PlasticFreeDanube

D3.2.1 MATERIAL FLOW ANALYSIS MODELL

Development of a Methodology for a Material-Flow-Analysis of Plastic Waste in and along the Danube River

DOCUMENT INFORMATION	
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1. INTRODUTION

This report describes the development of a methodology to systematically identify, structure and quantify the main sources and pathways of plastics in riverine systems. Deliverable of this process is a Material-Flow-Analysis (MFA) for the project region between Vienna and Gabčíkovo. The system boundaries consider the geographical boundaries and content- related limitations (like data limitations). The developed MFA diagram assigns the potential sources of pollution to the respective entry and discharge sources in the balance area and highlights hotspots of the plastic litter. Furthermore, a methodology for the data collection has been developed and listing of the necessary data has been started.

The first part of the report deals with the state of the literature, in particular the classification of potential sources and entry pathways of plastic pollution as well as points of release into the nature. The methodology for the identification, structuring and assessment of sources and paths of plastic waste in rivers is described in the second chapter and serves as a basis for the *report on available data concerning plastic pollution* (D 3.3.1). Core output of this development process is a register containing all relevant information for the evaluation of plastic pollution in the project area. The last part deals with the development of the material-flow-analysis (MFA) model that should highlights and visualise the most important sources and paths of plastic pollution in the considered Danube region.

2. LEVEL OF KNOWLEDGE

Litter entering running waters moves with the flowing wave from the point of entry to the estuary, into adjacent streams or lakes and ultimately into the seas and oceans where they are distributed with the global ocean currents. The associated potential ecological and economic impacts of floating debris are not limited to a local area, but are much more part of the global water cycle of all surface waters (Breitbarth, 2017).

Global estimations on plastics entering the oceans via rivers vary strongly in literature, the quantities range from 0.4 to 12.7 million tons annually (Jambeck et al., 2015; Lebreton et al., 2017; Schmidt et al., 2017). Nevertheless, it is widely used that up to 80% of marine debris originates from land and in this context, rivers are recognized as the main pathways of pollution (IMO et al., 1990; Jambeck et al., 2015).

According to initial studies - focussing more on micro plastic - by Lechner et al. (2014), the annual quantity of plastics via the Danube into the Black Sea is estimated at 1,530 tons. However, information on the amount and composition of macro plastic (> 5mm) is still missing.

Starting point for the assessment of plastic pollution in the PlasticFreeDanube project region is the identification of the most important sources (e.g. industry, agriculture, packaging, household waste, ships, ports, illegal landfills) and possible entry paths into the Danube river. Since a multitude of different classification and categorisation of macro-plastics already exists, the main approaches are summarised the following chapter.

2.1. Sources and Origin of plastic pollution

The sources of plastic litter in rivers are as manifold as the various types of waste themselves, and are the result of a wide variety of uses of the original plastic products. However, measures to prevent pollution from litter in rivers or in water bodies in general need to target these different sources. Identifying the origin of floating debris is a complex task as litter enters the ocean from various points and diffuse sources. Additionally, litter can travel long distances before being deposited onto riverbanks, shorelines or finally settling on the seabed. There are various approaches to classify sources of plastic pollution. The most common classifications of pollution sources are summarised in the following chapter.

2.1.1.Place of origin

This definition aims at the place of origin of the (plastic) pollution. The decisive factor is where the waste is generated or where it enters the watercourse.

2.1.1.1. Land- vs. sea-based sources

According to Galgani et al. (2013) land-based sources encompass tourism and recreational activities, general public, fly tipping, local businesses, industry, harbours and unprotected landfills. Litter from land-based activities and resulting from poor waste management enters the marine environment via drainage or sewage systems, drains, rivers, winds, road run-offs and storm-water outflows.

Sea-based sources of marine litter include merchant shipping, ferries and cruise liners, commercial and recreational fishing vessels, military fleets and research vessels, pleasure craft, offshore installations such as oil and gas platforms, drilling rigs and aquaculture sites. Factors such as ocean current patterns, winds and tides, and the proximity to urban centres, industrial and recreational areas, shipping lanes, and fishing grounds also influence the types, nature and amount of litter that is found in the open sea or collected along beaches, waterways or underwater.

Most of floating plastic litter in the oceans originally comes from the land via various routes such as rivers, beach litter, urban runoffs. Already at the beginning of the 90s, the United Nations Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) estimated that land-based sources account for up to 80% of global marine debris, which current studies continue to confirm (GESAMP, 1990). Primarily, inefficient or missing waste management can be seen as the main reason for the continuous discharge of land-based plastic pollution into the oceans. Especially in the case of natural disasters, such as tsunamis, floods, hurricanes, etc., huge amounts of plastic debris land up in the oceans within a very short time. One example is the tsunami of 2011, which transferred around 3 Mt of waste (80% plastics) from Japan's coastal areas to the Pacific Ocean (Vannela, 2012; Zettler et al., 2013).

