the development of international toolkits (e.g. Commonwealth Clean Ocean Alliance) and analyse Government strategies (e.g. the United Kingdom's Resources & Waste Strategy, [Common Seas, 2019a](#)). This further demonstrates the adaptability of PD and the value of its wider adoption as a consistent framework for comparing plastic waste generation, flows and leakage, and assisting decision making through the prioritisation of plastic leakage minimisation strategies.

Lessons learnt through the application of PD in the Maldives and other contexts also provided new insights about the support that decision makers need when developing strategies to prevent plastic pollution, particularly in countries with limited available waste systems data. It highlighted the value of enhanced strategic guidance and knowledge exchange to support the process of contextualising, adapting and implementing PD policy instruments. By engendering a deeper understanding of the antecedent social, financial, and environmental factors that influence the effectiveness of a plastic mitigation policy, PD could further ensure that instruments are designed and implemented to maximise intended effects and mitigate unintended consequences.

5. Conclusion

We have shown PD strikes a balance between generating data driven results and connecting with the culture and practices of policymakers and local stakeholders ([Nguyen et al., 2017](#)). It can be used to investigate the significance of different plastic waste flows, clearly visualise a country's plastic pollution challenge, investigate the potential effectiveness of the different policy instruments available to decision makers, and monitor change over time. In doing so, PD highlights the need for a holistic, system-wide approach combining both short- and long- term instruments to reduce plastic waste generation at source, as well as ensuring downstream management, (e.g. solid waste management) is in place.

As a boundary spanning tool, PD is proven to provide a framework for the equitable engagement of government representatives and stakeholders in a dialogue on plastic waste, leakage and instruments. PD's application in the Maldives demonstrates how it provided institutions and stakeholders with a mechanism through which to create shared goals and solutions, which gave the Maldives' Government the evidence base and confidence to set an ambitious target to phase out single-use plastics by 2023. It shows the importance of embedding data and modelling approaches within an engagement process when conceptualising and discussing 'wicked' problems. It also demonstrates the importance of effectively disseminating knowledge to enable robust and context-appropriate decision-making processes.

PD provides an ideal framework to enable these processes and it is anticipated that this framework could play a key role in determining effective and efficient solutions to reducing marine plastic pollution.

Funding sources

This work was financed by Common Seas. In addition ACC was funded by the UK Engineering and Physical Sciences Research Council grant (EP/S025456/1) and LCW partly supported by Nekton.

CRedit authorship contribution statement

Jo Royle: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Ben Jack:** Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Hannah Parris:**

Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Tim Elliott:** Conceptualization, Methodology, Software, Investigation, Data curation, Writing – review & editing. **Arturo Castillo Castillo:** Conceptualization, Writing – review & editing. **Shenali Kalawana:** Data curation, Writing – review & editing, Visualization. **Hawwa Nashfa:** Investigation, Writing – review & editing. **Lucy C. Woodall:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We are extremely grateful to Jenna Jambeck, who helped conceive the ideas behind Plastic Drawdown. We also thank Dominic Hogg who provided useful comments on the theoretical framework. In the field we are indebted to the Government of Maldives who facilitated our visit to Maldives and the Maldives Plastic Phase Out Committee who provided insightful inputs for Plastic Drawdown in Maldives and important insights. Finally we would like to acknowledge John Virdin and Nicky Beaumont who gave valuable comments and feedback on an earlier version of this manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.gloenvcha.2021.102442>.

