Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Energy and Process Engineering

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Monetary impacts of plastic pollution on coastal recreational ecosystem services

Developing effect factors for the use in Life Cycle Impact Assessment

Master's thesis in Industrial Ecology
Supervisor: Francesca Verones
Co-supervisor: Fei Song
June 2022

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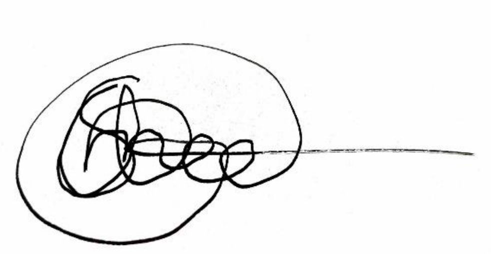
Preface

This thesis forms the final part of my Master of Science degree in Industrial Ecology at the Norwegian University of Science and Technology (NTNU) in Trondheim. The thesis was written as a follow-up on my master's project "Potential for the assessment of marine cultural ecosystem services in life-cycle assessment – a literature review" that I completed at the end of 2021. The project formed the starting point for the literature that was used to set up the effect factors that are presented in this thesis.

I would like to express special thanks to my supervisor Professor Francesca Verones and to my co-supervisor Fei Song for providing me with constructive feedback in the many meetings we had together. Their many comments on various aspects of my work helped to greatly improve the quality of my work.

In addition, I would like to thank my fellow students with whom I spent many hours in the study room working on our theses. The regular breaks we shared perfectly balanced the many days that we were working on our theses.

08.06.2022
Trondheim



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Abstract

The importance of Ecosystem Services (ES) and the threats human activity pose to their supply have become a common topic of academic research. In the marine environment, the steady increase of plastic pollution now threatens to compromise the supply of important marine ES. While current life cycle assessment methods have started to account for some of the ES impacts of plastic, they still fail to account for effects on marine cultural ES. This thesis presents an attempt to fill this research gap through the development of Effect Factors that can be used in Life-Cycle Impact Assessment to estimate the monetary impact of marine plastic and debris on coastal tourism.

Using data from Contingent Valuation Method studies and coastal clean-ups, several effect factors were developed that measure the monetary impact per kg of marine plastic and debris pollution. Two main effect factors were developed that can predict the monetary costs per kg marine plastic and debris for (1) a country or (2) for a smaller region. The monetary impacts are calculated using recreational value loss estimates and incurred cleaning costs. For the predicting of recreational value loss per kg of marine plastic and debris, the use of the Human Development Index was recommended.

The effect factors that are presented in this thesis are the first step in the development of a Characterization Factor to be incorporated in Life-cycle Impact Assessment. In addition to the need for the development of a Fate Factor, new research using Contingent Valuation Method with a wider geographical range and more standardized results is needed to improve the robustness of the effect factors.

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List of abbreviations

APEC	Asia-Pacific Economic Cooperation
CF	Characterization Factor
CVM	Contingent Valuation Method
EF	Effect Factor
ES	Ecosystem Service
FF	Fate Factor
GDP	Gross Domestic Product (per capita)
HDI	Human Development Index
LCA	Life-Cycle Assessment
LCA-ES	Life-Cycle Assessment including Ecosystem Services
LCIA	Life-Cycle Impact Assessment
MA	Millennium ecosystem Assessment
MCES	Marine Cultural Ecosystem Services
MPD	Marine Plastic and Debris
NV	No Valuation
PPP	Purchasing Power Parity
TEV	Total Economic Value
VL	Value Loss
WTP	Willingness-To-Pay

List of variables

Variable	Explanation	Unit	Equations
(A/S)	Shows what type of MPD pollution variable was based on. (A) = based on average MPD pollution for the years 2016-2021 and (S) = Based on the MPD pollution for the study year	-	5, 6, 9, 10, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27
$\boldsymbol{B_{x,y}}$	HDI, GDP per capita, or local MPD pollution	HDI (0-1), USD, or kg/km	7, 8, 14, 15, 16
$\boldsymbol{CC_{tonne}}$	Cleaning costs per kg of MPD pollution	$\frac{USD}{kg}$	9, 10, 13, 14, 15, 16
$\boldsymbol{CF(T/Y)_{MPD,(A/S),(z),x,y}}$	Total costs associated with an effective inflow of MPD pollution for (region "z" in) country "x" in year "y"	USD	17
$\boldsymbol{CL_{x,y}}$	Total coastal length over which MPD pollution was cleaned for country "x" in year "y"	Km	4
$\boldsymbol{EF(T/Y)_{country,(A/S),x,y}}$	Costs for value loss and cleaning costs per kg MPD for country "x" in year "y"	$\frac{USD}{kg}$	9, 10, 14, 15, 17, 22, 23, 24, 25
$\boldsymbol{EF(T)_{region,(A/S),z,x,y}}$	Costs for value loss and cleaning costs per kg MPD for region "z" in country "x" in year "y"	$\frac{USD}{kg}$	13, 16, 17, 26, 27
$\boldsymbol{FF_{(z),x,y}}$	Effective inflow of MPD pollution for (region "z" in) country "x" in year "y"	Kg	17
$\boldsymbol{GDP_{x,y}}$	GDP per capita for country "x" in year "y"	USD	19, 21, 23, 25, 27
$\boldsymbol{GR_{y+1}}$	Real GDP growth rate for year "y"+1	%	2
$\boldsymbol{HDI_{x,y}}$	HDI for country "x" in year "y"	0-1	18, 20, 22, 24, 26
$\boldsymbol{HS_{x,y}}$	Average household size for country "x" in year "y"	#persons	1

Variable	Explanation	Unit	Equations
$\boldsymbol{km_{coast,x}}$	Total coastal length for country "x"	Km	9, 10, 13, 14, 15, 16, 22, 23, 24, 25, 26, 27
$\boldsymbol{MPD_{dens,x,y}}$	Density of MPD pollution on the beach for country "x" in year "y"	Kg/km	4, 5
$\boldsymbol{MPD(T/Y)_{per\_USD,(A/S),x,y}}$	Density of MPD pollution per USD in recreational value loss for country "x" in year "y"	$\frac{kg * person * (trip\ \mathbf{or}\ year)}{km * USD}$	5
$\boldsymbol{MPD_{weight,x,y}}$	Total weight of MPD pollution gathered for country "x" in year "y"	Kg	4
$\boldsymbol{p_{x,y}}$	Population for country "x" in year "y"	#persons	9, 10, 14, 15, 22, 23, 24, 25
$\boldsymbol{PPP_{x,2020}}$	Purchasing Power Parity for country "x" in the year 2020	-	3
(T/Y)	Shows what type of WTP the variable is based on. (T) = variable uses Willingness-To-Pay per person per trip data and (Y) = variable uses Willingness-To-Pay per person per year data	-	2, 3, 5, 6, 7, 9, 10, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27
$\boldsymbol{trips_{x,y}}$	Average number of trips to the coast for people from country "x" in year "y"	#trips	9, 14, 22, 23
$\boldsymbol{visitors_{z,y}}$	Total number of visitors to region "z" in year "y"	#visitors	13, 16, 26, 27
$\boldsymbol{VL(T/Y)_{est,(A/S),x,y}}$	Estimate of the recreational value loss per kilogram per kilometre (density) MPD pollution for country "x" in year "y"	$\frac{USD * km}{person * (trip\ \mathbf{or}\ year) * kg}$	8, 18, 19, 20, 21

Variable	Explanation	Unit	Equations
$\boldsymbol{VL(T/Y)_{per\_dens,(A/S),x,y}}$	Recreational value loss per kilogram per kilometre (density) MPD pollution for country "x" in year "y"	$\frac{USD * km}{person * (trip\ \mathbf{or}\ year) * kg}$	6, 9, 10, 13
$\boldsymbol{WTP(T/Y)_{C,x,2020}}$	Willingness-To-Pay per person corrected for GDP growth and Purchasing Power Parity for country "x" to the year 2020	$\frac{USD}{person * (trip\ \mathbf{or}\ year)}$	3, 5, 6
$\boldsymbol{WTP(T/Y)_{est,x,y}}$	Estimate of the willingness-To-Pay per person for country "x" in year "y"	$\frac{USD}{person * (trip\ \mathbf{or}\ year)}$	7
$\boldsymbol{WTP(T/Y)_{GDP,x,2020}}$	Willingness-To-Pay per person corrected for GDP growth for country "x" to the year 2020	$\frac{USD}{person * (trip\ \mathbf{or}\ year)}$	2, 3
$\boldsymbol{WTP(T/Y)_{x,y}}$	Willingness-To-Pay per person for country "x" in year "y"	$\frac{USD}{person * (trip\ \mathbf{or}\ year)}$	2
$\boldsymbol{WTP(Y)_{h,x,y}}$	Willingness-To-Pay per household per year for country "x" in year "y"	$\frac{USD}{household * year}$	1
$\boldsymbol{WTP(Y)_{p,x,y}}$	Willingness-To-Pay per person per year for country "x" in year "y"	$\frac{USD}{person * year}$	1
$\boldsymbol{\varphi}$	Regression coefficient	-	7, 8, 14, 15, 16

1. Introduction

When the Millennium Ecosystem Assessment (MA) (Millennium ecosystem assessment, 2005) was published, the focus of environmental studies was readjusted to include not only how humans impact ecosystems directly but also how humans impact the benefits we gain from ecosystems (Carpenter et al., 2006; Carpenter et al., 2009). This led to a further establishing of the concept of ecosystem services (ES), the benefits we gain from ecosystems, and introduced the ES categorization of provisioning, regulating, supporting, and cultural services that is still used in many studies today (Evers et al., 2018). Since its publication, the importance of ES has become more evident to policy makers and academia leading to a dramatic increase in the amount of research on ES (Gangahagedara et al., 2021). A review of ES studies found however that twelve years after the MA was published, the research was plagued by inconsistencies and incomplete methods (Costanza et al., 2017). A call went out to encourage new research to use more standardized methods to make results more comparable. Since then, following a more recent bibliometric review (Wang et al., 2021), still little progress had been made towards this target. Both reviews by Costanza et al. (2017) and Wang et al. (2021) point out how still new research is needed to improve the methods we use to measure the pressures humans put on ES.

Although ES have received increasing attention over the past decades, not all ES types have been represented equally (Gangahagedara et al., 2021). Especially the impacts on ES provided by marine- and coastal ecosystems remain underrepresented in the literature (Liquete et al., 2013). This lack of representation is in spite of the important role that marine and coastal ecosystems play in supplying vital ES for humans (Cooley et al., 2009; Navrud et al., 2017). Important marine ES for each of the four ES categories include ocean fishing and water use (provisioning), storm protection and carbon sequestration (regulating), nutrient and heat transportation (supporting), and recreation and tourism (cultural) (Barbier, 2017). Research has shown that an increase in human activities in coastal and marine areas as well as increased marine pollution have resulted in increasing pressures on the delivery of many of these ES (Barbier, 2017; Buonocore et al., 2021; Cooley et al., 2009; Navrud et al., 2017). With the important role that marine ES play for many communities (Ross et al., 2019), it is important to increase our understanding of the impacts that human stressors have on the delivery of marine ES.

One of the main indirect causes of the increase in pressure on marine- and coastal ecosystems is the global population growth (Buonocore et al., 2021). The higher population numbers cause increased production and demand that can lead to fish stock depletion through overfishing and increased pressures from pollution and eutrophication. Especially the effects of plastic pollution (Thushari & Senevirathna, 2020) have become increasingly acknowledged to have a strong negative effect on the environment (Rajmohan et al., 2019; Ritchie & Roser, 2018; Thushari & Senevirathna, 2020; Wabnitz & Nichols, 2010). With the explosive increase of the use of plastic since the 1950s (Ritchie & Roser, 2018), it is more important than ever that research is devoted to the impacts that plastic pollution has on humans and the environmental.

Plastic pollution has been found to have a negative impact on all four categories defined by the MA (provisioning, regulating, supporting and cultural services) (Beaumont et al., 2019). Plastic pollution can be endangering marine species through entanglement and ingestion but also impact coastal communities through the impacts that site pollution can have on human health and recreation. In spite of some reports calling the current situation an "ocean emergency", the amount of plastic in the ocean is still increasing at an alarming rate (Wabnitz & Nichols, 2010). Of the total global annual plastic production, it is estimated that about three percent ends up in the ocean (Ritchie & Roser, 2018; Thushari & Senevirathna, 2020; Wabnitz & Nichols, 2010). If this trend of accumulating plastic stocks in the ocean is not halted, there might be severe societal impacts that could endanger global food security (Garcia & Rosenberg, 2010) and have a strong impact on the benefits gained from coastal recreation (Beaumont et al., 2019). Some of the studies that have looked specifically into the economic impacts of plastic pollution on recreation and ecotourism find impacts ranging between 29 million USD for South Korea following a high pollution event (Jang et al., 2014) to 6.41 billion USD for the entire APEC region (McIlgorm et al., 2022). The scale of these numbers shows how severe the impacts can be and encourages new research to investigate how plastic pollution relates to economic value loss. Understanding this relationship will make it easier to devise policies that can help to protect cultural ES against human stressors like plastic pollution. To be able to correctly assess this relationship, there is however a need for a method that can quantify these impacts.

One method that has been proposed to identify and quantify human impacts on marine ES is Life-Cycle Assessment (LCA) (Alejandre et al., 2019; Liu et al., 2018a, 2018b; VanderWilde & Newell, 2021). LCA is a method that assesses how the production, use, and end-of-life processing of a product or service affects the environment. Through midpoint indicators that translate the use of energy or material sources into impact scores, the results can be combined into endpoint indicators that assess the total impacts on human health, ecosystem quality, or resource depletion. This assessment encompasses the product or service's whole life cycle and can be used to uncover the direct- and indirect impacts caused by products or services that are needed to make the main product. Impacts on ES can be assessed in LCIA by expanding the assessment's scope to include the impacts on the delivery of ES. To be able to assess these impacts, Characterization Factors (CF) need to be developed that can shed light on how the use of certain materials or energy sources can impact the delivery of different types of ES. Using CFs, the quantified results could then be gathered under a new endpoint indicator specifically for ES that assesses the total impacts on ES (Verones et al., 2017).

Currently existing LCA methods are however still neglecting the impacts that plastic can have through mismanagement of waste and consequent impacts on ES (Rajmohan et al., 2019; Silva et al., 2021). First steps have been undertaken to try to assess the impacts of plastic leakage but the research is still very far from creating a comprehensive overview of all the possible impacts (Boulay et al., 2021). Two previous studies that have tried to incorporate the impacts of plastics in LCA have looked at the eco-toxic effects related to microplastic pollution (Saling et al., 2020) and the relationship between floating plastic and entanglement issues for marine species (Woods et al., 2019). The two studies follow up on the call made by the Medellin declaration (Sonnemann & Valdivia, 2017) for increased efforts to improve the LCA methods to incorporate the impacts from marine litter. The declaration emphasizes that impacts from plastic on the marine environment can have consequences beyond the impact on food provision. Negative impacts can include degradation of the ES that provide touristic opportunities and subsequently cause damage to socio-economic systems.

The socio-economic impacts of stressors is poorly understood for cultural ES in LCA studies owing to the low number of studies covering cultural ES (VanderWilde & Newell, 2021). The studies that have looked into the incorporation of ES in LCA rarely look into cultural ES. In a bibliometric review from 2021, only 6 out of the 91 reviewed LCA-ES studies covered cultural ES (VanderWilde & Newell, 2021). When looking at all studies focusing on marine cultural ecosystems (including studies using different methods than LCA), a similar trend can be found (Le Cozannet et al., 2015; Rodrigues et al., 2017). This problem is partially caused by the difficulties that come with the quantification of cultural ES. As a result, many studies that have looked into marine cultural ES only mention their importance but refrain from including any type of quantification of the impacts (Liquete et al., 2013). The overall lack of quantification makes it very hard to know exactly how impactful the degradation of cultural ES is which risks undervaluing their importance.

In preparation for this thesis, a master's project was done to assess the extent to which various marine cultural ES had been covered in the literature (Voorwalt, 2022). The master's project investigated studies that covered different types of marine cultural ES and to what degree they quantified them. For the different types of marine cultural ES that were covered, an overview was made to distinguish between studies that included any quantification or monetary valuation in their results. The project revealed that the most frequently studied marine cultural ES was "recreation and ecotourism" (204 studies). In addition, it was found that "recreation and ecotourism" was the most suited cultural ES type for the development of an EF based on the high share of quantified studies (64%). Although some other cultural ES like "aesthetic values" and "educational values" were covered relatively often as well (62 studies and 55 studies respectively), there was a general lack of quantified and valued studies for both (12% and 20% respectively). Based on the importance of data on monetary valuation, "recreation and ecotourism" was therefore recommended as the most suited cultural ES for the use in LCA.

This thesis was done with the aim to address two research gaps. The first is the poor coverage and quantification of cultural ES in general and more specifically in LCA studies. This gap is addressed through the focus on "recreation and ecotourism" as a cultural ES for the marine environment. The second addressed gap is the lack of a comprehensive method to assess the impact that marine plastic pollution has on the environment. This second gap is addressed through the focus on the impact that plastic pollution has on "recreation and ecotourism" as a marine cultural ES. For this, one part of a CF might be developed in the form of an Effect Factor (EF). This EF should be a tool to measure the monetary impact of plastic pollution on marine "recreation and ecotourism" to be used in the method of LCA. The objective of this thesis is summarized in the main research question:

> *"To what extent can current research on the monetary impact of marine plastic and debris on coastal tourism be used to develop an effect factor that can be used in life-cycle impact assessment?"*

The focus of this thesis is specifically on the development of EFs and does not include any attempt at developing a Fate Factor (FF) that would be needed for a CF to be operationalized in LCIA. The EF should predict the monetary impact per unit of marine plastic and debris whilst the FF would predict the effective amount of marine and plastic and debris that produces any monetary costs. The EF will be defined in monetary terms and should provide the monetary costs associated with the presence or inflow of one unit of Marine Plastic and Debris (MPD) pollution. A discussion of the global coverage of the EF will be included to assess to what degree the EF might be applied in different regions.

The thesis is organized in five main chapters, a list of references, and three appendices. Following the introduction, the second chapter describes the methods that were used for the development of the EFs. The methods describe the data that was used and the types of analyses that were done. The third chapter gives an overview of the main results in the form of equations, tables, and charts. These results are discussed in the fourth chapter. The discussion chapter also goes into any recommendations for the use of different types of data and the use of any eventual EFs. The fifth chapter summarizes the main findings and produces a short outlook that goes into any need for future research and the requirements for the implementation of the EFs in an eventual CF to be used in LCIA. Any references and supporting material can be found in chapter six and the three appendices that are attached at the end of the thesis.

2. Methods

2.1. Literature collection

In preparation for this thesis, a master's project was written to review and map the existing literature on Marine Cultural Ecosystem Services (MCES) (Voorwalt, 2022). The project created an overview of the different types of MCES (e.g., aesthetic, recreational, sense of place) that have been studied and mapped the geographical coverage for each type. The project's aim was to assess which types of MCES are most suitable for the creation of an Effect Factor (EF) that could be used in LCIA. The assessment was based on the availability of data for each type of MCES. The data-availability was measured in the sheer number of studies as well as the degree of geographical coverage. The project found recreational MCES to be the most frequently covered MCES offering in addition the best geographical coverage. Based on this finding, a dataset with 204 studies on recreational MCES formed the starting point for the collection of literature for this thesis.

The starting dataset on recreational MCES was narrowed down to the studies that assess the effect of one or several stressors on the delivery of recreational MCES. Of the initial dataset, 73 studies were found fit this criterium. These remaining 73 studies were further categorized by the type of stressors they covered. The number of stressors that were covered differed among studies but the most frequently found stressors included various parameters for water quality (42 studies), beach and marine litter (8 studies), fisheries and aquaculture (12 studies), and habitat destruction (8 studies). For the 42 studies focusing on water quality there was no consistency in the type of water quality parameters that were used. This lack of consistency and the perceived difficulty with the modelling of an EF for water quality were the main reasons to refrain from further research into the impact of water quality on recreational MCES. Instead, the choice was made to develop an EF for the impact of beach and marine litter. This decision was partly based on the master's project and thesis being linked to the Atlantis Project (Verones, 2022) that has a strong focus on the impact of plastic in the marine environment. Compared to the other two stressor types that were most frequently covered ("fisheries and aquaculture" and "habitat destruction"), the modelling of Marine Plastic and Debris (MPD) as a stressor was deemed most achievable within the time constraints. "Habitat destruction" can have many different possible causes and was deemed too complex for modelling whilst the impacts from "fisheries and aquaculture" were perceived as being too hard to conceptualize as a pressure caused through the use of a product or service in LCA.

The first collection of 8 studies that mentioned or went more deeply into the effect of MPD on recreational MCES was expanded on with an additional literature review using new searching terms. The new literature review was different from the one done in the master's project because it expanded the search beyond studies that specifically mentioned ES. The new search terms were focused on "plastic", "litter", "coastal tourism", and "Contingent Valuation Method". This second review revealed an additional 33 studies that were included in the dataset for this thesis. This resulted in a dataset of 41 studies that either quantified, valued, or uses an impact scale to rate the effect of MPD on the delivery of recreational MCES. The development of the EFs is based on the data retrieved from these studies.

2.2 Conceptual model

To understand how the coastal recreational value is affected by the presence of MPD, a conceptual model was developed that sheds light on the cause-effect relationships. This model is meant to specify in what ways the presence of MPD affects monetary values and how different parts of the system might be interlinked.