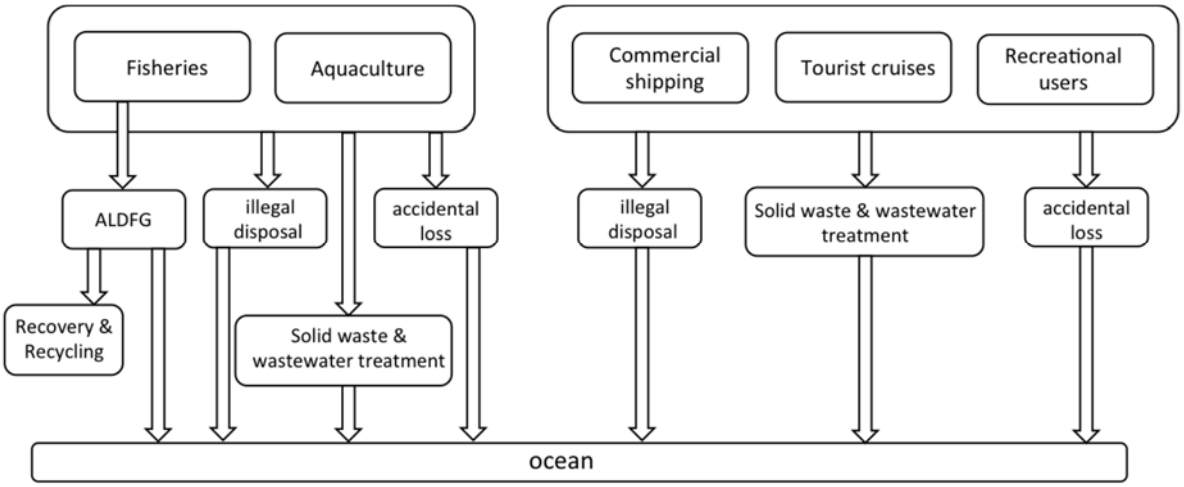


Figure 1: Sea-based sources of macroplastics and pathways to the ocean (original by P. J. Kershaw, UNEP, 2016)

The MSFD (Veiga et al., 2016) also refers to the most common general categorizations of origin between sea-based and land-based marine litter, but extends their model to pathways (like sewage, run-offs, etc.), type of input (direct or diffuse) and different transport mechanisms, taking four examples (cotton-bud sticks, plastic bags, plastic bottles and fishing nets/lines) into account.