References

- Ardichvili, A., Page, V., Wentling, T., 2003. Motivation and barriers to participation in virtual knowledge-sharing communities of practice. *J. Knowledge Manage.* 7 (1), 64–77. <https://doi.org/10.1108/13673270310463626>.
- Addison, P.F.E., Rumpff, L., Bau, S.S., Carey, J.M., Chee, Y.E., Jarrad, F.C., McBride, M.F., Burgman, M.A., Yemshanov, D., 2013. Practical solutions for making models indispensable in conservation decision-making. *Divers. Distrib.* 19 (5–6), 490–502.
- Asian Development Bank (2018) Greater Malé Environmental Improvement and Waste Management Project 51077-002. Asian Development Bank.
- Asian Development Bank (2020a) Economic forecasts Available at <https://www.adb.org/what-we-do/economic-forecasts/september-2020>.
- Asian Development Bank (2020b) ADB Approves \$73 Million Package to Develop Waste-to-Energy Facility in Maldives Available at [https://www.adb.org/news/adb-approves-73-million-package-develop-waste-energy-facility-maldives#:~:text=MANILA%2C%20PHILIPPINES%20\(12%20August%202020,Mal%3C%A9%20region%20and%20neighboring%20outer](https://www.adb.org/news/adb-approves-73-million-package-develop-waste-energy-facility-maldives#:~:text=MANILA%2C%20PHILIPPINES%20(12%20August%202020,Mal%3C%A9%20region%20and%20neighboring%20outer).
- Bednarek, A.T., Wyborn, C., Cvitanovic, C., Meyer, R., Colvin, R.M., Addison, P.F.E., Close, S.L., Curran, K., Faroque, M., Goldman, E., Hart, D., Mannix, H., McCreavy, B., Parris, A., Posner, S., Robinson, C., Ryan, M., Leith, P., 2018. Boundary spanning at the science-policy interface: the practitioners' perspectives. *Sustain. Sci.* 13 (4), 1175–1183.
- Bläsing, M., Amelung, W., 2018. Plastics in soil: analytical methods and possible sources. *Sci. Total Environ.* 612, 422–435.
- Borrelle, S.B., Ringma, J., Law, K.L., Monnahan, C.C., Lebreton, L., McGivern, A., Murphy, E., Jambeck, J., Leonard, G.H., Hilleary, M.A., Eriksen, M., Possingham, H. P., De Frond, H., Gerber, L.R., Polidoro, B., Tahir, A., Bernard, M., Mallos, N., Barnes, M., Rochman, C.M., 2020. Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. *Science* 369 (6510), 1515–1518.
- Boucher, J., Billard, G., Simeone, E., Sousa, J., 2020. The marine plastic footprint. *IUCN*, 2831720281.
- Bucci, K., Tullio, M., Rochman, C.M., 2020. What is known and unknown about the effects of plastic pollution: A meta-analysis and systematic review. *Ecol. Appl.* 30 (2) <https://doi.org/10.1002/eap.v30.210.1002/eap.2044>.
- Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. *Proc. Natl. Acad. Sci.* 100 (14), 8086–8091.
- Clark, W.C., van Kerkhoff, L., Lebel, L., Gallop, G.C., 2016a. Crafting usable knowledge for sustainable development. *Proc. Natl. Acad. Sci.* 113 (17), 4570–4578. <https://doi.org/10.1073/pnas.1601266113>.
- Clark, W.C., Tomich, T.P., Van Noordwijk, M., Guston, D., Catacutan, D., Dickson, N.M., McNie, E., 2016b. Boundary work for sustainable development: Natural resource management at the Consultative Group on International Agricultural Research (CGIAR). *Proceedings of the National Academy of Sciences* 113: 4615–4622.