The conceptual model divides the impact of MPD up into two impact pathways: the incurred cleaning costs and the recreational value loss (Figure 1). The two pathways differ in the type of monetary impact (costs and value-loss) but are combined in a net value of coastal recreation. The cleaning costs can be calculated in a 1:1 relationship where one uses the cleaning costs per kg or tonne. The recreational value loss is based on a more complex relationship between the presence of MPD pollution and people's WTP to prevent or reduce this pollution. Where the cleaning costs can be a simple fixed number per "x" unit of MPD, the WTP that affects recreational value can be dependent on various demographic, regional, or economic variables.

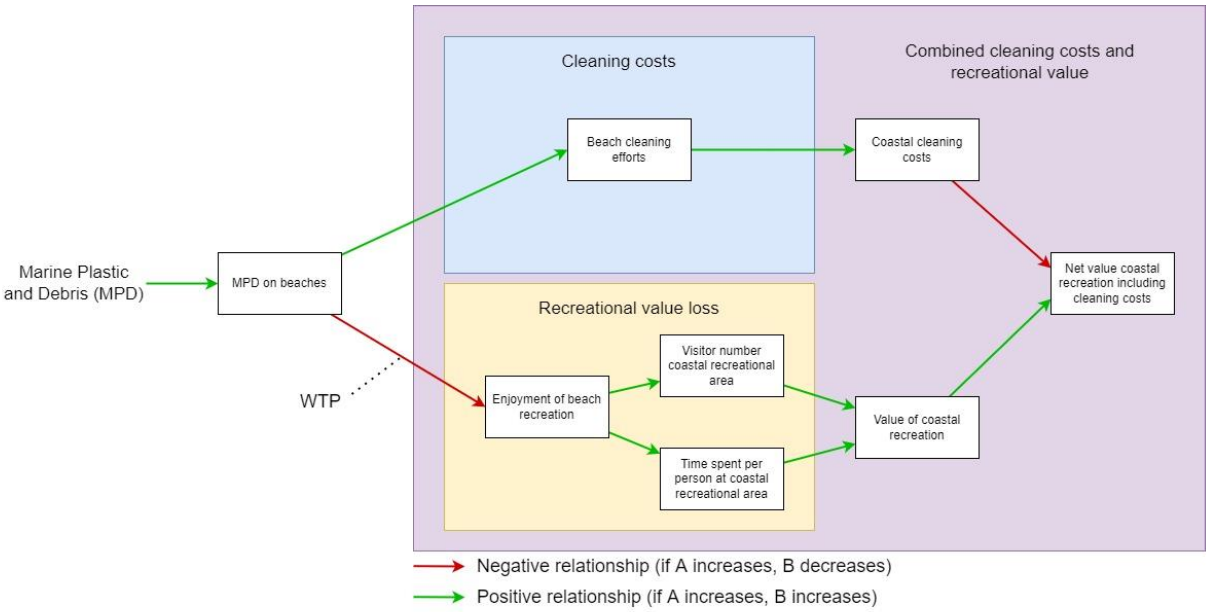

Figure 1 - Conceptual Model of the monetary impact of MPD pollution

The model is divided into three main parts following the inflow of the MPD onto beaches.

The "cleaning costs" describe how an increasing presence of MPD can necessitate an increase in coastal cleaning activities. This is based on the idea that countries or international regions have regulations in place to maintain a certain level of cleanliness on the beaches. A good example of this is the European threshold set in 2020 that advises a maximum of 20 litter items per 100 meter beach (Van Loon et al., 2020). An increase of MPD pollution in the coastal areas will therefore lead to an increase in cleaning efforts to maintain this cleanliness standard. If cleaning operations are managed by local governments or NGOs, the costs come directly from equipment costs and labour hours whilst they come indirectly from labour hours if operations are managed by volunteers. For both these types, the cleaning efforts are monetized and combined in the “Coastal cleaning costs”.

The “recreational value loss” describes how an increase of MPD pollution leads to a decrease in enjoyment of the recreational areas leading to lower visitor numbers or less time spent per person on the beach. The decrease in enjoyment and reduced frequenting and spending of time at the beach is combined in the “value of coastal recreation” and is dependent in its value on the Willingness-To-Pay (WTP) of people to prevent or reduce MPD pollution in coastal areas. The WTP presents the value that people attach to a clean beach that is conveyed through the WTP to reduce the MPD pollution.

Both approaches are combined into the “net value coastal recreation including cleaning costs”. The relationships (positive/negative) in the model show that there is a negating effect of some degree where increased cleaning will increase the cleaning costs and therewith *decrease the net value* (more costs = lower value) whilst this will at the same time reduce MPD pollution. This reduction of MPD pollution will consequently increase recreational value and subsequently *increase the total net value*. This must be taken into consideration when developing an effect factor that combines both approaches to avoid double counting or overestimating the monetary costs.

2.3. Categorization of studies

Based on the ways that the effect of MPD on marine recreation was assessed in the studies, three assessment categories were set up: “Non-valuation”, “Total Economic Value”, and “Contingent Valuation Method”. The categories were based on the type of monetary valuation that the studies from the dataset used. Sorting the studies into these three categories revealed that 5 studies had no valuation of any type (NV), 6 studies used a total economic value method (TEV), and 30 studies used the contingent valuation method (CVM) (Table 1).

Table 1 - Overview of the assessment categories found for the studies on the impact of MDP pollution on marine recreation

Categories	Explanation
Non-Valuation (NV)	Studies that mention the impact that MPD pollution has on MR without valuing or quantifying to what degree.
Total Economic Value (TEV)	Studies that assess the impact of MPD pollution using high-pollution events, scenarios, or macro-economical models.
Contingent Valuation Method (CVM)	Studies that make use of contingent valuation to assess the willingness-to-pay of people to reduce or minimize further MPD pollution.

This categorization was made to further distinguish between the available studies to find which studies could be used in the development of an EF. For the development of an EF, it is important that the monetary values can be compared with the local MPD pollution level. Based on this, the three categories are discussed below.

The first category of non-valuation studies offered no monetary value at all and was therefore not useful for the development of an EF.

The second category of TEV offered the monetary costs associated with large pollution events (or scenarios) or the estimated costs over large geographical regions. Despite the monetary valuation that these studies provide, the scale of the assessed regions and the extreme levels of pollution complicate the development of an EF. Using the TEV studies that use a large geographical scale would make the development of an EF on a country- or regional scale impossible. For the studies focusing on specific high pollution events, the problem of implementing a pollution event into a steady-state LCA model would arise. Based on this, the TEV studies were not used for the further development of any EFs.

The CVM studies presented people's WTP for the reduction of MPD pollution on a much smaller geographical scale. These studies did not focus on extreme pollution events but rather on continuous pollution levels and the effects on recreation. Based on the need to couple local MPD pollution levels to a monetary impact, the CVM studies were deemed most suited for the development of an EF. Using the WTP numbers, an EF might be developed that describes the impact per kilogram of MPD pollution on the recreational value on the beach.

An overview of the CVM studies is given in chapter 2.4. whilst an overview of the other studies (using NV and TEV) can be found in Appendix A.

2.4. Contingent Valuation Method

The studies that used CVM showed three main WTP types (Table 2).

Table 2 - Overview of the WTP types that were found among the CVM studies on the impacts of MPD pollution on marine recreation

CVM type	Explanation
WTP per person per trip	Describes the WTP for each person to reduce current- or prevent future MPD pollution on a per trip basis presented as an entrance fee or environment fee.
WTP per person per year	Describes the WTP for each person to reduce current- or prevent future MPD pollution on a per year basis presented as some sort of environmental tax.
WTP per household per year	Describes the WTP for each household to reduce current- or prevent future MPD pollution on a per year basis presented as some sort of environmental tax.

To maximize the robustness of the EFs, the CVM studies should fit into a minimal number of WTP categories. Since there are only 30 CVM studies, the use of only one or two categories would make sure that any eventual EF is based on as many data-points as possible (max 30). For this thesis, the number of categories could be brought down to two categories by recategorizing one category of the three categories in Table 2. The recategorization was done for the studies using "WTP per household per year" ($WTP(Y)_h$) which were recategorized into "WTP per person per year" ($WTP(Y)_p$) using the average household size (HS) for the year (y) and country (x) of the study - Equation (1) (Table 3). A total of 9 studies were recategorized in this way.

$$WTPY_{p,x,y} = \frac{WTPY_{h,x,y}}{HS_{x,y}} \tag{1}$$

Table 3 - Overview of variables used in Equation 1

Variable	Explanation	Unit
$\boldsymbol{WTP(Y)_{p,x,y}}$	Willingness-To-Pay per person per year for country "x" in year "y"	$\frac{USD}{person * year}$
$\boldsymbol{WTP(Y)_{h,x,y}}$	Willingness-To-Pay per household per year for country "x" in year "y"	$\frac{USD}{household * year}$
$\boldsymbol{HS_{x,y}}$	Average household size for country "x" in year "y"	#persons

Following this recategorization, the variables that are based on- or representing WTP per person per trip are recognized by a (T) whilst the variables that are based on- or representing WTP per person per year are recognized by a (Y).

Studies that showed a range of WTP based on the various interviewed groups were simplified to the average of the WTP over all the groups in the studies. This was done for 22 studies.

To further improve the comparability, the studies were adjusted for GDP growth, purchasing power, and converted to the same currency (USD). This was done in a three-step process.

(I) The WTP numbers (described here as: $WTP(T/Y)_{x,y}$) were first corrected using the cumulative real GDP growth rate (GR) from the year of the studies to the year 2020 – Equation (2) (Table 4) (The World Bank, 2020). This corrects the WTP numbers for GDP growth or crimping based on the country where the study was conducted and makes sure that further comparison is done using the same base year (2020).

$$WTP(T/Y)_{GDP,x,2020} = \prod_{y}^{2020} GR_{y+1} * WTP(T/Y)_{x,y} \quad (2)$$

Table 4 - Overview of variables used in Equation 2

Variable	Explanation	Unit
$\boldsymbol{GR_{y+1}}$	Real GDP growth rate for year “y”+1	%
$\boldsymbol{WTP(T/Y)_{x,y}}$	Willingness-To-Pay for country “x” in year “y”	$\frac{USD}{person * (trip \ \mathbf{or} \ year)}$
$\boldsymbol{WTP(T/Y)_{GDP,x,2020}}$	Willingness-To-Pay corrected for GDP growth for country “x” to the year 2020	$\frac{USD}{person * (trip \ \mathbf{or} \ year)}$
(T)	Based on Willingness-To-Pay per person per trip data	-
(Y)	Based on Willingness-To-Pay per person per year data	-

(II) Any studies that had calculated the WTP in a currency other than the local currency had to be changed back to the local currency. The average exchange rate for the used currency to the local currency for the year of the study was used for this (Exchange Rates, 2022). This step was necessary because the correcting for purchasing power with the use of the Purchasing Power Parity (PPP) is done using the local currency in comparison to USD. In total, 9 studies had their results converted back to the local currency.

(III) The WTP numbers that were corrected for GDP growth were then corrected for purchasing power using the PPP numbers for 2020 compared to the USD (OECD Data, 2021). This gave the corrected WTP numbers for the base year of 2020 ($WTP(T/Y)_{C,x,2020}$) - Equation (3) (Table 5).

$$WTP(T/Y)_{C,x,2020} = \frac{WTP(T/Y)_{GDP,x,2020}}{PPP_{x,2020}} \tag{3}$$

Table 5 - Overview of variables used in Equation 3

Variable	Explanation	Unit
$\boldsymbol{WTP(T/Y)_{C,x,2020}}$	Willingness-To-Pay corrected for GDP growth and Purchasing Power Parity for country "x" to the year 2020	$\frac{USD}{person * (trip\ \mathbf{or}\ year)}$
$\boldsymbol{WTP(T/Y)_{GDP,x,2020}}$	Willingness-To-Pay corrected for GDP growth for country "x" to the year 2020	$\frac{USD}{person * (trip\ \mathbf{or}\ year)}$
$\boldsymbol{PPP_{x,2020}}$	Purchasing Power Parity for country "x" in the year 2020	-
(T)	Based on Willingness-To-Pay per person per trip data	-
(Y)	Based on Willingness-To-Pay per person per year data	-

2.5. Baseline MPD pollution

The creation of an EF that assesses the monetary impact of MPD pollution required a coupling of the WTP numbers with a certain level of MPD pollution. The WTP numbers are interpreted as a direct representation of the level of (dis-)satisfaction with the local MPD pollution levels. Higher WTP numbers are then representative of a higher level of dissatisfaction with the local MPD levels whilst lower WTP number show a higher satisfaction. This reasoning is supported by the general idea that increased uncleanliness on beaches leads to negative economic impacts for tourism (McIlgorm et al., 2011; McIlgorm et al., 2022). By using the WTP numbers as a measure of dissatisfaction, they can be combined with local MPD pollution numbers to find the impact per unit of MPD pollution. Combining those numbers can reveal for different regions how impactful MPD pollution is on recreational value.

2.5.1. MPD pollution on the beach

Beach clean-up data for specific countries (x) and years (y) were available through the Ocean Conservancy Clean up reports (Ocean Conservancy, 2022). In these reports, the data was retrieved from the "ocean trash index". From the tables presented in the ocean trash index, data was retrieved on the weight of MPD that was cleaned up and the coastal length that was cleaned during that year. The weight of the cleaned MPD (MPD_{weight}) was combined with the cleaned coastal length (CL) to reveal the MPD density in kilogram per coastal kilometre (MPD_{dens}) - Equation (4) (Table 6).

$$MPD_{dens,x,y} = \frac{MPD_{weight,x,y}}{CL_{x,y}} \tag{4}$$

Table 6 - Overview of variables used in Equation 4

Variable	**Explanation**	**Unit**
$\boldsymbol{MPD_{dens,x,y}}$	Density of MPD pollution on the beach for country "x" in year "y"	Kg/km
$\boldsymbol{MPD_{weight,x,y}}$	Total weight of MPD pollution gathered for country "x" in year "y"	Kg
$\boldsymbol{CL_{x,y}}$	Total coastal length over which MPD pollution was cleaned for country "x" in year "y"	km

In addition to the MPD pollution per kilometre for the study year, the average MPD pollution over the years 2016-2021 was calculated. The reason to use two types of data for the MPD pollution was to test if the MPD pollution found for the study year differed significantly from the average over several years and to see if people's WTP was more affected by the MPD pollution over a longer period or by the specific MPD pollution levels for the study year. To differentiate between the two types of pollution, the formula reads $MPD_{dens,(A),x,y}$ for the average MPD pollution numbers and $MPD_{dens,(S),x,y}$ for the study year MPD pollution numbers.

2.6. Recreational value loss

Combining the corrected WTP numbers with the baseline MPD densities for the year and each country gives the value loss associated with a certain amount of MPD pollution. This value loss can be described in two ways. The first describes how many kilograms of MPD pollution per kilometre cause one USD in value loss ($MPD_{per\_USD,x,y}$) - Equation (5) (Table 7). The second describes how much value loss one kilogram of MPD pollution per kilometre causes ($VL_{per\_dens,x,y}$) - Equation (6) (Table 7). Both factors are in practice the other's inverse and only differ in the way the results are presented.

$$MPD(T/Y)_{per\_USD,(A/S),x,y} = \frac{MPD_{dens,(A/S),x,y}}{WTP(T/Y)_{C,x,2020}} \tag{5}$$

$$VL(T/Y)_{per\_dens,(A/S),x,y} = \frac{WTP(T/Y)_{C,x,2020}}{MPD_{dens,(A/S),x,y}} \tag{6}$$

Table 7 - Overview of variables used in Equations 5 and 6

Variable	Explanation	Unit
$\boldsymbol{MPD(T/Y)_{per\_USD,(A/S),x,y}}$	Density of MPD pollution per USD in recreational value loss for country "x" in year "y"	$\frac{kg * person * (trip\ \mathbf{or}\ year)}{km * USD}$
$\boldsymbol{MPD_{dens,x,y}}$	Density of MPD pollution on the beach for country "x" in year "y"	Kg/km
$\boldsymbol{WTP(T/Y)_{C,x,2020}}$	Willingness-To-Pay corrected for GDP growth and Purchasing Power Parity for country "x" to the year 2020	$\frac{USD}{person * (trip\ \mathbf{or}\ year)}$
$\boldsymbol{VL(T/Y)_{per\_dens,(A/S),x,y}}$	Recreational value loss per kilogram per kilometre (density) MPD pollution for country "x" in year "y"	$\frac{USD * km}{person * (trip\ \mathbf{or}\ year) * kg}$
(T)	Based on Willingness-To-Pay per person per trip data	-
(Y)	Based on Willingness-To-Pay per person per year data	-
(A)	Based on average MPD pollution for the years 2016-2021	-
(S)	Based on the MPD pollution for the study year	-

2.7. Cleaning costs

In addition to the value that is lost through the effect that MPD pollution has on marine recreation, there are costs associated with the cleaning of the MPD pollution on the beaches. The occurrence of such costs is reliant on there being local or regional regulations in place to uphold certain standards or volunteering practices like the Ocean Conservancy organisation (see also chapter 2.2.). The cleaning costs used in this thesis are based on the average of what is found in relevant literature. The main two sources (McIlgorm et al., 2011; Winterstetter et al., 2021) revealed an average cost of 1500 USD/tonne MPD - and 600 USD/tonne MPD, respectively. Based on these numbers, an average cleaning cost of 1050 USD/tonne MPD (CC_{tonne}) was used.

2.8. Correlation analysis

The combining of the WTP with the MPD pollution levels is likely to give different results for different countries. Results may however be similar for countries in a specific region or for countries with the same level of economic- or human development. To test if this true, three correlation analyses were done.

The first correlation analysis involved the WTP results that were tested for correlations with the average- (A) and the study year (S) MPD pollution numbers. The same WTP results were in addition tested for correlations with the HDI, and the GDP per capita for the country and year in which the study was conducted.

The second correlation analysis involved the Value Loss (VL) results that were combined with the Human Develop Index (HDI) and GDP per capita and tested for correlations. In total, four types of value loss based on the WTP type (T/Y) and MPD pollution type (A/S) were used in this analysis.

The third correlation analysis involved testing for correlations based on study location. For this, the first two analyses were repeated after the studies were grouped by continent.

The HDI and the GDP per capita were used to test whether the WTP or Value loss were most strongly correlated to human development (HDI) or purely economic development (GDP per capita). Although the HDI is based partially on economic development since (Gross National Income), the factor was still deemed sufficiently different from the GDP per. The strength of all correlations was assessed using the R square method that explains what share of the total variance is explained by the regression curve (Corporate Finance Instititue, 2022).

2.8.1. Human Development Index

The HDI was used to assess if the WTP and VL results were linked to the level of human development in a country. The HDI is a metric that measures the level of development in a country based on three main pillars: health, knowledge, and standard of living (Stanton, 2007; World Health Organization, 2022). It is and index that looks beyond economic development alone and was used in this thesis to assess if the WTP for the reduction of MPD pollution was linked predominantly to economic development or to human development (HDI). The HDI numbers were retrieved for the year in which the study was done and for the country in which the study was conducted (United Nations Development Programme, 2020) and coupled with the WTP numbers (T/Y) and the value loss numbers $(T/Y)_{(A/S)}$. Regression curves were set to intercept at X=0, Y=0 since a country that has no human development would not have any resources to spend on MPD reduction.

2.8.2. GDP per capita

To test if there is a correlation between the economic development in a country and the WTP for the reduction of MPD pollution, the metric “GDP per capita” was used. Whereas the HDI is based on the Gross National Income (GNI) combined with knowledge and health factors (World Health Organization, 2022), the GDP per capita is a purely economic metric that uses the total economic production divided by the population (per capita) (The World Bank, 2020). It was used in this thesis to test specifically for the relationship between the economic development in a country and the WTP (T/Y) and VL $(T/Y)_{(A/S)}$ results. The GDP per capita numbers used were retrieved for the year in which the study was done and for the country in which the study was conducted (The World Bank, 2020) and coupled with the WTP numbers (per year and per trip) and the value loss numbers (per year and per trip). Regression curves were again set to intercept at X=0, Y=0 since a country with a GDP per capita of zero would not have any resources to spend on MPD pollution reduction.

2.8.3. Location

The testing for correlations regionally was done by sorting the results into one of five continents (Asia, Europe, North America, South America, or Oceania) based on to the study locations. Africa was not included since no studies from the dataset were conducted on this continent. If a continent had a high enough number of studies (n>5), the numbers from the studies for specifically that continent were further tested for correlations using the same correlation analyses used before.

2.8.4. Overview correlation analyses

An overview of all the correlation analyses that were tested is provided in Table 8.

Table 8 - Overview of combinations of variables that were tested for correlations. (T) = WTP per person per trip, (Y) = WTP per person per year, (A) = Average MPD pollution, (S) = Study year MPD pollution, HDI = Human Development Index, GDP = GDP per capita

	WTP (T)	**VL (T)$_{(A)}$**	**VL (T)$_{(S)}$**	**WTP (Y)**	**VL (Y)$_{(A)}$**	**VL (Y)$_{(S)}$**
(S)	X			X		
(A)	X			X		
HDI	X	X	X	X	X	X
GDP	X	X	X	X	X	X

The location-based correlation analysis involves the same tests as displayed in Table 8 for studies from the same continent.

2.9. Predicting WTP and Value Loss

The correlation analysis was done to be able to predict WTP based on either MPD pollution levels, HDI, GDP per capita or location and VL based on either HDI, GDP per capita, or location. The ability to predict these values makes it possible to estimate them for any country or region. The strength of the correlations can show which variable is most suited for this. Estimating the value of the WTP or VL is based on the regression curve that is retrieved from the correlation analyses. For the WTP or VL, the value is therefore dependent on the regression coefficient "φ" that is retrieved from the correlation analysis and the value "B" that is the country's HDI, GDP per capita, or local MPD pollution (average or for the study year) - Equation (7) and (8) (Table 9).

$$WTP(T/Y)_{est,x,y} = \varphi * B_{x,y} \tag{7}$$

$$VL(T/Y)_{est,(A/S),x,y} = \varphi_{(A/S)} * B_{x,y} \tag{8}$$

Table 9 - Overview of variables used in Equation 7 and 8

Variable	Explanation	Unit
$\boldsymbol{WTP(T/Y)_{est,x,y}}$	Estimate of the willingness-To-Pay for country "x" in year "y"	$\frac{USD}{person * (trip\ \mathbf{or}\ year)}$
$\boldsymbol{VL(T/Y)_{est,(A/S),x,y}}$	Estimate of the recreational value loss per kilogram per kilometre (density) MPD pollution for country "x" in year "y"	$\frac{USD * km}{person * (trip\ \mathbf{or}\ year) * kg}$
φ	Regression coefficient	-
$\boldsymbol{B_{x,y}}$	HDI, GDP per capita, or local MPD pollution of country "x" in year "y"	HDI (0-1), USD, or kg/km
(T)	Based on Willingness-To-Pay per person per trip data	-
(Y)	Based on Willingness-To-Pay per person per year data	-
(A)	Based on average MPD pollution for the years 2016-2021	-
(S)	Based on the MPD pollution for the study year	-

The VL can only be calculated using the HDI or the GDP per capita because a correlation analysis with local MPD pollution levels would lead to interdependency issues. The inflow of MPD directly impacts the local MPD pollution levels which links variable VL_{est} and the local MPD pollution levels together. The calculation of the VL can therefore only be done by using either the HDI or the GDP per capita as a predictor ("B"). The choice for either would be dependent on the strength of the correlations found from the studies assessed in this thesis.

2.10. Modelling an Effect Factor

The cleaning of MPD pollution has a direct effect on the value loss that is caused by the presence of MPD pollution. Following the same assumption used earlier that when there is no MPD pollution, people have a WTP of zero, there would no longer be any recreational value loss directly after a clean-up. To be able to account for both the cleaning costs and the value loss caused by the presence of MPD pollution, the EF needs to model the value loss that is caused "in between" each clean-up. The EF that is described here calculates the costs per kilogram of MPD pollution for one year. The cleaning process is then simplified to hypothetically occur once a year. In practice, cleaning activities can happen at any time during the year, but this is impossible to include in a static model like LCA. The simplification to one hypothetical cleaning a year allows the EF to account for the costs for both the cleaning and the recreational value loss without losing the negating effect of cleaning on the recreational value loss. The total costs then describe the total costs that are caused by an inflow of MPD pollution for one specific year. Each new year, the costs are in a way "reset". The inflow of MPD should then also always be specified for that year.

Based on this, using the previously described variables, an EF can be set up that describes the costs caused per kg of MPD pollution. For both the "VL(T)" and the "VL(Y)" one has to multiply with the population for country "x" in year "y" ($p_{x,y}$) and divide by the coastal length ($km_{coast,x,y}$). For the "VL(T)" however, an additional multiplication with the number of trips to the beach per person for the "WTP per person per trip" ($trips_{x,y}$) is necessary. In doing so, both formulas calculate the EF that is the costs for cleaning and recreational value loss based on either "WTP per person per trip" (T) or "WTP per person per year" (Y) and the average- (A) or study year (S) MPD pollution numbers ($EF(T/Y)_{(A/S)}$) per kg of MPD pollution – Equation (9) and (10) (Table 10).

$$EF(T)_{country,(A/S),x,y} = \frac{VL(T)_{per_{dens},(A/S),x,y} * p_{x,y} * trips_{x,y}}{km_{coast,x}} + CC_{tonne} \tag{9}$$

$$EF(Y)_{country,(A/S),x,y} = \frac{VL(Y)_{per_{dens},(A/S),x,y} * p_{x,y}}{km_{coast,x,y}} + CC_{tonne} \tag{10}$$

Table 10 - Overview of variables used in Equation 9 and 10

Variable	Explanation	Unit
$\boldsymbol{EF(T/Y)_{country,(A/S),x,y}}$	Total costs for value loss and cleaning costs per kg MPD for country "x" in year "y"	$\frac{USD}{kg}$
$\boldsymbol{VL(T/Y)_{per_{dens},(A/S),x,y}}$	Recreational value loss per kilogram per kilometre (density) MPD pollution for country "x" in year "y"	$\frac{USD * km}{person * (trip\ \mathbf{or}\ year) * kg}$
$\boldsymbol{p_{x,y}}$	Population for country "x" in year "y"	#persons
$\boldsymbol{trips_{x,y}}$	Average number of trips to the coast for people from country "x" in year "y"	#trips
$\boldsymbol{km_{coast,x}}$	Total coastal length for country "x"	Km
$\boldsymbol{CC_{tonne}}$	Cleaning costs per kg of MPD pollution	$\frac{USD}{kg}$
(T)	Based on Willingness-To-Pay per person per trip data	-
(Y)	Based on Willingness-To-Pay per person per year data	-
(A)	Based on average MPD pollution for the years 2016-2021	-
(S)	Based on the MPD pollution for the study year	-

A further elaboration of the units of the formulas can be shown - Equation (11) and (12). Note that for the year-based EF ($EF(Y)_{country,x,y}$), the "year" variables would always be equal to "1" since the EF calculates costs per density MPD pollution per year. This is also the reason that it is not included in equation (10).

$$\frac{USD}{kg} = \frac{\frac{USD * km}{person * (trip\ \mathbf{or}\ year) * kg} * person * (trip\ \mathbf{or}\ year)}{km} + \frac{USD}{kg} \tag{11}$$

$$\frac{USD}{kg} = \frac{\frac{USD * \cancel{km}}{\cancel{person} * (\cancel{trip\ \mathbf{or}\ year}) * kg} * \cancel{person} * (\cancel{trip\ \mathbf{or}\ year})}{\cancel{km}} + \frac{USD}{kg} \tag{12}$$

The EF based on the WTP per person per trip (T) may also be adapted to estimate the costs for a smaller region. Instead of using the country's population and average number of trips per year, the total number of visitors to that specific region can be used instead. The total number of visitors to a region implicitly represents the population of a country multiplied with the average number of trips *to specifically that region*. As a result, for a region with one or several beaches, the number of yearly visitors can be used instead of the country's population coupled with the average number of trips per year. A new formula for the costs per kg MPD for region "z" in country "x" for the year "y" can be described accordingly – Equation (13) (Table 11).

$$EF(T)_{region,(A/S),z,x,y} = \frac{VL(T)_{per_{dens},(A/S),x,y} * visitors_{z,y}}{km_{coast,z,y}} + CC_{tonne} \tag{13}$$

Table 11 - Overview of variables used in Equation 13

Variable	Explanation	Unit
$\boldsymbol{EF(T)_{region,(A/S),z,x,y}}$	Total costs for value loss and cleaning costs per kg MPD for region "z" in country "x" in year "y"	$\frac{USD}{kg}$
$\boldsymbol{VL(T)_{per_{dens},(A/S),x,y}}$	Recreational value loss per kilogram per kilometre (density) MPD pollution for country "x" in year "y"	$\frac{USD * km}{person * trip * kg}$
$\boldsymbol{visitors_{z,y}}$	Total number of visitors to region "z" in year "y"	#visitors
$\boldsymbol{km_{coast,x}}$	Total coastal length for country "x"	Km
$\boldsymbol{CC_{tonne}}$	Cleaning costs per kg of MPD pollution	$\frac{USD}{kg}$
(T)	Based on Willingness-To-Pay per person per trip data	-
(A)	Based on average MPD pollution for the years 2016-2021	-
(S)	Based on the MPD pollution for the study year	-

The EFs can expanded to include the predictor formula for recreational value loss. The formula to predict VL can be used directly in the previously described EFs to replace the VL variable. Including this formula, adding the regression coefficient "φ" and predictor variable "B" for the calculation of the VL, then presents the full EFs - Equations (14), (15) & (16) (Table 12).

$$EF(T)_{country,(A/S),x,y} = \frac{(\varphi_{(A/S)} * B_{x,y}) * p_{x,y} * trips_{x,y}}{km_{coast,x,y}} + CC_{tonne} \quad (14)$$

$$EF(Y)_{country,(A/S),x,y} = \frac{(\varphi_{(A/S)} * B_{x,y}) * p_{x,y}}{km_{coast,x,y}} + CC_{tonne} \quad (15)$$

$$EF(T)_{region,(A/S),z,x,y} = \frac{(\varphi_{(A/S)} * B_{x,y}) * visitors_{z,y}}{km_{coast,z,y}} + CC_{tonne} \quad (16)$$

Table 12 - Overview of variables used in Equations 14, 15, and 16

Variable	Explanation	Unit
$\boldsymbol{EF(T)_{country,(A/S),x,y}}$	Total costs for value loss and cleaning costs per kg MPD based on the WTP per person per trip for country "x" in year "y"	$\frac{USD}{kg}$
$\boldsymbol{EF(Y)_{country,(A/S),x,y}}$	Total costs for value loss and cleaning costs per kg MPD based on the WTP per person per year for country "x" in year "y"	$\frac{USD}{kg}$
$\boldsymbol{EF(T)_{region,(A/S),z,x,y}}$	Total costs for value loss and cleaning costs per kg MPD for region "z" in country "x" in year "y"	$\frac{USD}{kg}$
$\boldsymbol{\varphi_{(A/S)}}$	Regression coefficient	-
$\boldsymbol{B_{x,y}}$	HDI, GDP per capita, or local MPD pollution	HDI (0-1), USD, or kg/km
$\boldsymbol{p_{x,y}}$	Population for country "x" in year "y"	#persons
$\boldsymbol{trips_{x,y}}$	Average number of trips to the coast for people from country "x" in year "y"	#trips
$\boldsymbol{visitors_{z,y}}$	Total number of visitors to region "z" in year "y"	#visitors
$\boldsymbol{km_{coast,x}}$	Total coastal length for country "x"	Km
$\boldsymbol{CC_{tonne}}$	Cleaning costs per kg of MPD pollution	$\frac{USD}{kg}$
(T)	Based on Willingness-To-Pay per person per trip data	-
(Y)	Based on Willingness-To-Pay per person per year data	-
(A)	Based on average MPD pollution for the years 2016-2021	-
(S)	Based on the MPD pollution for the study year	-

2.11. Example cases

To show how the EF might be used, example cases were set up with a simplified Fate Factor (FF) for three countries and three regions. The costs for year "y" associated with the inflow of a certain amount MPD pollution can be described by simple multiplication of the EF and the FF to form a simplified version of an eventual Characterization Factor (CF) - Equation (17) (Table 13).

$$CF(T/Y)_{MPD,(A/S),(z),x,y} = EF(T/Y)_{(A/S),(z),x,y} * FF_{x/z,y} \tag{17}$$

Table 13 - Overview of variables used in Equation 17

Variable	Explanation	Unit
$\boldsymbol{CF(T/Y)_{MPD,(A/S),(z),x,y}}$	Total costs associated with an effective inflow of MPD pollution for (region "z" in) country "x" in year "y"	USD
$\boldsymbol{EF(T/Y)_{(A/S),(z),x,y}}$	Costs for value loss and cleaning costs per kg MPD for (region "z" in) country "x" in year "y"	$\frac{USD}{kg}$
$\boldsymbol{FF_{x/z,y}}$	Effective inflow of MPD pollution for country "x" **or** region "z" in year "y"	Kg
(T)	Based on Willingness-To-Pay per person per trip data	-
(Y)	Based on Willingness-To-Pay per person per year data	-
(A)	Based on average MPD pollution for the years 2016-2021	-
(S)	Based on the MPD pollution for the study year	-

The FF used in the example cases is simplified to represent a measure of the total effective inflow of the MPD pollution onto the beach. All inflow in this simplified formula is impacting the total costs per kg of MPD presented in the EF. For all the example cases, the study year MPD pollution numbers (S) are used whilst both the EF based on the "WTP per person per trip" (T) and the EF based on the "WTP per person per year" (Y) were used.

The first application was done for three countries based on an increase in the density of MPD per kilometre of coast. The example countries were the Netherlands in 2017 (Brouwer et al., 2017), Benin in 2021 (Houngbeme et al., 2021), and South Africa in 2015 (Lucrezi & Van der Merwe, 2015). Both the example CFs using the EF based on the WTP per person per trip (T) and the CF using the EF based on the WTP per person per year (Y) were used for these cases. The inflow of MPD for each country was adapted such that all countries used in the example would have the same increase in the density of MPD pollution on their beaches. This allowed for easier comparison of the differences between the impacts for different countries based on a similar increase in MPD pollution density. A country with a coastline of 100 kilometre would consequently have an inflow of 2500 kilogram of MPD whilst a country with a coastline of 1500 kilometre would have an inflow of 37,500 kilogram of MPD. The needed data for the example cases were retrieved from the case studies (average number of trips to the beach per year, GDP per capita in year "y", HDI in year "y") (Brouwer et al., 2017; Houngbeme et al., 2021; Lucrezi & Van der Merwe, 2015; The World Bank, 2020; United Nations Development Programme, 2020) or from simple google searches (population in year "y", coastline length).

The second application was based on the example CF using the EF based on the WTP per person per trip (T) to calculate the impact of an inflow of MPD for a specific region. The regions that were used were Delaware's Bay – United States in 2013 (Parsons et al., 2013), Rhodes Island – Greece in 2021 (Vandarakis et al., 2021), and the Southern Californian Beaches – United States in 2007 (Dwight et al., 2007). The regions were chosen based on what data could be found for the total number of visitors per year to these regions. For these cases, the number of visitors to the region for year "y" was retrieved from studies (Dwight et al., 2007; Parsons et al., 2013; Vandarakis et al., 2021) whilst the HDI and GDP per capita were based on the numbers for the country the region was in (The World Bank, 2020; United Nations Development Programme, 2020). Coastline length was based on numbers found in the study that was the source for the visitor numbers or from simple google searches.

The results from the example cases for the countries are given as the CFs based on the $EF(T)_{country,(S),x,y}$ or the $EF(Y)_{country,(S),x,y}$ ($CF(T)_{MPD,(S),x,y}$ or $CF(Y)_{MPD,(S),x,y}$) using either the HDI or the GDP per capita as predictors for the recreational value loss. The results from the example cases for the regions is given as the CF based on the $EF(T)_{region,(S),z,y}$ ($CF(T)_{MPD,(S),z,y}$) using HDI or the GDP per capita as predictors for the recreational value loss.

3. Results

3.1. Descriptive statistics

A total of 41 studies were collected that mentioned and/or quantified the impact of MPD on coastal recreation. The review of these studies revealed a total of 30 studies using CVM, 6 studies using TEV, and 5 studies using no valuation methods (NV) (see Appendix A). 27 of the 30 CVM studies were used in the further development of the EF. Three CVM studies were excluded based on WTP results not being specific for MPD pollution (Rulleau et al., 2012), the use of a WTP category that could not be recategorized (Schuhmann et al., 2016), or difficulties in the interpretation of the results (Khedr et al., 2021). For the remaining CVM studies used in this thesis, the research was mostly done in the 2010s (Figure 2).

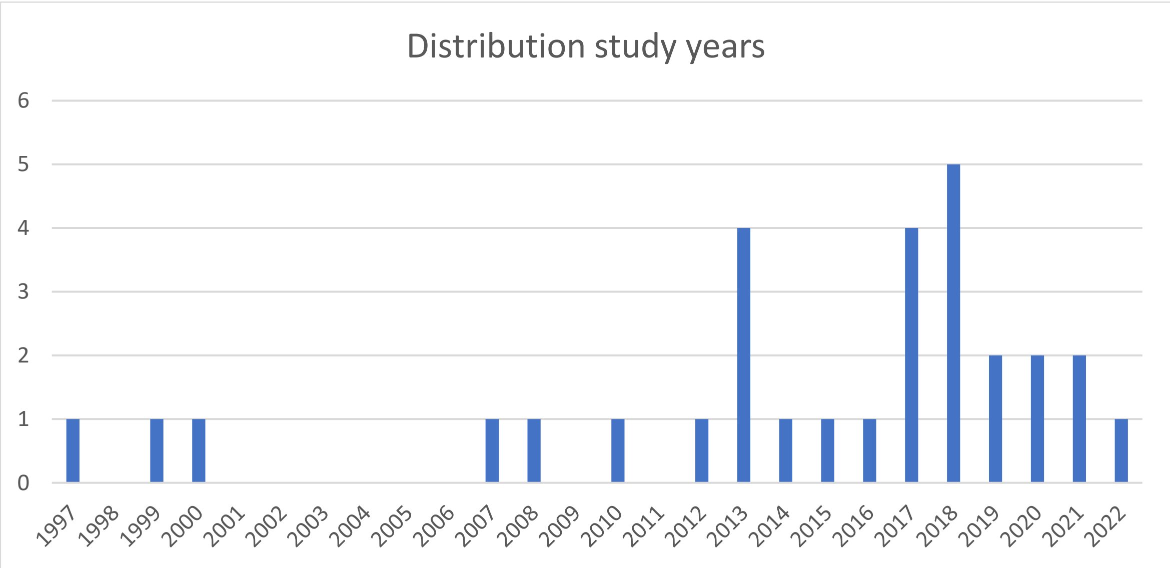

Figure 2 - Distribution of the publication years for the CVM studies used for the development of the EFs

Geographically, the research was spread over several regions around the world with only a slight concentration in Turkey where four studies had been conducted (Figure 3).

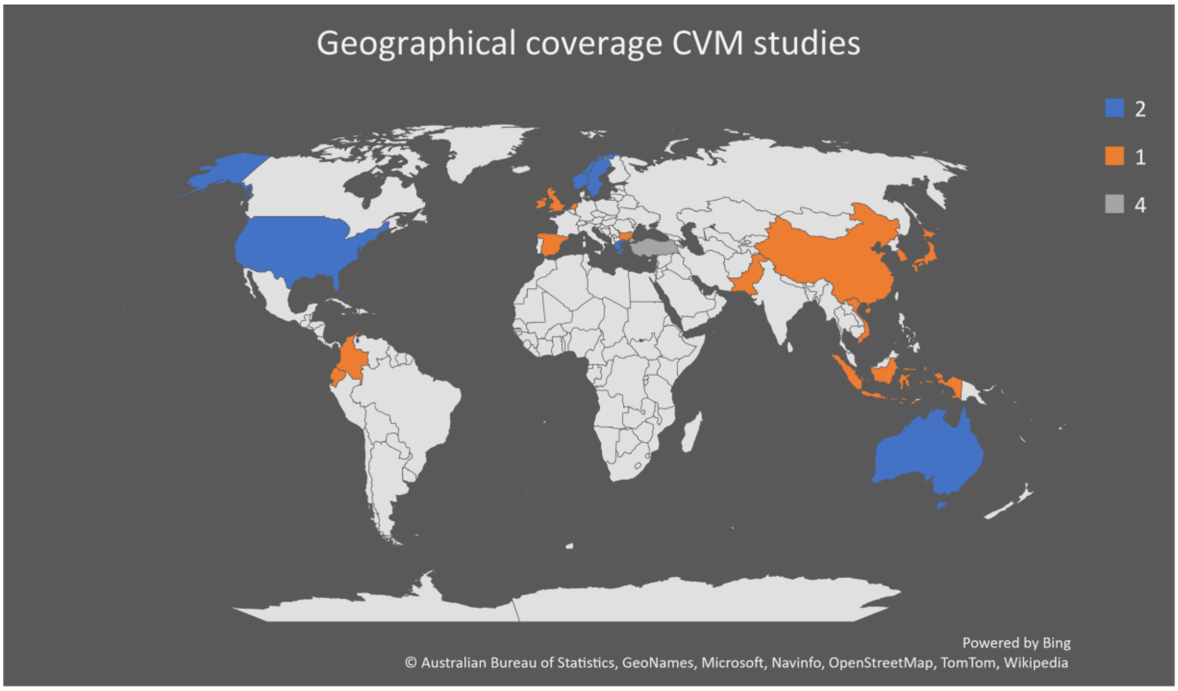

Figure 3 - Geographical coverage of the CVM studies used for the development of the EF

Other regions that had more than one study conducted were Norway, Sweden, Australia, and the United States. No studies on the impact of MPD on coastal tourism were found in Africa, large parts of South- and Middle America, and North-Western Asia.

3.2. WTP numbers

The WTP categories varied among the CVM studies and included (I) “WTP per person per trip”, (II) “WTP per person per year”, (III) “WTP per household per year”, and (IV) “WTP per 2 persons per night (hotel)”. The “WTP per household per year” numbers were recategorized to “WTP per person per year” by using the average household sizes for the country in the year the study was conducted. The one study that used the “WTP per 2 persons per night” (Schuhmann et al., 2016) could not be refitted into “WTP per person per trip” or “WTP per person per year” and was therefore left out of any further analysis. The two main categories were then “WTP per person per trip” with 10 studies and “WTP per person per year” with 17 studies. The WTP numbers in these two categories were corrected for inflation and GDP growth using Real GDP growth and Purchasing Power Parity (PPP) (International Monetary Fund, 2022; OECD Data, 2021) (Appendix B – Table B6).