- Common Seas (2019a) Plastic Drawdown Technical Report & Policy Analysis. Available at <https://commonseas.com/programmes/plastic-drawdown>.
- Common Seas (2019b) Plastic Drawdown Summary for Indonesia. Available at <https://commonseas.com/programmes/plastic-drawdown>.
- Dryzek, J.S., 1993. Policy analysis and planning: From science to argument. In *The argumentative turn in policy analysis and planning* Fischer F & Forester J (eds) 213–232 Duke University Press.
- Eriksen, M., Thiel, M., Prindiville, M., Kiessling, T., 2018. Microplastic: what are the solutions. In *Freshwater Microplastics* Wagner M & Lamber S (eds) *The Handbook of Chemistry V* 58 Springer, Chem 273–298.
- Ford, H.V., Jones, N.H., Davies, A.J., Godley, B.J., Jambeck, J.R., Napper, I.E., Suckling, C.C., Williams, G.J., Woodall, L.C., Koldewey, H.J., 2022. The fundamental links between climate change and marine plastic pollution. *Sci. Total Environ.* 806, 150392. <https://doi.org/10.1016/j.scitotenv.2021.150392>.
- Gilman, E., Chopin, F., Suuronen, P., Kuemlangan, B., 2016. Abandoned, lost and discarded gillnets and trammel nets: methods to estimate ghost fishing mortality, and the status of regional monitoring and management. Fisheries and Aquaculture Technical Paper: 600. FAO, Rome.
- Geyer, R., Jambeck, J.R., Law, K.L., 2017. Production, use, and fate of all plastics ever made. *Sci. Adv.* 3 (7) <https://doi.org/10.1126/sciadv.1700782>.
- Hawwa, N., 2020. Single Use Plastic Phaseout Plan, Ministry of Environment, Maldives. Available at <https://www.environment.gov.mv/v2/en/download/11572>.
- Horton, A.A., Walton, A., Spurgeon, D.J., Lahive, E., Svendsen, C., 2017. Microplastics in freshwater and terrestrial environments: evaluating the current understanding to identify the knowledge gaps and future research priorities. *Sci. Total Environ.* 586, 127–141.
- Jambeck, J., Moss, E., Dubey, B., Arifin, Z., Godfrey, L., Hardesty, B.D., Hendrawan, I.G., Hien, T.T., Junguo, L., Matlock, M., Pahl, S., Raubenheimer, K., Thiel, M., Thompson, R.C., Woodall, L.C., 2020. Leveraging Multi-Target Strategies to Address Plastic Pollution in the Context of an Already Stressed Ocean. World Resources Institute, Washington DC.
- Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Plastic waste inputs from land into the ocean. *Science* 347 (6223), 768–771.
- Karasik, R., Vegh, T., Diana, Z., Bering, J., Caldas, J., Pickle, A., Rittschof, D., Virdin, J., 2020. 20 Years of Government Responses to the Global Plastic Pollution Problem: The Plastics Policy Inventory. Duke University, Durham.
- Lau, W.W.Y., Shiran, Y., Bailey, R.M., Cook, E.d., Stuchtey, M.R., Koskella, J., Velis, C.A., Godfrey, L., Boucher, J., Murphy, M.B., Thompson, R.C., Jankowska, E., Castillo Castillo, A., Pilditch, T.D., Dixon, B., Koerselman, L., Kosior, E., Favoino, E., Gutberlet, J., Baulch, S., Atreya, M.E., Fischer, D., He, K.K., Petit, M.M., Sumaila, U. R., Neil, E., Bernhofen, M.V., Lawrence, K., Palardy, J.E., 2020. Evaluating scenarios toward zero plastic pollution. *Science* 369 (6510), 1455–1461.
- Law, K.L., 2017. Plastics in the marine environment. *Annu. Rev. Marine Sci.* 9 (1), 205–229.
- Lebreton, L., Andrady, A., 2019. Future scenarios of global plastic waste generation and disposal. *Palgrave Commun.* 5, 1–11.
- May, R.M., Oster, G.F., 1976. Bifurcations and dynamic complexity in simple ecological models. *Am. Nat.* 110 (974), 573–599.
- Ministry of Environment and Energy, 2018. Greater Malé Environmental Improvement and Waste Management Project–Transfer Station Improvements Subproject for Malé and Villingilli, Sian Development Bank Project 51077-002, Male, Maldives.
- Ministry of Environment Maldives, 2019. Regional Waste Management Strategy and Action Plan for Zone 6, Republic of Maldives.
- Nash, A.D., 1992. Impacts of marine debris on subsistence fishermen: an exploratory study. *Mar. Pollut. Bull.* 24 (3), 150–156.
- National Bureau of Statistics M (2020) Statistical yearbook of Maldives, Male, Maldives.
- National Research Council (2015) Decision Making for the Environment: Social and Behavioral Science Research Priorities eds. Brewer GD & Stern PC, Committee on the Human Dimensions of Global Change Center for Governance, Economics, and International Studies Division of Behavioral and Social Sciences and Education, Washington DC, The National Academies Press.
- Nguyen, V.M., Young, N., Cooke, S.J., 2017. A roadmap for knowledge exchange and mobilization research in conservation and natural resource management. *Conserv. Biol.* 31 (4), 789–798.
- Nikas, A., Doukas, H., Lieu, J., Alvarez Tinoco, R., Charisopoulos, V., van der Gaast, W., 2017. Managing stakeholder knowledge for the evaluation of innovation systems in the face of climate change. *J. Knowledge Manage.* 21 (5), 1013–1034.
- Otten, J.J., Cheng, K., Drewnowski, A., 2015. Infographics and public policy: using data visualization to convey complex information. *Health Aff.* 34 (11), 1901–1907.
- Outlook (2020) Soneva Launches its Namoonaa Baa Initiative: Maalhos Becomes the First Maldivian Island to Stop Open Burning. Available at : <https://www.outlookindia.com/newscroll/soneva-launches-its-namoonaa-baa-initiative-maalhos-becomes-the-first-maldivian-island-to-stop-open-burning/1744897>.
- Rodríguez, Y., Ressurreição, A., Pham, C.K., 2020. Socio-economic impacts of marine litter for remote oceanic islands: The case of the Azores. *Mar. Pollut. Bull.* 160, 111631. <https://doi.org/10.1016/j.marpolbul.2020.111631>.
- Shafir, E. (Ed.), 2013. *The Behavioral Foundations of Public Policy*. Princeton University Press.
- Stoett P, Vince J (2019) The plastic-climate nexus: linking science, policy, and justice. In *Climate Change and Ocean Governance: Politics and Policy for Threatened Seas*, Cambridge University Press, PG Harris (ed), Cambridge, pp. 345–361.
- Tammemagi HY (1999) The waste crisis: landfills, incinerators, and the search for a sustainable future. Oxford University Press, Oxford.
- Turrell, W.R., 2020. Estimating a regional budget of marine plastic litter in order to advise on marine management measures. *Mar. Pollut. Bull.* 150, 110725. <https://doi.org/10.1016/j.marpolbul.2019.110725>.
- UNEP (2018) Legal Limits on Single-Use Plastics and Microplastics: A Global Review of National Laws and Regulations. UNEP, Nairobi.
- Van Kerkhoff, L.E., Lebel, L., 2015. Coproductive capacities: rethinking science-governance relations in a diverse world. *Ecol. Soc.* 20, 14. <https://doi.org/10.5751/ES-07188-200114>.
- World Bank, 2021. Plastic Waste Discharges from Rivers and Coastlines in Indonesia : Indonesia Plastic Waste Discharges from Rivers and Coastlines. Marine Plastics Series, Washington D.C. Available at <https://documents.worldbank.org/en/publication/documents-reports/documentdetail/146261621356766241/main-report>.
- Xanthos, D., Walker, T.R., 2017. International policies to reduce plastic marine pollution from single-use plastics (plastic bags and microbeads): a review. *Mar. Pollut. Bull.* 118 (1–2), 17–26.