A box-and-whisker diagram for the WTP numbers for both the “WTP per person per trip” and “WTP per person per year” shows the distribution and outliers in the resulting data (Figure 4).

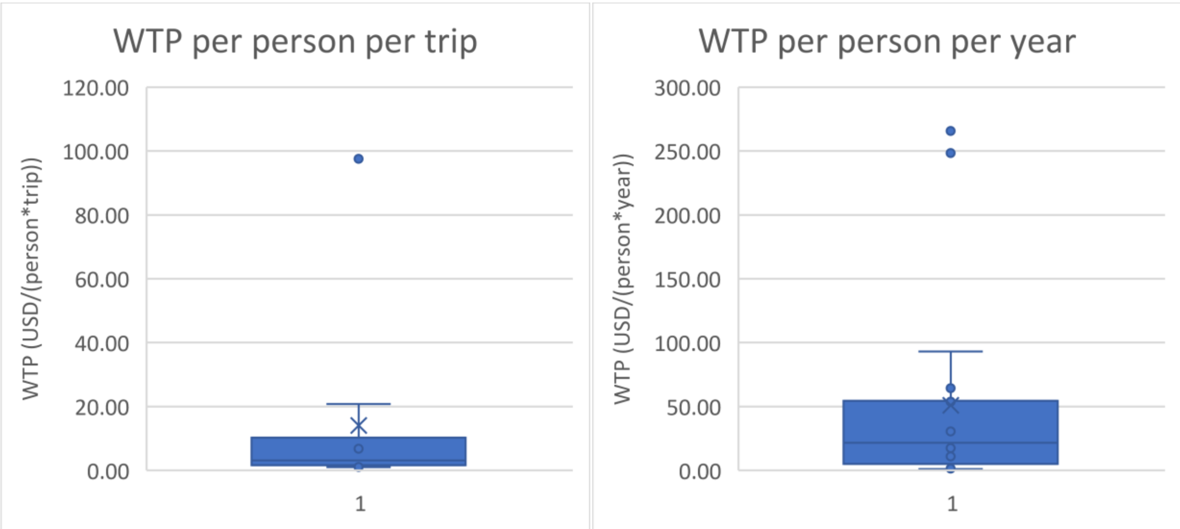

Figure 4 - Box-and-whisker diagrams displaying the distribution and outliers for the WTP per person per trip and WTP per person per year data

The “WTP per person per trip” numbers ranged from \$1.06 to \$97.52 with an average of \$14.08. Based on the Figure 4, a study done in Puerto Rico with the highest WTP (\$97.52) (Loomis & Santiago, 2013) was treated as an outlier.

For the “WTP per person per year” the numbers ranged from \$1.08 to \$265.55 with an average of \$50.85. Based again on the diagram in Figure 4, two studies were treated as outliers with WTP numbers of \$265.55 for a study done in Colombia (Enriquez-Acevedo et al., 2018) and

$248.26 for a study done in Norway (Abate et al., 2020). The third highest WTP was found at $93.04 for a Swedish study (Östberg et al., 2013).

An overview of all the WTP results can be found in Appendix B in Table B1 and Table B2.

3.3. Baseline MPD pollution

Based on the beach clean-up reports (Ocean Conservancy, 2022), a reference level could be set for the presence of MPD for each study area in the respective years when the study was conducted (Appendix A, Table B3). In addition to the MPD density for the study year, the average MPD density per year from clean-up data for the years 2016-2021 was included.

The differences between MPD pollution data for the study year and the average over the years 2016-2021 were small for most studies. Only 3 out of the 30 studies had an MPD pollution density in the study year that differed more than one standard deviation from the average (2016-2021) MPD pollution number (Beharry-Borg & Scarpa, 2010; Smith et al., 1997; Tyllianakis & Ferrini, 2021). The average MPD pollution for the study year MPD pollution was 273 kg/km whilst the average for the average (2016-2021) MPD pollution was 246 kg/km.

3.4. Value loss numbers

Using the reference levels from the beach clean-up reports, the value-loss per kg of MPD was calculated for both types of WTP (T/Y) resulting in four types of Value Loss (VL) numbers: VL per person per trip using (I) study year MPD pollution numbers and (II) average (2016-2021) MPD pollution numbers and VL per person per year using (III) study year MPD pollution numbers and (IV) average (2016-2021) MPD pollution numbers (Appendix B, Table B4 & B5).

An overview of the range of values found for the value loss for all the four types including the lowest, highest, and average value is displayed in Table 14. An explanation of the VL variables can be found in Table 7.

Table 14 - Distribution of Value Loss numbers

	Value loss (USD) per kg/km per person per trip		Value loss (USD) per kg/km per person per year	
	Study year MPD (I)	*Average MPD (II)*	*Study year MPD (III)*	*Average MPD (IV)*
Variable	*VL(T)(S)*	*VL(T)(A)*	*VL(Y)(S)*	*VL(Y)(A)*
Lowest value	2.18E-03	3.03E-03	7.99E-04	1.31E-03
Highest Value	8.93E-01	8.19E-01	1.94E+00	1.47E+00
Average Value	1.79E-01	1.73E-01	4.23E-01	3.20E-01

3.5. Correlation analysis

The results for both the WTP numbers and the VL numbers were used in three correlation analyses (see chapter 2.8.) to assess the strength of any correlation with the HDI, GDP per capita, or MPD pollution numbers for the country and the year in which the study was conducted. The results for the WTP per person per trip and VL per person per trip are shown followed by the results for the WTP per person per year and the VL per person per year. Only the charts with the strongest correlations are displayed in this chapter whilst an overview of all the correlation strengths (R^2) and the corresponding regression coefficient (φ) is provided at the end of the chapter (Table 16 & Table 17). Appendix C gives an overview of some additional correlation charts for each category that showed a high R^2.

3.5.1. WTP per person per trip

The main correlation analysis for WTP per person per trip was done excluding two studies done in Puerto Rico (Talpur et al., 2018) and Pakistan (Loomis & Santiago, 2013).

The WTP numbers were most strongly correlated with the HDI (R^2=0.77, φ=3.72e+0) (Figure 5). For the study year MPD pollution numbers and the average MPD pollution numbers, the study year numbers correlated the strongest with the WTP numbers (R^2=0.59, φ=6.11e-3).

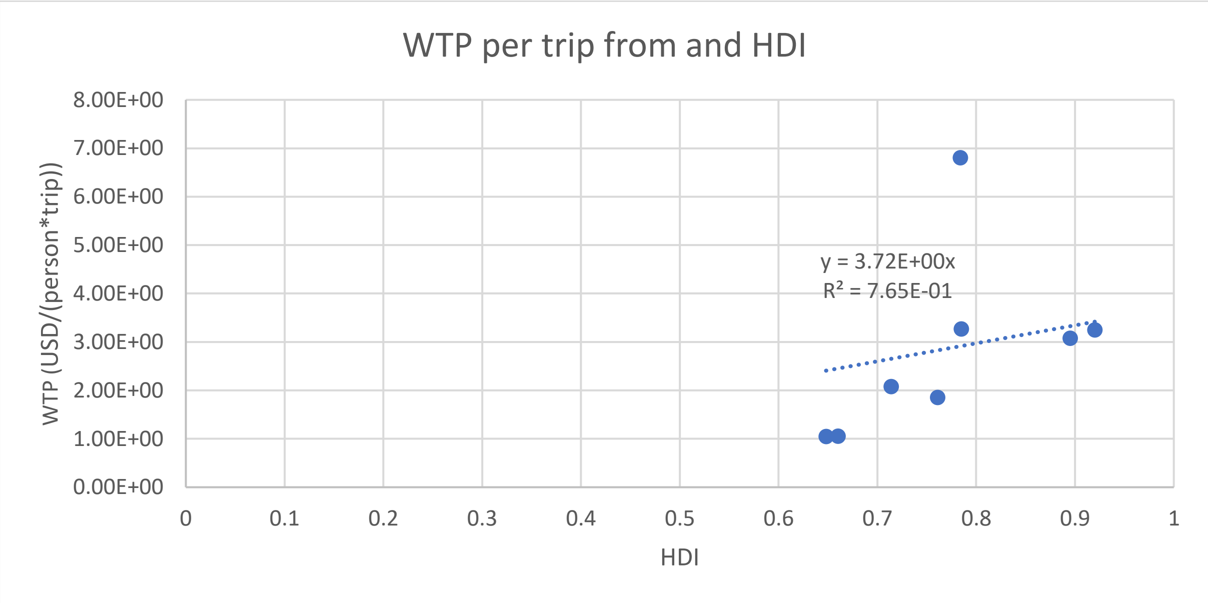

Figure 5 - Correlation chart for WTP per person per trip and HDI. Chart shows correlation excluding outliers Pakistan & Puerto Rico. Variables: WTP(T)xHDI.

For the VL per person per trip numbers, the strongest correlations were found with GDP per capita for both the value loss numbers based on the study year MPD pollution numbers (R^2=0.81, $\varphi_{(S)}$=5.57e-7) and the average MPD pollution numbers (R^2=0.88, $\varphi_{(A)}$=7.09e-7) (Figure 6). The correlation with the HDI was strongest for the study year MPD numbers (R^2=0.74, $\varphi_{(S)}$=1.60e-2).

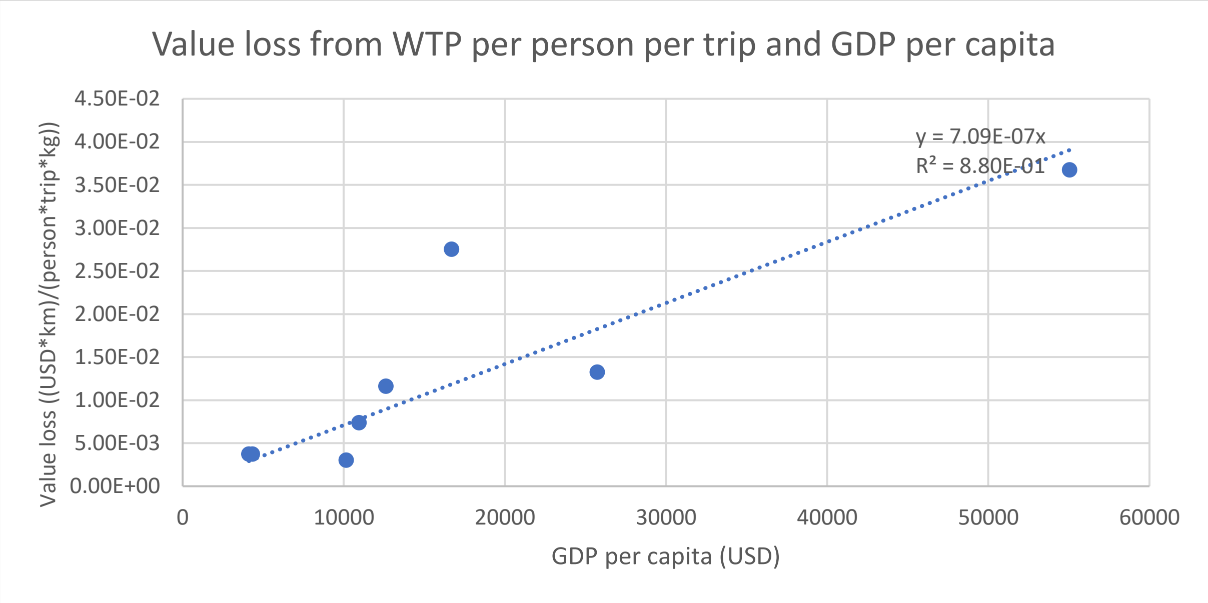

Figure 6 - Correlation chart for Value Loss based on WTP per person per trip and average MPD pollution compared with GDP per capita. Chart shows correlation excluding outliers Pakistan & Puerto Rico. Variables: VL(T)$_{(A)}$xGDP.

After sorting the data for WTP per person per trip and VL per person per trip by continent, it was found that on none of the continents, the minimum of five studies had been conducted. The WTP per person per trip and VL per person per trip numbers were consequently not tested for correlations based on location (see also chapter 2.8.3).

3.5.2. WTP per person per year

The correlation analysis for the WTP per person per year numbers was done excluding three studies (Abate et al., 2020; Choi & Lee, 2018; Enriquez-Acevedo et al., 2018). For the value loss numbers, only two studies were excluded depending on the MPD pollution numbers that were used. For the average MPD pollution numbers, a study conducted in South Korea (Choi & Lee, 2018) and a study conducted in Norway (Abate et al., 2020) were excluded. For the study year MPD pollution numbers the same study conducted in South Korea (Choi & Lee, 2018) and a study conducted in Colombia (Enriquez-Acevedo et al., 2018) were excluded.

The WTP numbers were most strongly correlated with the HDI (R^2=0.54, φ=3.25e+1) (Figure 7). For the two types of MPD pollution numbers, the average MPD numbers showed the strongest correlation with the WTP numbers (R^2=0.27, φ=8.25e-2).

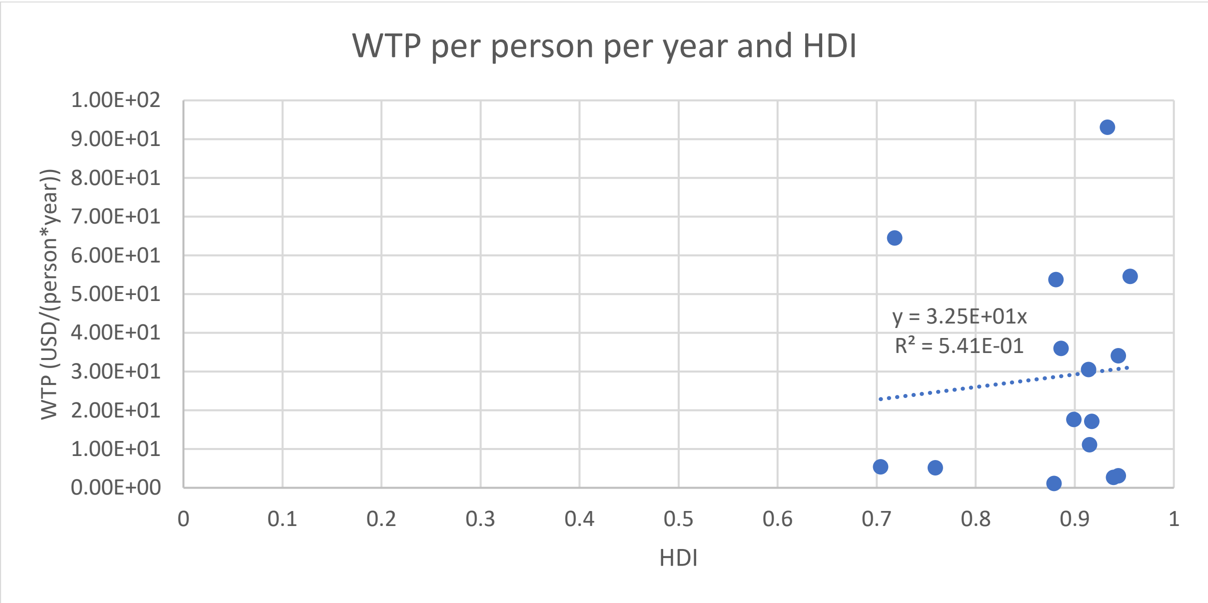

Figure 7 - Correlation chart for WTP per person per year and HDI. Chart displays correlation excluding outliers Norway, South Korea, and Colombia. Variables: WTP(Y)xHDI.

For the value loss numbers based on the WTP per person per year, the strongest correlation was found with GDP per capita using the study year MPD numbers (R^2=0.52, $\varphi_{(S)}$=8.38e-6) (Figure 8). For the HDI, it was found that the strongest correlation was with the value loss numbers based on the study year MPD numbers (R^2=0.45, $\varphi_{(S)}$=4.12e-1).

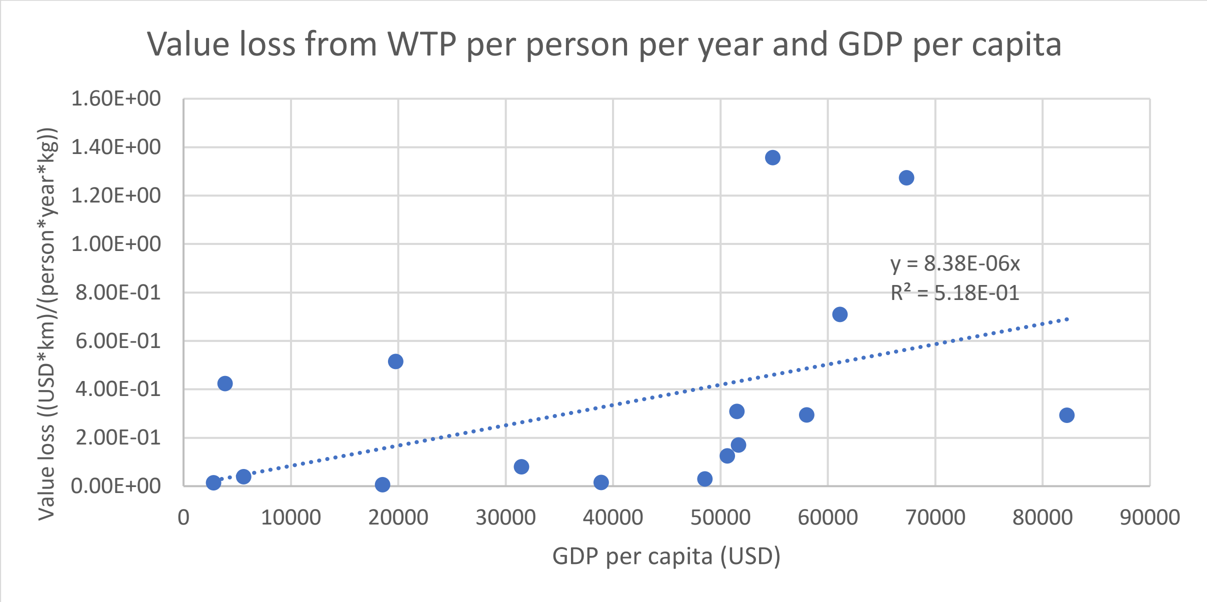

Figure 8 - Correlation chart for Value Loss based on WTP per person per year and study year MPD pollution compared with GDP per capita. Chart shows correlation excluding outliers South Korea, and Colombia. Variables: VL(Y)$_{(S)}$xGDP.

After sorting the WTP per person per year and VL per person per year studies by continent, it was found that enough studies (n>5) had been conducted in Europe to do a separate continent-based correlation analysis. In this analysis, the WTP per person per year and the VL per person per year numbers from nine studies from Europe were tested for correlations. For these European studies, the strongest correlation was found with GDP per capita (R^2=0.48, φ=1.19e-3). The study year MPD numbers (R^2=0.53, φ=5.33e-1) correlated more strongly with the WTP per person per year numbers than the average MPD numbers (R^2=0.29, φ=2.28e-1).

The value loss numbers for the European studies were most strongly correlated with the GDP per capita numbers for both the study year MPD numbers (R^2=0.58, $\varphi_{(S)}$=7.63e-6) and the average MPD numbers (R^2=0.44, $\varphi_{(A)}$=6.63e-6). Correlations with HDI were strongest for the study year MPD numbers as well (R^2=0.50, $\varphi_{(S)}$=4.01e-1).

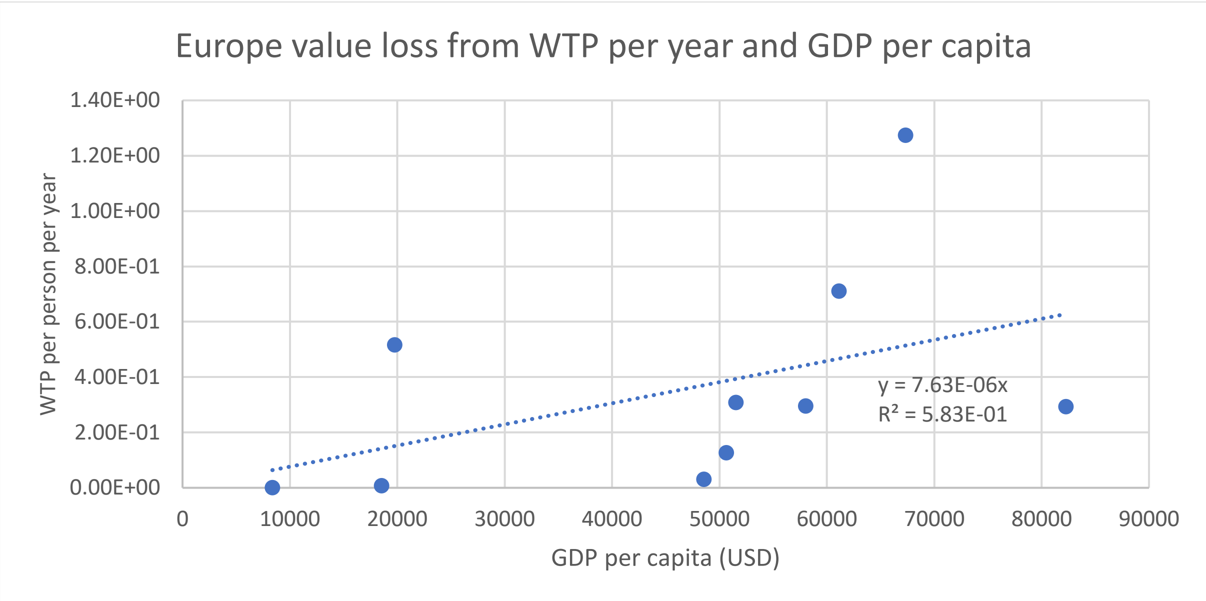

Figure 9 – Correlation chart for Value Loss based on WTP per person per year and study year MPD compared with GDP per capita for studies done in Europe. Variables: VL(Y)$_{(S)}$xGDP.

3.5.3. Correlations overview

The strongest correlation that was found was between the VL per person per trip based on the average MPD pollution numbers and the GDP per capita numbers (R^2 = 0.88, φ = 7.09E-7). All the correlations were combined in two tables that show the strength of the correlations in the first (R^2) and the regression coefficient (φ) in the second (Table 16 & Table 17). To differentiate between stronger and weaker correlations, correlations with an R^2 above 0.6 are double-underscored whilst R^2 between 0.4 and 0.6 are single-underscored. These threshold values were chosen by the author and do not portray any more meaning than to improve the readability of the tables. The tables include several abbreviations that are described in Table 15.

Table 15 - Overview of abbreviations used in Table 15

Abbreviations	
WTP	Willingness-To-Pay
VL	Value loss per kg MPD pollution
(S)	(based on) Study year MPD pollution numbers
(A)	(based on) Average MPD pollution numbers for 2016-2021
HDI	Human Development Index
GDP	GDP per capita

Table 16 - Overview the R^2 for all the correlation analyses.

R^2	WTP per person per trip WTP(T)		VL per person per trip VL(T)		WTP per person per year WTP(Y)			VL per person per year VL(Y)		
	all studies	excl. outliers	all studies	excl. outliers	all studies	excl. outliers	European studies	all studies	excl. outliers	European studies
(S)	0.03	0.59			0.04	0.22	0.53			
(A)	0.04	0.49			0.15	0.27	0.29			
HDI	0.23	0.77			0.31	0.54	0.39			
GDP	0.45	0.56			0.25	0.51	0.48			
(S) HDI			0.20	0.74				0.37	0.45	0.50
(A) HDI			0.21	0.65				0.40	0.45	0.40
(S) GDP			0.21	0.81				0.30	0.52	0.58
(A) GDP			0.24	0.88				0.36	0.29	0.44

Table 17 - Overview of the phi (regression coefficient) for all the correlation analyses. Underscores are based on the strength of the correlations found in Table 16. Double underscore: R^2>0.6, single underscore: R^2>0.4 and R^2<0.6.

φ	WTP per person per trip WTP(T)		VL per person per trip VL(T)		WTP per person per year WTP(Y)			VL per person per year VL(Y)		
	all studies	excl. outliers	all studies	excl. outliers	all studies	excl. outliers	European studies	all studies	excl. outliers	European studies
(S)	1.49E-02	6.11E-03			3.55E-02	6.96E-02	4.98E-01			
(A)	2.18E-02	7.27E-03			9.97E-02	8.25E-02	2.28E-01			
HDI	1.99E+01	3.72E+00			5.86E+01	3.25E+01	6.10E+01			
GDP	7.87E-04	1.06E-04			1.03E-03	6.18E-04	1.19E-03			
(S) HDI			2.19E-01	1.60E-02				4.76E-01	4.12E-01	4.01E-01
(A) HDI			2.15E-01	1.84E-02				3.61E-01	2.98E-01	3.59E-01
(S) GDP			6.44E-06	5.57E-07				8.47E-06	8.38E-06	7.66E-06
(A) GDP			6.63E-06	7.09E-07				6.81E-06	4.82E-06	6.63E-06

3.6. Effect factors

The correlation analysis for both types of VL (T/Y) showed that the correlations based on the study year MPD pollution (S) with the HDI and GDP per capita were stronger than those based on the average MPD pollution (A) for three of the four correlations. Based on this result, the regression coefficients "φ" from the correlation analyses for the VL based on the study year MPD pollution (S) were used to predict the VL. The regression coefficients "$\varphi_{(S)}$" can then be combined with the HDI and GDP per capita to estimate the VL per person per trip for country "x" in year "y" - Equation (18) and (19).

$$VL(T)_{est,(S)x,y} = 1.60\text{e} - 2 * HDI_{x,y} \tag{18}$$

$$VL(T)_{est,(S)x,y} = 5.57\text{e} - 7 * GDP_{x,y} \tag{19}$$

In a similar fashion, the VL per person per year can be estimated using the regression coefficient "$\varphi_{(S)}$" with the HDI and GDP per capita for the VL per person per year for country "x" in year "y" - Equation (20) and (21).

$$VL(Y)_{est,(S)x,y} = 4.12\text{e} - 1 \ * HDI_{x,y} \tag{20}$$

$$VL(Y)_{est,(S),x,y} = 8.38\text{e} - 6 * GDP_{x,y} \tag{21}$$

Using these definitions of the VL, the complete EF for the calculation of the monetary costs per kg MPD pollution can be formulated for country "x" in year "y". The cleaning costs used here are 1.05 USD/kg based on what was found in literature on the subject (see chapter 2.5.). The first two EFs show the total costs based on the VL per person per trip whilst the third and fourth show the total costs for the VL per person per year – Equations (22), (23), (24) & (25). An overview of all the variables with explanation can be found in Table 12.

$$EF(T)_{country,(S),x,y} = \frac{(1.60\text{e} - 2 * HDI_{x,y}) * p_{x,y} * trips_{x,y}}{km_{coast,x,y}} + 1.05 \tag{22}$$

$$EF(T)_{country,(S),x,y} = \frac{(5.57\text{e} - 7 * GDP_{x,y}) * p_{x,y} * trips_{x,y}}{km_{coast,x,y}} + 1.05 \tag{23}$$

$$EF(Y)_{country,(S),x,y} = \frac{(4.12\text{e} - 1 \ * HDI_{x,y}) * p_{x,y}}{km_{coast,x,y}} + 1.05 \tag{24}$$

$$EF(Y)_{country,(S),x,y} = \frac{(8.38\text{e} - 6 * GDP_{x,y}) * p_{x,y}}{km_{coast,x,y}} + 1.05 \tag{25}$$

The EF for the calculation of the total costs for a specific region is then based on the EF formula where the "$p_{x,y}$" and "$trips_{x,y}$" are changed out for "$visitors_{z,y}$". The formula displays the total costs per kg MPD pollution for region "z" in country "x" for year "y" – Equations (26) and (27).

$$EF(T)_{region,(S),z,x,y} = \frac{1.60\text{e} - 2 * HDI_{x,y} * visitors_{z,y}}{km_{coast,z,y}} + 1.05 \tag{26}$$

$$EF(T)_{region,(S),z,x,y} = \frac{5.57\text{e} - 7 * GDP_{x,y} * visitors_{z,y}}{km_{coast,z,y}} + 1.05 \tag{27}$$

3.7. Example cases

3.7.1. Country example cases

The country example cases show an estimation of the costs associated with an inflow that causes an increase of 25 kg per km of beach using the simplified CFs. One of the countries that was used as an example is the Netherlands for the year 2017 (Brouwer et al., 2017). The Netherlands has a coastline of 451 km, a population of 17.13 million, and an average of 32.4 beach trips per person per year (Brouwer et al., 2017). The GDP per capita and HDI were respectively 48555 USD and 0.939 in 2017 (The World Bank, 2020; United Nations Development Programme, 2020). Assuming an inflow that leads to an increase of 25 kg/km (11,275 kg) on the beaches in the Netherlands, the total costs can be calculated using the simplified example CFs. Using equation (17) for the CF, depending on the used predictor (HDI/GDP per capita) and the chosen EF formula (based on VL per person per trip or VL per person per year) the total costs can be calculated (Table 18). The same calculations were done for Benin and South Africa with the average number of beach visits per year retrieved from studies (Brouwer et al., 2017; Houngbeme et al., 2021; Lucrezi & Van der Merwe, 2015) (Table 18, Figure 10).

Table 18 – Simplified Characterization Factor results for country example cases for the Netherlands, Benin, and South Africa for an increase of 25 kg/km MPD pollution. CF=Characterization Factor, (T)=based on VL per person per trip, (Y)=based on WTP per person per year, (S)=based on study MPD pollution numbers

Country	**Netherlands**	**Benin**	**South Africa**
Year	2017	2021	2015
Coastline (km)	451	400	2850
population	1.71E+07	1.21E+07	5.93E+07
#beach trips/year	32.4	12.8	8.8
GDP per capita (USD)	48555	1291	6260
HDI	0.939	0.545	0.701
CF type and *VL predictor*:			
$\boldsymbol{CF(T)_{MPD,(S),x,y}}$ *HDI* (USD)	2.08E+09	3.38E+08	1.46E+09
$\boldsymbol{CF(T)_{MPD,(S),x,y}}$ *GDP* (USD)	3.75E+08	2.80E+06	4.56E+07
$\boldsymbol{CF(Y)_{MPD,(S),x,y}}$ *HDI* (USD)	1.66E+08	6.80E+07	4.28E+08
$\boldsymbol{CF(Y)_{MPD,(S),x,y}}$ *GDP* (USD)	1.74E+08	3.29E+06	7.79E+07

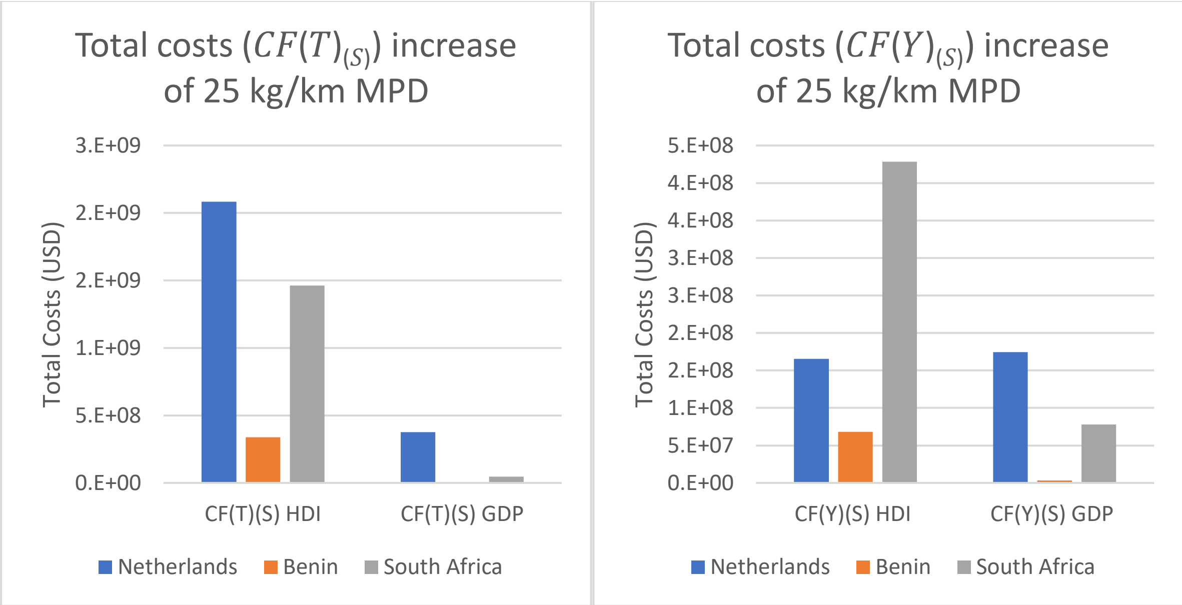

Figure 10 - Bar graphs of the total costs for the country example cases for the Netherlands, Benin, and South Africa for an increase of 25 kg/km MPD pollution. CF=Characterization Factor, (T)=based on VL per person per trip, (Y)=based on WTP per person per year, (S)=based on study MPD pollution numbers.

3.7.2. Region example cases

For the region-based example cases, three cases were based off studies in Delaware's Bay - United States (Parsons et al., 2013), Southern California – United States (Dwight et al., 2007), and Rhodes Island – Greece (Vandarakis et al., 2021). The three cases show different region sizes and visitor numbers to show how the total costs differ for various case studies (Table 19).

Table 19 - Overview of simplified Characterization Factor results for region example cases for Delaware's Bay, Rhodes Island, and the Southern Californian beaches for an increase of 25 kg/km MPD pollution. CF=Characterization Factor, (T)=based on VL per person per trip, (S)=based on study MPD pollution numbers

Region	**Delaware's Bay Beaches - United States**	**Rhodes island - Greece**	**Southern Californian beaches - United States**
Year	2013	2021	2007
Coastline (km)	3.9	253	350
Visitors per year	4.90E+04	2.00E+06	1.29E+08
GDP per capita (USD)	53107	17623	47976
HDI	0.918	0.888	0.906
CF type and *VL predictor*:			
$\boldsymbol{CF(T)_{MPD,(S),z,x,y}}$ *HDI* (USD)	1.80E+05	7.11E+06	4.68E+08
$\boldsymbol{CF(T)_{MPD,(S),z,,xy}}$ *GDP* (USD)	3.63E+04	4.97E+05	8.62E+07

4. Discussion

4.1. Study distributions

The 30 CVM studies that were used for the development of the EFs were only covering a few regions in the world (Figure 3). No studies conducted in Africa were found and large areas of Europe, Asia, and South America were not covered by any of the CVM studies. One of the reasons for the poor coverage might be that the literature review was focused mostly on English publications. Other causes might be a lack of research funding or a low prioritization of MPD pollution as a problem for some regions. The lack of data from these regions creates the risk that the EFs are less accurate in predicting the costs associated with MPD pollution for those areas. Additional research that covers at least parts of these regions would increase the relevance and accuracy of the EF on a global scale. Expanding the literature research to include more languages like Chinese, Spanish, and Japanese might help with this.

4.2. WTP numbers

4.2.1. Categorization

The three main categories that were found for the CVM studies (Table 2) show how much variance there is in the presentation of results for CVM studies that study the same topic. The recategorization only succeeded in recategorizing the studies into two WTP types. This meant that the results and EFs had to be split into two categories with fewer datapoints for both which ultimately decreased the robustness of the developed EFs. This subchapter explains the recategorization process and some of the choices that were made during it.

After the first recategorization of the “WTP per household per year” data to “WTP per person per year”, an initial attempt was also made to recategorize the “WTP per person per year” numbers into the “WTP per person per trip” category. This was done using the average number of trips per person per year to the beach/coast. For some of the CVM studies, this number was provided in their results (Brouwer et al., 2017; Hynes et al., 2013; Östberg et al., 2012). By dividing the “WTP per person per year” by this average number of trips, an attempt was made to recategorize the data into the “WTP per person per trip” category. The results after this attempt were, however, so low that the recategorized WTP data in “WTP per person per trip” was often several factors lower than the studies that had originally presented their results in “WTP per person per trip”. This shows that there appears to be a large difference in the WTP that people have depending on the type of WTP that they are inquired about. It appears that people are prepared to pay a much higher sum on a yearly basis when asked to pay every trip than when they are asked for their WTP for one amount per year. This finding was reason enough to decide to keep two WTP categories without recategorizing them into one category.

A fourth category that was found for one CVM study, “WTP per 2 persons per night”, was not used in the development of the EF since it appeared to be linked directly to the service of staying in a hotel (per night). The WTP format was in addition deemed unfit to be recategorized into one of the other two WTP types because of difficulties converting “per night” into “per year” or “per trip”. For it to be recategorized into “WTP per person per trip”, the WTP for MPD pollution reduction should have been independent of other variables. For these reasons, this study was left out of the database for the development of the EFs.

The variation in the surveys and the presentation of the results that was found among the CVM studies complicated the comparison of their results. Inevitably, with the recategorizing of the WTP types, the robustness of the results decreases. For future research into the impacts of MPD pollution on coastal tourism, an effort should be made to develop a CVM standard among the studies to avoid these differences. Such a standard should at least limit the use of WTP types to only one.

4.2.3. Variation among CVM studies

The studies that were used for the development of the EF were all using a type of CVM but showed differences in their methods. Even though efforts were made to make the results more comparable by recategorizing the WTP types and correcting results from different years for GDP growth and PPP, there were still differences that could not be corrected. Three of these differences are discussed in this sub-chapter.

A first variation among studies was the way in which a reduction of MPD pollution was described. Some studies did not describe any level of MPD pollution at the time of interviewing and merely asked for the WTP for a general reduction of MPD pollution (Birdir et al., 2013; Hynes et al., 2013). Other studies provided a number on the current MPD pollution and requested people to give their WTP for reduction of the pollution to a specific lower level (Beharry-Borg & Scarpa, 2010; Borriello & Rose, 2022; Leggett et al., 2014). A third type of studies reported on a WTP to prevent further MPD pollution instead of reduction of the current pollution (Aanesen et al., 2018). The variation shows that although all of the studies assess a certain level of discomfort with- or dislike of MPD pollution, the WTP was measured in varying degrees of reduction or prevention of MPD pollution. This variation might have caused slight differences in the resulting WTP numbers.

A second factor that was found to differ among the studies was the type of MPD pollution that was researched. Whereas most studies looked into the effect of larger items of MPD pollution (Balance & Turpie, 2000; Brouwer et al., 2017), some looked specifically into the effects of microplastic pollution (Abate et al., 2020; Borriello & Rose, 2022; Choi & Lee, 2018). Although all studies reported on MPD pollution in general, these different types of pollution might also have affected people's WTP.

A third variation that might affect some of the results is based on whether studies looked at WTP for MPD pollution prevention/reduction only or if they combined it with WTP for other services. Although studies that looked into the WTP for other services in addition to the WTP for MPD pollution prevention/reduction often corrected for each service using statistical analysis, the results might still have been affected based on the survey method. Studies that look into additional pollution factors like water quality or noise pollution (Östberg et al., 2012) might get different results compared to studies that looked only into MPD pollution (Smith et al., 1997). When people are asked for their WTP for the reduction of MPD pollution alone, they might report a higher or lower WTP than when they are asked for their WTP for a combination of services.

The three examples of differences among the CVM studies that were used in this thesis show the extent of the variation that can be found among studies that look into people's WTP for the reduction of MPD pollution. For the further improvement of the EFs created in this thesis, it is important that studies reporting on the WTP for the reduction of MPD pollution minimize the differences between their methods to deliver more comparable results. This would aid in the development of more reliable and robust EFs.

4.3. Baseline MPD pollution

For the baseline MPD pollution data, it was important that the method that was used to collect the data was as consistent as possible. The data-source was in addition ideally able to provide data for all the countries and years in which the CVM studies conducted. These two requirements were reason to use the clean-up data from the Ocean Conservancy Organisation. The clean-up reports go back all the way to 1986 and offer clean-up data on a large number of countries in the world. Using different clean-up or monitoring reports from various organizations might have caused larger differences based on varying cleaning or monitoring methods. Using data from one organization was meant to minimize this risk to make the data-collection method for the MPD pollution numbers used in this thesis as similar as possible.

The two types of MPD pollution levels (study year & average 2016-2021) were used to test if people's WTP was correlated strongest to current MPD pollution or to MPD pollution over a longer period. Using the average MPD pollution over several years was in addition meant to correct for any peaks in the cleaning up done by the Ocean Conservancy organisation. Whether this would improve the strength of the correlations was investigated through the correlation analyses (see discussion chapter 4.6.1).

To check if any pollution outliers were found in the study year MPD pollution numbers, a comparison of the study year and average MPD pollution levels was done. This was done by looking if the study year MPD pollution numbers were within one standard deviation from the average MPD pollution numbers for the years 2016-2021. This test showed that only three studies had a study year MPD pollution level that was more than one standard deviation from the average MPD pollution level (Beharry-Borg & Scarpa, 2010; Smith et al., 1997; Tyllianakis & Ferrini, 2021). This shows that the study year MPD pollution levels generally did not have any outlying pollution peaks and were relatively similar to the previous or following years.

The clean-up data that was used might, however, still have been affected by irregularities in the cleaning activities. All the clean-up data that was used was based on yearly reports. Clean-ups might have been done solely in peak-pollution areas or only during a short period of the year. As a result, the baseline MPD pollution might be an over- or underestimation of the actual MPD pollution on the beaches. Because of a lack of a better source and the time constraints for this thesis, this was a limitation that was accepted. For future research, it would however be fruitful to invest more time in the retrieving of MPD pollution level data for the study areas of the CVM studies. One way in which this might be done is by integrating an assessment of the local MPD pollution level in the CVM studies using a consistent measuring method. Local pollution data from the time of the study would help to increase the robustness of the results therewith the EFs.

4.4. Value loss numbers

The calculation of the VL numbers was based on the assumption that people's WTP is directly correlated to the MPD pollution in the country or region. For the WTP per person per trip, this assumption is supported by the strength of the correlations that were tested for in this thesis. The correlations were found to have an $R^2$of 0.59 and 0.49 for study year and average MPD pollution numbers respectively. The correlations between the WTP per person per year and the MPD pollution were not as strong and had an R^2 of 0.22 (study year MPD pollution numbers) and 0.27 (average MPD pollution numbers). Despite the weaker correlations found between the WTP per person per year and MPD pollution levels, the decision was made to base the VL numbers on a linear relation between WTP and local MPD pollution. This decision was made based on the fact that many of the CVM studies that were used for the development of the EF reported on the WTP to reduce MPD pollution down to a certain level (e.g.: (Beharry-Borg & Scarpa, 2010; Borriello & Rose, 2022; Leggett et al., 2014)). The WTP was therefore based on a relative change in MPD pollution from the current situation. Consequently, the reaching of the in the CVM studies proposed level of MPD pollution would theoretically eliminate people's WTP. Because of this concept of WTP for the reduction of MPD, the choice to assume a linear relationship between people's WTP and local MDP pollution levels was justified.

4.5. Correlation analysis

4.5.1. WTP per person per trip

The main correlation analysis for the WTP per person per trip had two studies excluded. The exclusion of the two studies done in Puerto Rico (Talpur et al., 2018) and Pakistan (Loomis & Santiago, 2013) was done based on both studies having a significantly higher WTP per person per trip than the other studies used in the analysis. Based on the box-and-whisker diagram (Figure 4) and the studies presenting WTP of over a factor 3 and 15 compared to the third highest WTP found (USD 6.81) (Beharry-Borg & Scarpa, 2010), the studies were deemed outliers.

The testing for continent-based regional correlations revealed that the number of "WTP per person per trip" studies was too low (<5) for any of the continents to be able to test for any correlation based on location. The highest number of WTP per person per trip studies available for any of the continent was three for Europe which was deemed too few to be able to conduct a robust correlation analysis.

4.5.2. WTP per person per year

The main correlation analysis for the WTP per person per year numbers had three studies excluded (Abate et al., 2020; Choi & Lee, 2018; Enriquez-Acevedo et al., 2018). One South Korean study was excluded because of the low WTP found (USD 1.47) and the high MPD pollution numbers for that year (study year: 1845 kg/km, average: 1123 kg/km) which resulted in the VL number being extremely low (1.31E-03) causing it to be an outlier in comparison to the other studies. The other two studies conducted in Norway and Colombia had the highest WTP numbers amongst all the studies (USD 248.26 and USD 265.55 respectively) and were found as outliers in the box-and-whisker diagram (Figure 4).

The division of the results per continent gave a sufficiently high number of “WTP per person per year” studies (nine studies) in Europe to repeat the correlation analyses for “WTP per person per year” studies from Europe. The strength of the correlations for the WTP per person per year and VL per person per year for Europe showed mixed results. Some of the correlations were stronger (5 correlations, average R^2=45% stronger) than the correlations found among all “WTP per person per year” studies (excluding outliers) whilst some correlations were weaker (3 correlations, average R^2=14% weaker) (Table 16). This shows that there is little certainty that the results for the European studies are more reliable overall than the correlations for all the “WTP per person per year” studies.

If an EF for one specific region would be developed, it should be grounded on strong evidence that the correlations found for studies in that specific region are significantly stronger compared to the complete dataset. The European studies used in this thesis were not representative of the whole European region with large parts of central, west, and southern Europe not covered by any studies. Based on this poor coverage and the small differences in the strength of the correlations that were found for the European region, the decision was made to not develop a European EF.

4.5.3. Predicting WTP

The results show how people’s WTP is correlated with several country specific variables (HDI, GDP per capita, MPD pollution levels). Although the correlation analysis for the WTP was not used for the development of the EFs (see chapter 4.8.2), it can still serve as helpful tool for policy makers. For both the WTP per person per trip and the WTP per person per year, the HDI was found to be the strongest predictor (per trip: R^2=0.77, φ=3.72E+0, per year: R^2=0.54, φ=3.25e+1). For a governmental body that wants to implement an ecotax per trip or per year might use the predictors presented in this thesis. By using the HDI of the country, a decent estimate can be made of people's WTP for such an ecotax. The results might as such help to pave the way to improved preservation and cleanliness in coastal areas.

4.5.4. Correlation type

All the correlations were tested using a linear correlation/regression model. The decision to use a linear model instead of an exponential or logarithmic model was based on simple fitting tests. For all the correlation charts, the strength of the correlations was compared based on different trendlines. This process revealed that for the majority of the 24 main correlations, the R^2 was strongest using a linear trendline. Although 3 correlations had a higher R^2 using an exponential trendline, it was decided to be consistent in the type of trendline that was used for all the correlations. As a result, a linear trendline was used for all the correlations.

4.6. Effect factors

4.6.1. Average MPD pollution and Study Year MPD pollution

The strength of the correlations shown in the results display how there is a clear difference between using the MPD pollution numbers for the study year and the average MPD pollution numbers over the years 2016-2021 (Table 16). The WTP and the VL numbers correlated most strongly with the study year MPD pollution numbers for all except two correlations (WTP per person per year and GDP per capita with VL per person per trip). This shows that for most of the correlations, the WTP and VL are more strongly linked with the MPD pollution for the study year than with the average MPD pollution over a longer period (2016-2021). These results suggest that people are more strongly influenced by current MPD pollution than MPD pollution over a longer period. The EFs were therefore modelled after the regression coefficients "φ" that were found for the VL numbers based on the MPD pollution for the study years coupled with the HDI and GDP per capita: $EF(T/Y)_{(S)}$.

4.6.2. HDI and GDP per capita

For the HDI and GDP per capita, no clear trend can be found in the results where one was correlated stronger with the majority of the WTP or VL numbers (Table 16). For the WTP numbers for both WTP per person per trip and WTP per person per year, the correlation with the HDI was stronger whilst the correlations with the VL numbers were found stronger with the GDP per capita. The stronger correlations with the GDP per capita for the VL numbers initially suggest that GDP per capita is the preferred choice to predict VL caused by MPD pollution. The differences between the strength of the correlations with GDP per capita and with HDI are however small. Following the decision to focus on the study year MPD pollution based VL numbers (see chapter 4.6.1), the correlation strengths show how small the differences are between the two predictor variables HDI and GDP per capita. For the VL per person per trip, the HDI correlation has an R^2 of 0.74 (study year MPD numbers) whilst the GDP per capita has an R^2 of 0.81 (study year MPD numbers). The difference here is only 0.07 and although the GDP per capita correlates stronger with the VL per person per trip, both correlations with HDI and with GDP per capita have an R^2 of over 0.7 and can be considered relatively strong. For the VL per person per year numbers, the difference in correlation strength is equally small where the HDI shows a correlation with an R^2 of 0.45 (study year MPD numbers) whilst the GDP per capita correlation shows an R^2 of 0.52 (study year MPD numbers). Again, the difference here is only 0.07 for the R^2.

When considering the choice between HDI and GDP per capita, it must be noted that the two are often correlated to a significant degree (Elistia & Syahzuni, 2018; Islam, 1995). This correlation is partially explained by the fact that one of the factors that determines the HDI is an economic variable: the Gross National Income (GNI) (World Health Organization, 2022). The question is whether the WTP to reduce plastic pollution is based on the availability of financial means only (or predominantly) or if other factors like health and education are equally important. In previous research, affluence was not found to have a strong correlation with pro-environmental behaviour (Capstick et al., 2022; Gatersleben et al., 2014). Although the availability of financial means was seen to enable people to take pro-environmental actions that incur costs, it was not found to be a strong predictor of overall environmental behaviour. These findings can be useful if one considers the WTP for the reduction of MPD pollution on beaches to be an implicit statement of pro-environmental behaviour. This is based on the idea that people's WTP people is correlated strongly with the level of pro-environmental behaviour they exhibit (Batel et al., 2014; Park & Yoon, 2017). Based on the weak correlation between affluence and pro-environmental behaviour and the stronger correlation between WTP and pro-environmental behaviour, the use of HDI was deemed more suitable than GDP per capita to predict value loss caused by MPD pollution. The reasoning behind this decision is that GDP per capita is more resembling of affluence (economic variable) than HDI and should therefore in theory be less correlated with people's WTP and level of pro-environmental behaviour. The strength of the correlations for HDI were in addition not different enough from those for the GDP per capita to make a decision based purely on the correlation analyses. These findings were reason for the author to recommend the use of the EFs that use HDI as a predictor of VL.

4.6.3. Comparing country Effect Factors

When comparing the $EF(T)_{country}$ and the $EF(Y)_{country}$ (see chapter 3.6.), the main difference is the additional multiplication with the average number of trips per year to the beach for people from country "x" for $EF(T)_{country}$. Using the regression coefficients found in Table 17, one can then calculate how many trips per year would cause both EFs to give the same result for the same country. It was found that for the recommended use of the HDI and study year MPD pollution (see chapter 4.6.1. and 4.6.2.), the $EF(T)_{country,(S)}$ gives the same result (for the same country) as the $EF(Y)_{country,(S)}$ when people take an average of 26 trips to the beach per year (regression coefficients: 4.12e-1/1.60e-2=26). For countries where people visit the beaches frequently (more than 26 times per year), the costs are therefore estimated to be higher when using $EF(T)_{country,(S)}$ than when using $EF(Y)_{country,(S)}$. It also points to the differences in survey methods for the CVM studies using either "WTP per person per trip" or "WTP per person per year" (see chapter 4.2.1.).

For the $EF(T)_{country,(S)}$, it must also be noted that the data was often retrieved from surveys that were done on-site where any visitors including international tourists might have been interviewed. The $EF(T)_{country,(S)}$ does however not incorporate the values for tourists but looks instead only at the population of the country and the average number of trips to the beach they make (domestic tourists). This might in turn lead to an underestimation of the costs when using $EF(T)_{country,(S)}$ based on the lack of a variable for international tourists in the EF. It must be noted that this problem is solved for the region-based EF ($EF(T)_{region}$) where the population and average number of trips per year are replaced with the visitor numbers to the region per year. For the $EF(Y)_{country}$ this problem does not arise because the CVM studies that this EF is based on were more often using national surveys rather than local on-site surveys. The results for the $EF(Y)_{country}$ are therefore not at risk of underestimating the costs since the EF is based only on data from the country's population.

4.7. Example cases

This chapter presents a discussion of the example cases on country-scale and region-scale. The discussion includes the results from the CFs using the GDP per capita because the cases were set up before the recommendation to use the HDI was formulated. Note however that the recommendation remains to use the HDI instead of the GDP per capita.

4.7.1. Country example cases

The country cases show how the level of development in a country is an important predictor for the total costs associated with an increase of MPD pollution (Table 18, Figure 10).

The comparison of the Netherlands and Benin is useful for comparing two countries that have a similar population size and coastline but different GDP per capita and HDI. The same increase in MPD pollution leads to much higher costs for the Netherlands than for Benin. The impact of the number of beach trips per year is also shown through the high costs for the Netherlands for the $CF(T)_{MPD,(S),x,y}\ HDI$ and the $CF(T)(S)_{MPD,(S),x,y}\ GDP$. This shows how richer and more developed countries have higher costs associated with a similar increase in MPD pollution than less developed countries.

The case for South Africa shows how countries with larger populations can have higher costs associated with MPD pollution whilst still being constrained by their HDI and GDP per capita. The population of South Africa is more than a factor 3 larger than the Netherlands but still has lower total costs for all but one CF type. This is caused again by the effect that the level of development and affluence in a country have on the incurred costs of a similar increase in MPD pollution. Since South Africa has a lower HDI and GDP per capita than the Netherlands, the costs per capita are much lower than they are for the Netherlands.

4.7.2. Region example cases

The three region-based examples show three different levels of visitor numbers and serve as examples for how the EF might be used for specific regions instead of countries (Table 19). Although the total costs for the three regions differ significantly, the differences between Delaware's Bay and Rhodes Island are smaller than the difference in visitor numbers would suggest. This again points to the importance of GDP per capita and HDI in the predicting of the costs associated with the MPD pollution.

4.8. Data requirements for the Effect Factors

4.8.1. Country-level Effect Factors

The recommendation to use HDI instead of GDP per capita and study year MPD pollution instead of average MPD pollution still leaves the choice between the $EF(T)_{country}$ and the $EF(Y)_{country}$ when calculating on a country-scale. The main difference between the two EFs for country-scale assessment is the additional need for data on the average number of beach visits per year for country "x" for the $EF(T)_{country}$. Based on the data-requirements, an overview of all the main EFs can be useful to consider a choice between the two country-scale EFs (Table 20).

Table 20 - Overview of data requirements for three of the developed EFs.

	$\boldsymbol{EF(Y)_{country}}$	$\boldsymbol{EF(T)_{country}}$	$\boldsymbol{EF(T)_{region}}$
HDI	X	X	X
Coast length	X	X	X
Population	X	X	
Average number of trips per person per year to coast		X	
Number of visitors to region per year			X

The table shows how two EFs ($EF(Y)_{country}$ & $EF(T)_{region}$) require three separate variables whilst the other EF ($EF(T)_{country}$) requires four. The need for the extra data on the average number of trips to the coast for the $EF(T)_{country}$ which might not always be readily available can make the use of this EF more difficult in practice. Based on this difference in data-requirement and the risk of underestimation of costs for $EF(T)_{country}$ (see chapter 4.6.3. second section), the recommendation is therefore to use the $EF(Y)_{country}$ for country-scale assessments.

4.8.2. Willingness-to-pay and Value loss

To use VL numbers instead of WTP numbers was decided because of the additional data on local MPD pollution that would be needed for an EF based on WTP to calculate the VL. Although an estimation of people's WTP based on the correlation analysis could be made for the use in an EF, there would still be the need to calculate the VL from this WTP number. To be able to calculate the VL, data would be needed on the local MPD pollution. To avoid this extra step and data requirement, the choice to use VL instead of WTP in the EFs was made.

4.9. Impact of cleaning cost

The impact of the cleaning of MPD pollution at the beaches can be divided into two parts: direct cleaning costs and the negating effect on the effect MPD pollution has on recreational value.

The first part is calculated through the direct costs of cleaning, i.e., 1050 USD per tonne (see chapter 2.7.). When looking at the example cases, these costs only make up a tiny fraction of the total costs. When looking at the recommended EFs in the example cases, the cleaning costs make up 0.007-0.017% on a country-scale and 0.001-0.129% on a region-scale. This makes the costs of cleaning almost negligible in comparison to the value loss that is caused by the impact that the presence of MPD pollution has on coastal recreation.

The indirect impact of cleaning through the removal of the negative effect of MPD pollution on recreational value is however a lot bigger. The value loss incurred by the presence of MPD pollution is based on people's wish (WTP) to reduce MPD pollution to a lower level. When the MPD pollution is cleared away, this lower level is reached, and the wish disappears (WTP=0). This impact that cleaning has on the total costs is why it is important to look at the impact of MPD in one-year cohorts. The model is then based on the idea that all the build-up of MPD pollution is hypothetically cleaned once a year which resets the total costs counter back to zero. Using the EF to calculate the total costs for the inflow of a certain amount of MPD is therefore always for one specific year. If the inflow of MPD is spread out over several years because of various pollution pathways, the costs must also be spread over several years.

4.10. High pollution events

The EFs that were developed in this thesis use a linear model that describes a linear increase in total costs with increased MPD pollution. In practice, it is likely that recreational value will disappear almost completely beyond a certain level of MPD pollution. An extreme inflow of MPD pollution might therefore be undervalued by the EFs that were developed in this thesis. Some of the studies that were looked into before focusing on CVM studies looked into the effects of such high pollution events (Jang et al., 2014; Ofiara & Brown, 1999). These studies calculated the TEV loss caused by the high pollution event. Some other studies created a model where pollution scenarios were coupled with the potential loss of economic value if said scenario would occur (Balance & Turpie, 2000; Krelling et al., 2017). These studies show that when high pollution events occur, the costs can go up quickly.

Extreme pollution events might however affect regions in different ways. To model the effects that high pollution events have on recreational value could therefore require separate threshold values for different regions. If thresholds would indeed differ based on regions, separate regional EFs would have to be developed.

The occurrence of high pollution events is in addition more dependent on local climate events and less affected by the actual inflow of MPD caused by the use of a single product or service. As such, it might be hard to predict what share of plastic in a product might contribute to a high pollution event since LCA is a steady state method. The modelling of even a single high pollution event would therefore provide modelling problems. The integration of high pollution events into the EF was therefore deemed too complex considering the time-constraints and the perceived difficulties for the modelling of high pollution events in LCA.

5. Conclusions and outlook

The aim of this thesis was to investigate the extent to which one or several EFs could be developed that could be used to measure the monetary impact that MPD pollution has on coastal recreation.

Based on the available data that was retrieved from studies using CVM, three EFs were developed that predict the total costs per kilogram of MPD per kilometre of beach. The EFs combine costs caused by recreational value loss and cleaning costs that are incurred per kilogram of MPD pollution to estimate the total costs for one year. The value loss was based on a combination of data on WTP for the reduction of MPD pollution and the local MPD pollution numbers based on coastal clean-up reports for the year in which the study was conducted.

Following the discussion of the correlation analysis, the HDI was recommended as a variable to estimate the recreational value loss associated with the presence of MPD pollution for different countries. Based again on the correlation analysis and the data-requirements, the EF based on WTP per person per year was recommended to use for country-scale assessments ($EF(Y)_{country,(S)}$) whilst the adapted EF based on WTP per person per trip ($EF(T)_{region,(S)}$) was recommended for smaller region-scale assessments. Data requirements for the two recommended EFs differ where the country-scale EF requires data on HDI, coastal length, and population and the region-scale EF requires data on HDI, coastal length, and yearly visitor numbers to the region. Due to a lack of WTP data, no EFs could be developed for specific continents.

The EFs are in theory useable on a global scale with varying levels of relevance for different regions based on the differences in the availability of WTP data. For the two cost types that were integrated in the EFs (recreational value loss and cleaning costs), the direct cleaning costs were found to only represent a very small part of the total costs (<1%).

Many of the inconsistency problems related to the WTP data that was used can be fixed by additional more standardized CVM research. Increasing the geographical coverage of CVM studies in addition to a standardization of results and CVM methods can help in improving the robustness of the developed EFs. Reporting on local MPD pollution levels and using only one WTP type should be the minimum requirements of such a CVM standard.

The EFs that were developed in this thesis are but one part of an eventual Characterization Factor (CF) that can be implemented in the LCIA method. The EFs describe how each additional kilogram of MPD pollution per kilometre of beach affects recreational value and cleaning costs. They do however not say anything about how the use of a certain amount of product or service affects the amount of MPD that ends up on the coast in a specific region. This effective inflow of MPD pollution caused by plastic use is another piece of the puzzle that needs to be solved before a CF can be operationalized. The factor that is needed to estimate this effective inflow caused by plastic use is the Fate Factor (FF). The example cases used a very simplified version of a FF that represented a direct fictive inflow of MPD. Combining the EFs that were developed in this thesis with a fully operationalized FF can give the total costs associated with the use of one product or service caused by the increase in MPD on beaches that it causes. The integration of a CF that combines the EFs and a FF in LCIA could then help to create understanding of how the plastic use can have monetary consequences for coastal recreation.

The EFs presented in this thesis show that it is possible to estimate the monetary impact of plastic pollution on coastal tourism. It is the first step towards the integration of such costs in the LCA method. The understanding and quantification of such impacts is essential to avoid underestimating the pressures that plastic puts on important ES. The proper valuation of these impacts can help to get the issues that plastic pollution cause higher on the political agenda. Appropriate and timely action against such pollution might in turn prevent possible negative long-term effects. The development of a FF is encouraged to allow for the quickest possible operationalization of a CF using the EFs developed in this thesis.

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Appendix A – Overview TEV and NV studies

This Appendix presents an overview of the studies that were found that looked into the effects of MPD on coastal recreation using a different method than CVM. The first table (Table A1) presents a description of all the TEV studies followed by a short text that describes why the remaining studies were not used in the development of the EF.

Table A1 - Overview of studies using TEV to assess monetary impacts of plastic pollution on tourism.

Study	Country/region	Description
(Balance & Turpie, 2000)	South Africa	Use of pollution scenarios to estimate loss of visitor numbers. Estimates an **85-97 percent** reduction in visitor numbers for respectively 2 and 10 MPD items per square meter.
(Jang et al., 2014)	South Korea	2011 marine pollution event. Estimates a **49.7 percent** decrease in visitor numbers because of the pollution event. This responds to a loss of **29-37 million USD** in revenue.
(Krelling et al., 2017)	Brazil	Use of pollution scenarios to estimate loss of visitor numbers. Estimates a **19.9-39.7 percent** decrease in visitor numbers for pollution levels ranging from 2.5-15 items per square meter. This responds to a loss of **0.88-3.27 million USD** in revenue.
(McIlgorm et al., 2011)	APEC	Regional overview of impacts for APEC countries. Estimates a damage of **0.62 billion USD** to the marine tourism sector for the entire region.
(McIlgorm et al., 2022)	APEC	Regional overview of impacts for APEC countries. Estimates a damage of **6.41 billion USD** to the marine tourism sector for the entire region.
(Ofiara & Brown, 1999)	New York, United States	1988 marine pollution event. **Estimates 9.9-44 percent** decrease in visitor numbers because of pollution. This amount to a loss of **131.7-644.0 million USD** in revenue.

The remaining six studies were then either not specific of the impact that MPD had on marine recreational value (Beaumont et al., 2019), only identified the fact that MPD pollution has an influence on marine recreational value without further quantification (Cabana et al., 2020; Kontogianni & Emmanouilides, 2014; Pinheiro et al., 2021), or only applied a vulnerability score without further quantification (Cabral et al., 2015).

Appendix B – WTP, VL, MPD, HDI, and GDP per capita data

This appendix presents all the results on WTP and VL and presents the data that was used for the MPD pollution densities and the HDI and GDP per capita numbers.

Table B1 - Overview of WTP per person per trip numbers found for the CVM studies.

Study	**Country of study**	**WTP per person per trip (USD)**
(Alves et al., 2015)	Spain	3.08
(Beharry-Borg & Scarpa, 2010)	Trinidad and Tobago	6.81
(Birdir et al., 2013)	Turkey	3.27
(Blakemore & Williams, 2008)	Turkey	1.06
(Blakemore & Williams, 2008)	Turkey	2.08
(Leggett et al., 2014)	United States	3.25
(Loomis & Santiago, 2013)	Puerto Rico	97.52
(Shen et al., 2019)	China	1.85
(Talpur et al., 2018)	Pakistan	20.83
(Ünal & Williams, 1999)	Turkey	1.05

Table B2 - Overview of WTP per person per year numbers found for the CVM studies.

Study	**Country of study**	**WTP per person per year (USD)**
(Aanesen et al., 2018)	Norway	54.51
(Abate et al., 2020)	Norway	248.26
(Börger et al., 2021)	Vietnam	5.36
(Borriello & Rose, 2022)	Australia	3.04
(Brouwer et al., 2017)	Greece	1.08
(Brouwer et al., 2017)	The Netherlands	2.65
(Brouwer et al., 2017)	Bulgaria	21.66
(Choi & Lee, 2018)	South Korea	1.47
(Davis et al., 2019)	Australia	34.05
(Enriquez-Acevedo et al., 2018)	Colombia	265.55
(Hanley et al., 2007)	United Kingdom	17.59
(Hynes et al., 2013)	Ireland	17.08
(Latinopoulos et al., 2018)	Greece	53.74
(Östberg et al., 2012)	Sweden	30.53
(Östberg et al., 2013)	Sweden	93.04
(Smith et al., 1997)	United States	35.94
(Tyllianakis & Ferrini, 2021)	Indonesia	64.47
(Zambrano-Monserrate & Ruano, 2020)	Ecuador	5.13
(中西悠 et al., 2017)	Japan	11.07

Table B 3- Overview of the MPD pollution numbers for the study year and the average for the years 2016-2021 based on data retrieved from the ocean conservancy clean-up reports (Ocean Conservancy, 1997, 1999, 2000, 2007, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021)

Year of study	Country of study	Beach MPD clean-up for study year (kg/km)	Average for study country 2016-2021 (kg/km)	Data retrieved from ocean conservancy source for study:
2018	Norway	185.75	168.99	*(Aanesen et al., 2018)*
2020	Norway	194.87	168.99	*(Abate et al., 2020)*
2015	Spain	354.95	232.16	*(Alves et al., 2015)*
2010	Trinidad and Tobago	480.98	247.29	*(Beharry-Borg & Scarpa, 2010)*
2013	Turkey	482.43	281.32	*(Birdir et al., 2013)*
2008	Turkey	121.76	281.32	*(Blakemore & Williams, 2008)*
2000	Turkey	121.76	281.32	*(Blakemore et al., 2000)*
2021	Vietnam	389.08	563.44	*(Börger et al., 2021)*
2022	Australia	17.81	40.89	*(Borriello & Rose, 2022)*
2017	Bulgaria	NO CLEAN-UP DATA	65.00	*(Brouwer et al., 2017)*
2017	Greece	160.15	159.95	*(Brouwer et al., 2017)*
2017	Netherlands	88.43	116.70	*(Brouwer et al., 2017)*
2018	South Korea	1845.29	1123.32	*(Choi & Lee, 2018)*
2019	Australia	25.09	40.89	*(Davis et al., 2019)*
2018	Colombia	136.58	458.33	*(Enriquez-Acevedo et al., 2018)*
2007	United Kingdom	139.88	113.10	*(Hanley et al., 2007)*
2013	Ireland	55.38	435.73	*(Hynes et al., 2013)*
2018	Greece	104.18	159.95	*(Latinopoulos et al., 2018)*
2014	United States	112.08	88.47	*(Leggett et al., 2014)*
2013	Puerto Rico	121.44	119.01	*(Loomis & Santiago, 2013)*
2012	Sweden	103.45	237.05	*(Östberg et al., 2012)*
2013	Sweden	131.03	237.05	*(Östberg et al., 2013)*
2019	China	851.89	611.48	*(Shen et al., 2019)*
1997	United States	446.50	88.47	*(Smith et al., 1997)*
2018	Pakistan	23.33	26.04	*(Talpur et al., 2018)*
2021	Indonesia	151.95	71.10	*(Tyllianakis & Ferrini, 2021)*
1999	Turkey	110.77	281.32	*(Ünal & Williams, 1999)*
2020	Ecuador	128.78	179.47	*(Zambrano-Monserrate & Ruano, 2020)*
2017	Japan	720.88	373.98	*(中西悠 et al., 2017)*

Table B4 - Overview of value loss numbers based on the WTP per person per trip.

WTP per person per trip		*Based on MPD density in study year*	*Based on average MPD density for 2016-2021*
Study	**Country of study**	**Value loss (USD) per kg/km per person per trip**	**Value loss (USD) per kg/km per person per trip**
(Alves et al., 2015)	Spain	8.68E-03	1.33E-02
(Beharry-Borg & Scarpa, 2010)	Trinidad and Tobago	1.41E-02	2.75E-02
(Birdir et al., 2013)	Turkey	6.77E-03	1.16E-02
(Blakemore & Williams, 2008)	Turkey	8.68E-03	3.75E-03
(Blakemore & Williams, 2008)	Turkey	1.88E-02	7.39E-03
(Leggett et al., 2014)	United States	2.90E-02	3.67E-02
(Loomis & Santiago, 2013)	Puerto Rico	8.03E-01	8.19E-01
(Shen et al., 2019)	China	2.18E-03	3.03E-03
(Talpur et al., 2018)	Pakistan	8.93E-01	8.00E-01
(Ünal & Williams, 1999)	Turkey	8.62E-03	3.73E-03

Table B5 - Overview of value loss numbers based on the WTP per person per year.

WTP per person per year		*Based on MPD density in study year*	*Based on average MPD density for 2016-2021*
Study	**Country of study**	**Value loss (USD) per kg/km per person per year**	**Value loss (USD) per kg/km per person per year**
(Aanesen et al., 2018)	Norway	2.93E-01	3.23E-01
(Abate et al., 2020)	Norway	1.27E+00	1.47E+00
(Börger et al., 2021)	Vietnam	1.38E-02	9.50E-03
(Borriello & Rose, 2022)	Australia	1.71E-01	7.44E-02
(Brouwer et al., 2017)	Greece	6.71E-03	6.72E-03
(Brouwer et al., 2017)	Netherlands	3.00E-02	2.27E-02
(Brouwer et al., 2017)	Bulgaria	NO CLEAN-UP DATA	3.33E-01
(Choi & Lee, 2018)	South Korea	7.99E-04	1.31E-03
(Davis et al., 2019)	Australia	1.36E+00	8.33E-01
(Enriquez-Acevedo et al., 2018)	Colombia	1.94E+00	5.79E-01
(Hanley et al., 2007)	United Kingdom	1.26E-01	1.56E-01
(Hynes et al., 2013)	Ireland	3.08E-01	3.92E-02
(Latinopoulos et al., 2018)	Greece	5.16E-01	3.36E-01
(Östberg et al., 2012)	Sweden	7.10E-01	3.92E-01
(Östberg et al., 2013)	Sweden	2.95E-01	1.29E-01
(Smith et al., 1997)	United States	8.05E-02	4.06E-01
(Tyllianakis & Ferrini, 2021)	Indonesia	4.24E-01	9.07E-01
(Zambrano-Monserrate & Ruano, 2020)	Ecuador	3.99E-02	2.86E-02
(中西悠 et al., 2017)	Japan	1.54E-02	2.96E-02

Table B6 - HDI and GDP per capita numbers for country and year for the studies used in the development of the EF. Data is based on data retrieved from The World Banks and the UNDP (The World Bank, 2020; United Nations Development Programme, 2020).

Year of study	Country of study	HDI	GDP per capita	HDI and GDP per capita data retrieved for study:
2018	Norway	0.956	82268	*(Aanesen et al., 2018)*
2020	Norway	0.957	67330	*(Abate et al., 2020)*
2015	Spain	0.895	25732	*(Alves et al., 2015)*
2010	Trinidad and Tobago	0.784	16683	*(Beharry-Borg & Scarpa, 2010)*
2013	Turkey	0.785	12615	*(Birdir et al., 2013)*
2008	Turkey	0.714	10941	*(Blakemore & Williams, 2008)*
2000	Turkey	0.66	4337	*(Blakemore et al., 2000)*
2021	Vietnam	0.704	2786	*(Börger et al., 2021)*
2022	Australia	0.944	51693	*(Borriello & Rose, 2022)*
2017	Bulgaria	0.879	18536	*(Brouwer et al., 2017)*
2017	Greece	0.811	8366	*(Brouwer et al., 2017)*
2017	Netherlands	0.939	48555	*(Brouwer et al., 2017)*
2018	South Korea	0.914	33423	*(Choi & Lee, 2018)*
2019	Australia	0.944	54875	*(Davis et al., 2019)*
2018	Colombia	0.764	6730	*(Enriquez-Acevedo et al., 2018)*
2007	United Kingdom	0.899	50653	*(Hanley et al., 2007)*
2013	Ireland	0.917	51518	*(Hynes et al., 2013)*
2018	Greece	0.881	19747	*(Latinopoulos et al., 2018)*
2014	United States	0.92	55050	*(Leggett et al., 2014)*
2013	Puerto Rico	0.918	53107	*(Loomis & Santiago, 2013)*
2012	Sweden	0.933	61127	*(Östberg et al., 2012)*
2013	Sweden	0.914	58038	*(Östberg et al., 2013)*
2019	China	0.811	16900	*(Shen et al., 2019)*
1997	United States	0.761	10144	*(Smith et al., 1997)*
2018	Pakistan	0.886	31459	*(Talpur et al., 2018)*
2021	Indonesia	0.552	1482	*(Tyllianakis & Ferrini, 2021)*
1999	Turkey	0.718	3870	*(Ünal & Williams, 1999)*
2020	Ecuador	0.648	4116	*(Zambrano-Monserrate & Ruano, 2020)*
2017	Japan	0.759	5600	*(中西悠 et al., 2017)*

Appendix C – Correlation charts

This appendix shows some of the correlation charts that had a relatively high R^2.

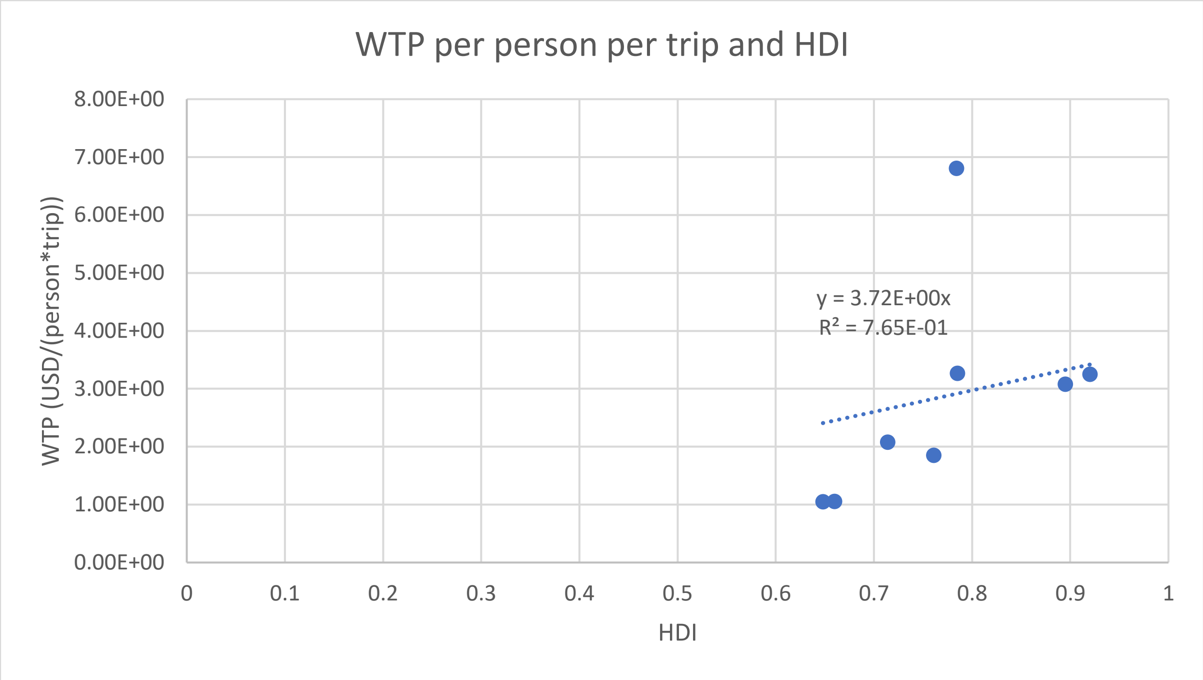

Figure C1 - Correlation chart for WTP per person per trip and HDI. Chart shows correlation excluding outliers Pakistan & Puerto Rico.

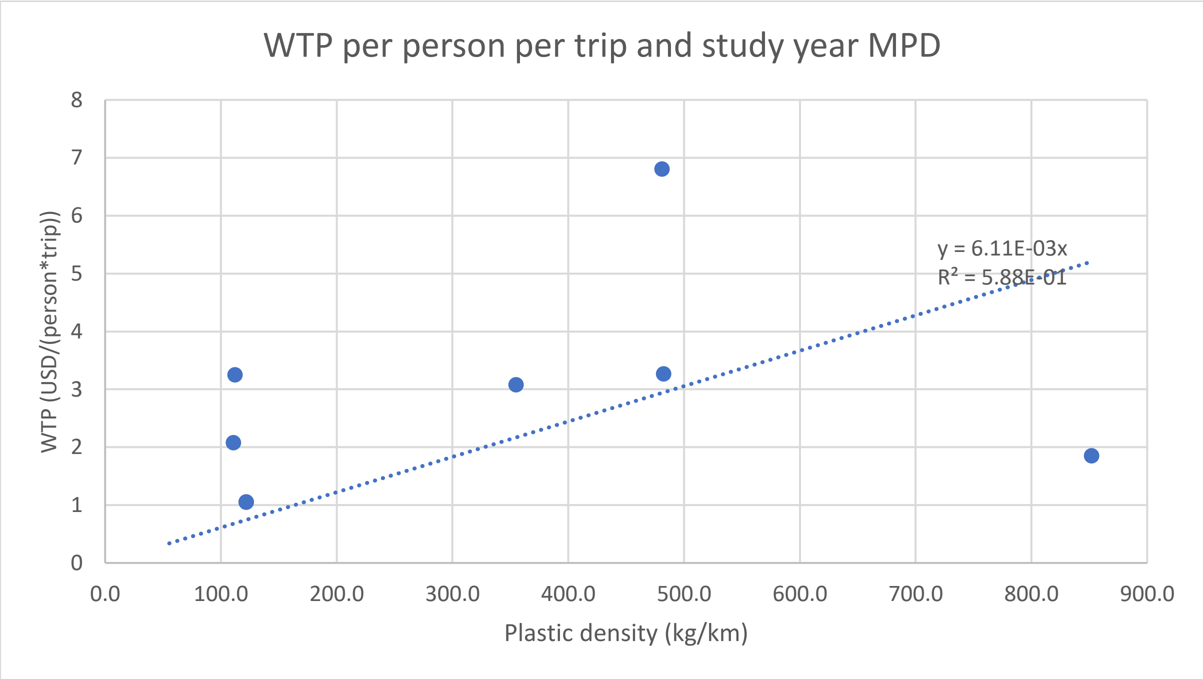

Figure C2 - Correlation chart for WTP per person per trip and study year MPD pollution. Chart shows correlation excluding outliers Pakistan and Puerto Rico.

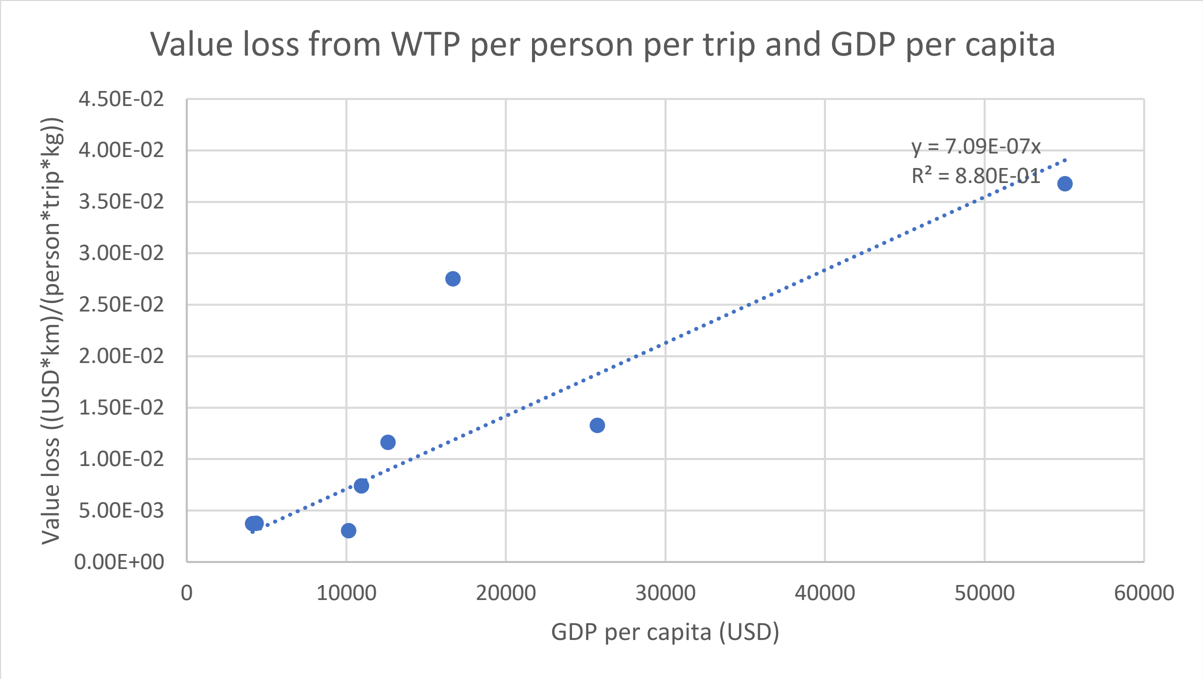

Figure C3 - Correlation chart for Value Loss based on WTP per person per trip and average MPD pollution compared with GDP per capita. Chart shows correlation excluding outliers Pakistan and Puerto Rico.

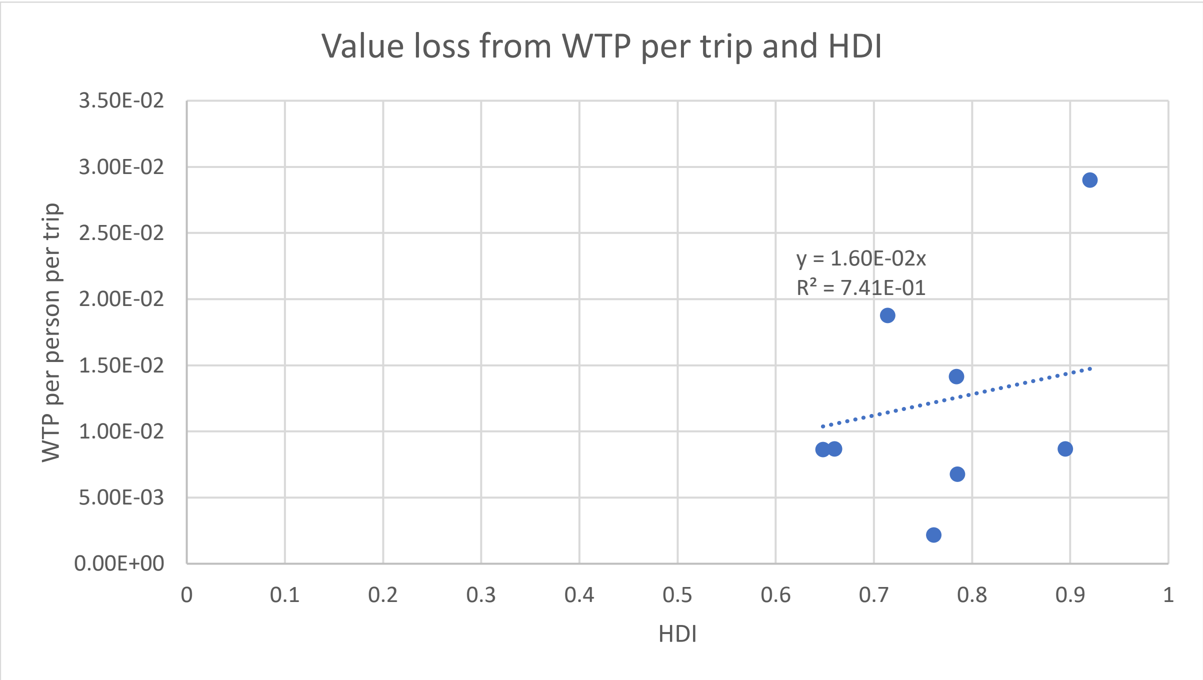

Figure C4 - Correlation chart for Value Loss based on WTP per person per trip and study year MPD pollution compared with HDI. Chart shows correlation excluding outliers Pakistan and Puerto Rico.

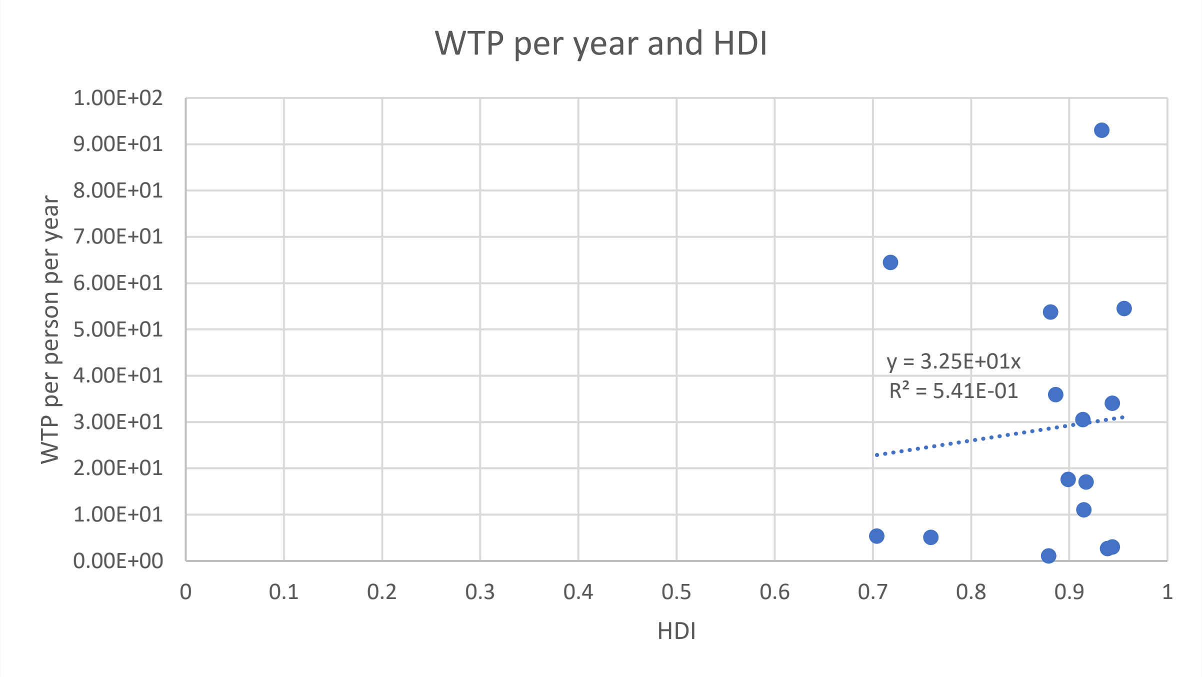

Figure C5 - Correlation chart for WTP per person per year and HDI. Chart shows correlation excluding outliers Norway, South Korea, and Colombia.

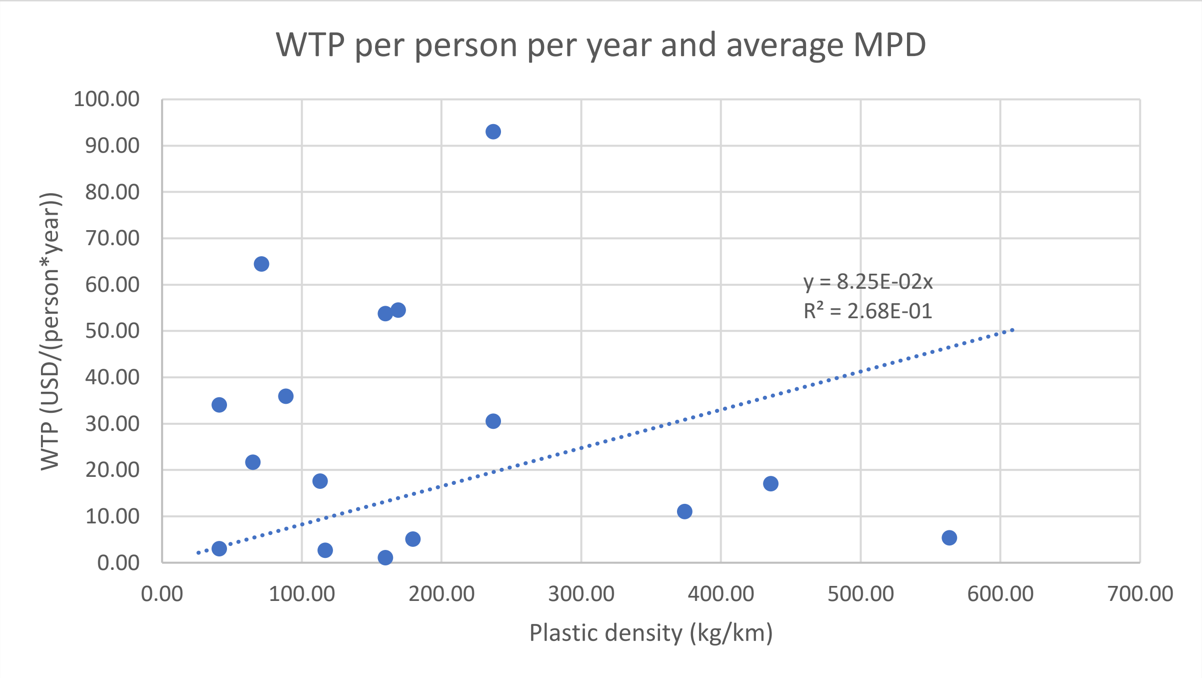

Figure C6 - Correlation chart for WTP per person per year and average MPD pollution. Chart shows correlation excluding outliers Norway, South Korea, and Colombia.

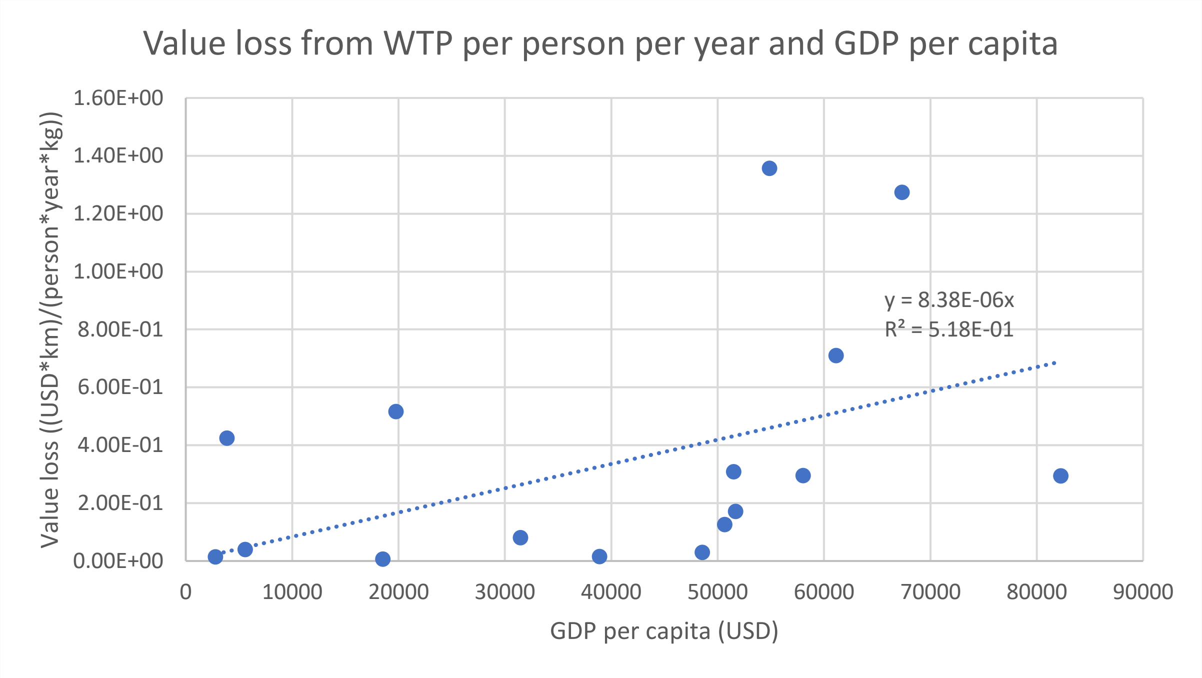

Figure C7 - Correlation chart for Value Loss based on WTP per person per year and study year MPD pollution compared with GDP per capita. Chart shows correlation excluding outliers South Korea and Colombia.

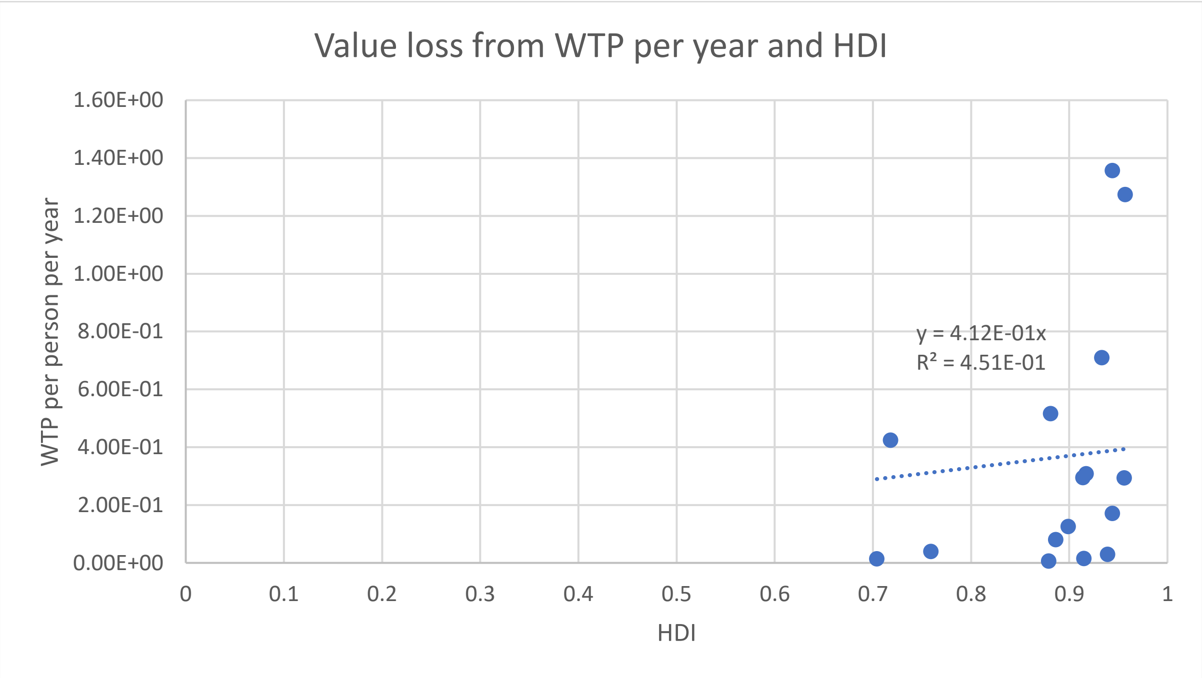

Figure C8 - Correlation chart for Value Loss based on WTP per person per year and study year MPD pollution compared with HDI. Chart shows correlation excluding outliers South Korea and Colombia.

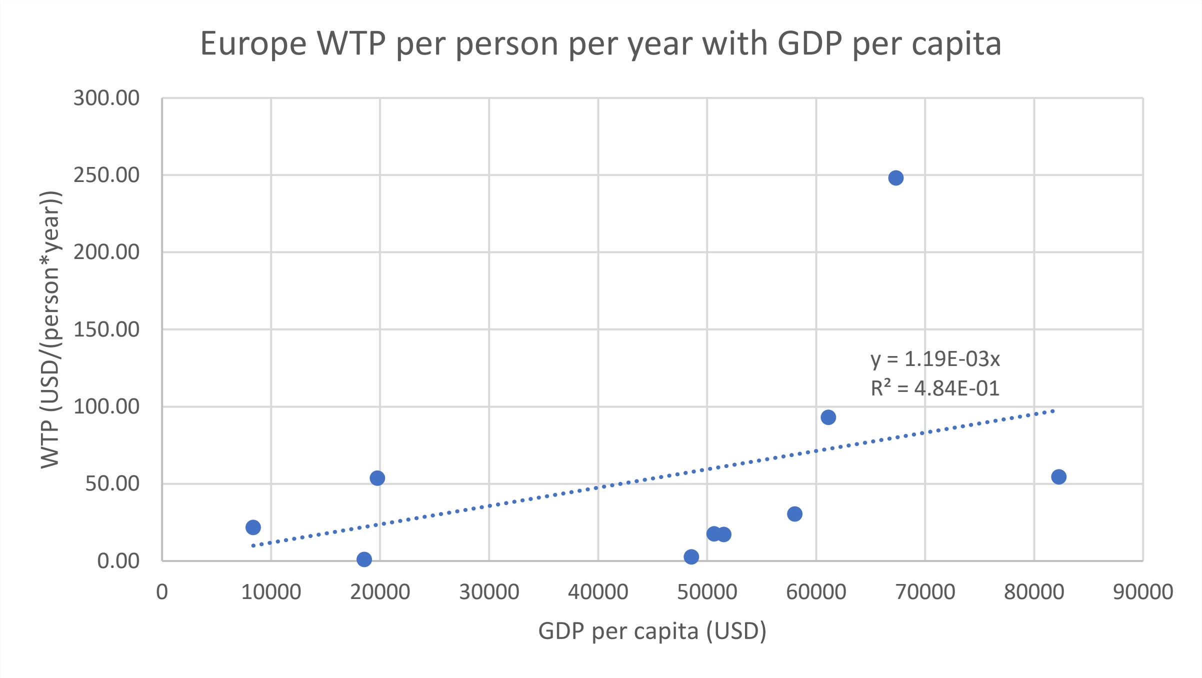

Figure C9 - Correlation chart for WTP per person per year and GDP per capita for studies within Europe.

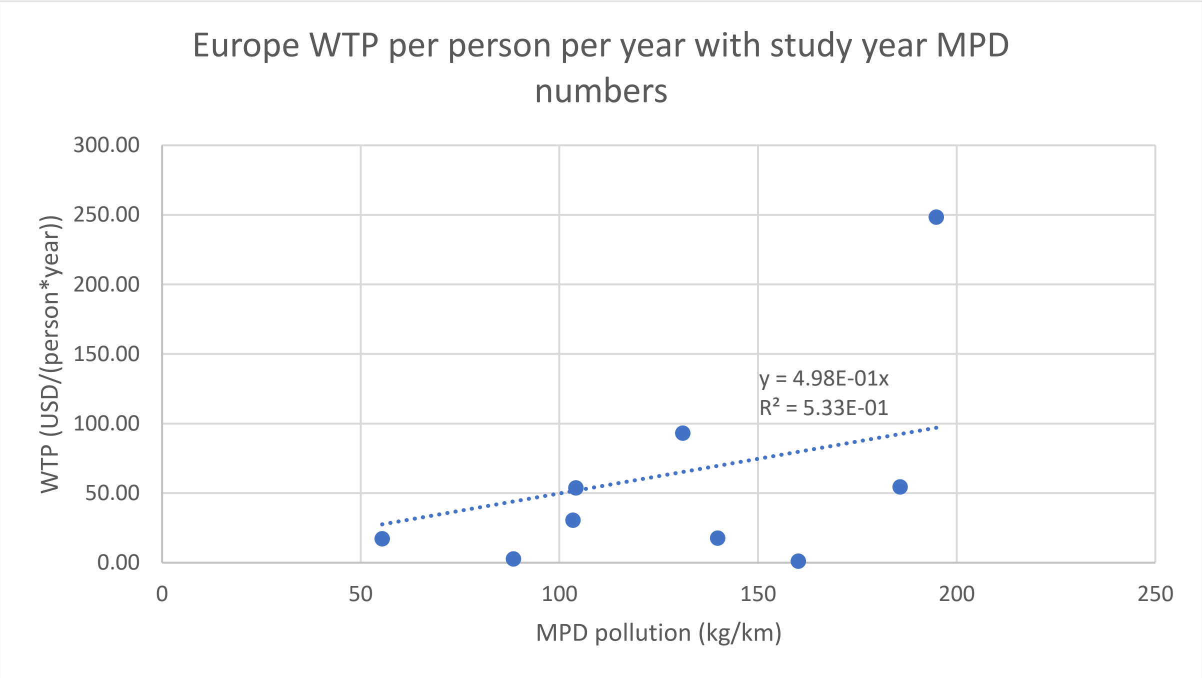

Figure C10 - Correlation chart for WTP per person per year and study year MPD for studies within Europe.

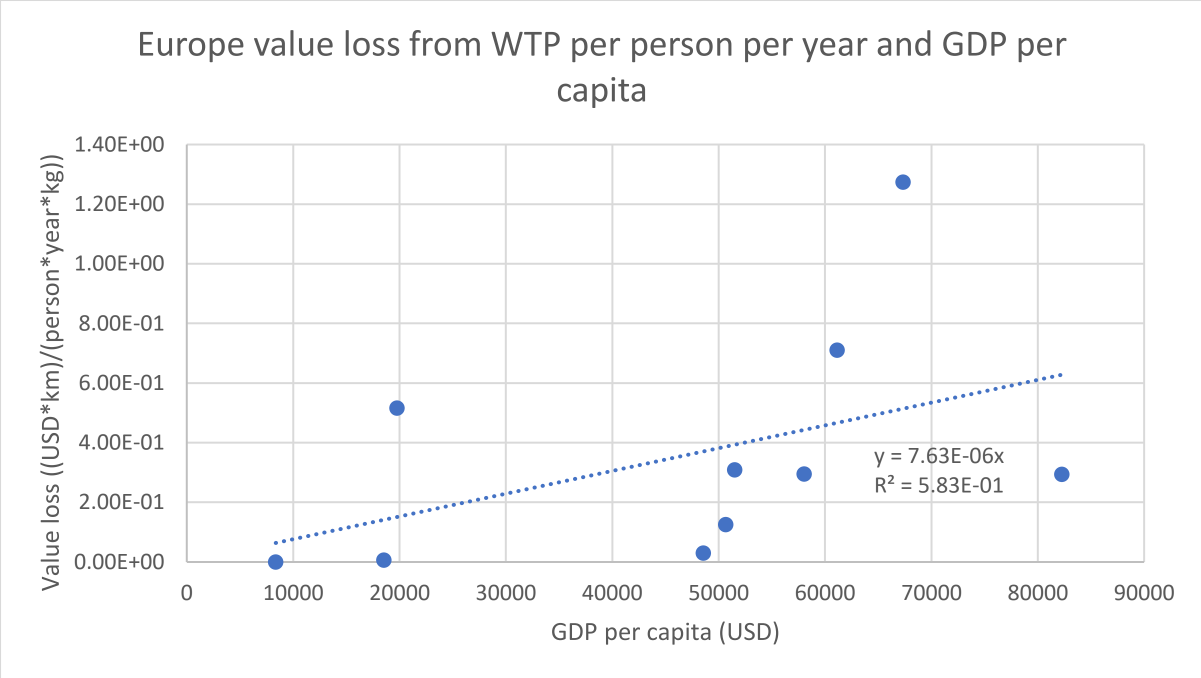

Figure C11 - Correlation chart for Value Loss based on WTP per person per year and study year MPD pollution compared with GDP per capita for studies within Europe.

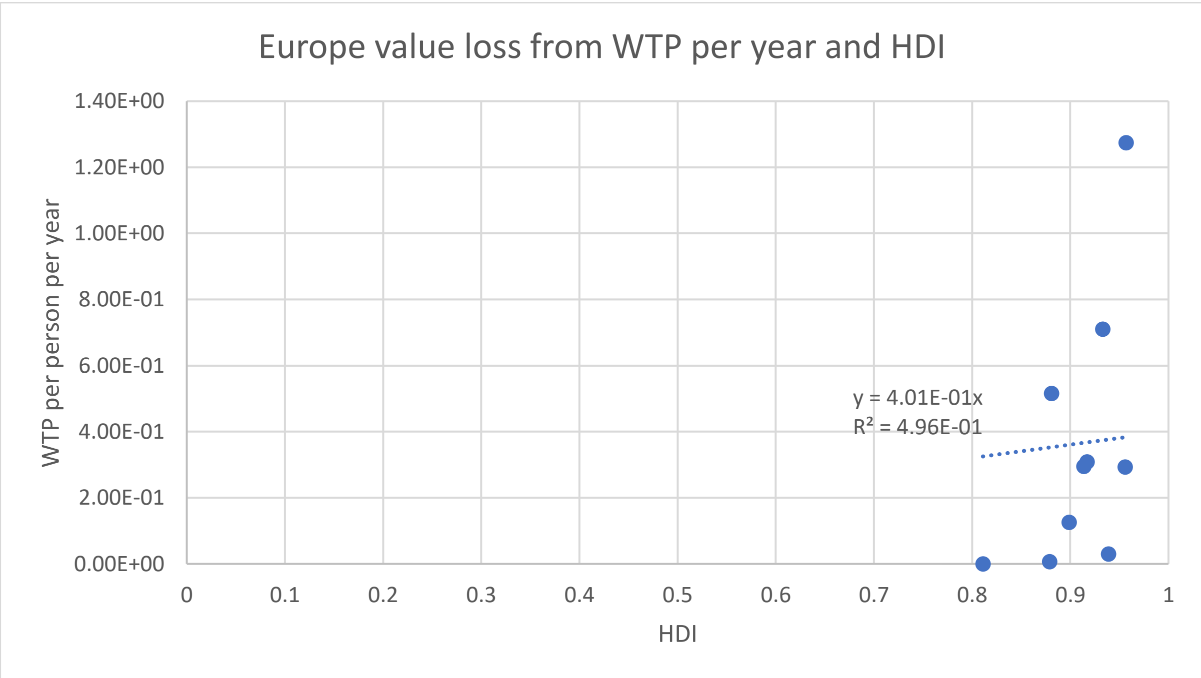

Figure C12 - Correlation chart for Value Loss based on WTP per person per year and study year MPD pollution compared with HDI for studies within Europe.

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