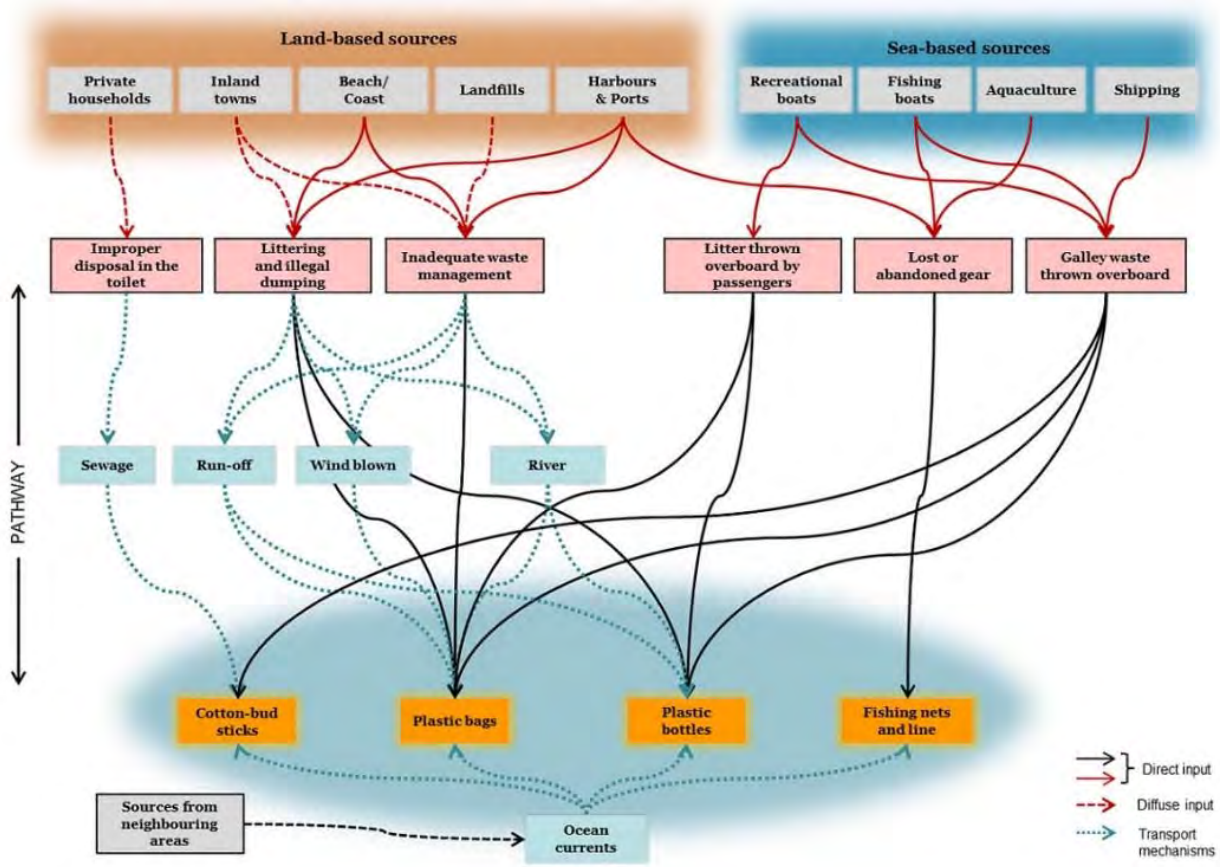


Figure 2: Multiple sea- and land-based sources (grey boxes) of 4 common items of marine litter and their potential pathways of entrance (blue boxes) into the marine environment (Veiga et al., 2016).

2.1.1.2. Direct vs indirect entry

Another approach to assign plastic entry in running waters is to distinguish between indirect direct or entry. In case of indirect discharges, waste is initially littered in the riparian/ bank zones and the areas adjacent to them. Ultimately, the litter discharged by drifts, by wildlife (e.g. crows) or by inundations without human intervention.

Direct entry mainly includes discharges from drainage systems into running waters. These include entries from domestic wastewater collection and entries from inundations as part of precipitation collection on public and private areas. In addition, this waste is often flushed from regions far from the water body. Shipping waste that enters the river is also part of the direct input as well as when someone throws their trash, e.g. the take-away cup, directly into the water.
Running waters are generally fed by numerous natural and artificial tributaries. Floating waste of these tributaries also rank among direct entry. These tributaries considerably extend the catchment area for waste input (Breitbarth, 2017).

2.1.1.3. Point and diffuse sources

In terms of spatial characteristics, sources can be classified into point sources and diffuse sources (= line sources). Because point sources can usually be detected and eliminated in a more targeted manner, according to Breitbarth (2017) this distinction is relevant for the type and effort of potential avoidance measures.

Diffuse sources cannot be assigned to a specific location, so they are much more difficult to identify. Consequently, corresponding measures turn out to be challenging.

An example will illustrate this distinction: If, for instance, a tennis ball is found on the riverbank, it is probably still difficult to actually assign this item to a single source. The ball could have come from a tennis court or been used as a toy for a dog that was lost during a walk. An assignment to a point or line source would not yet be possible. If, however, one finds several tennis balls and a tennis court is also located in the immediate surroundings of the examined water, an assignment to the direct source is very likely possible. Avoidance measures can thus be taken and implemented relatively easily.

In general, littering can be considered a diffuse/line source. The discharged packaging foil that has been washed ashore miles from the place of origin cannot be assigned to a certain location.

2.1.2. Type of use

Depending on the task at hand or issue, it may make sense to assign plastic waste to its original form of use. The focus of this definition is on the time aspect of use as well as how often a product is used.

2.1.2.1. Short-term & single-use vs. Long-term & multiple-use

Contrary to the original intention of establishing plastic as a high-quality material, today it is mainly used for the production of packaging materials and single-use items. Many of these products are only used once and usually for a short time before they end up in the trash.

Figure 3 illustrates the regions of the world where mainly disposable plastics are produced and consumed. These are China, North America, the Middle East and Western Europe. If these production figures are combined with the population density and the established waste management systems (see also Figure 5), it quickly becomes clear why it is precisely in these areas that plastic is increasingly being released into the environment.

Figure 1But western countries also have to deal with plastic pollution. Therefore, the European Parliament and Council of the EuropeanUnion (2019) wants to declare war on disposable plastic products and has passed the Single-Use Plastic Directive (2019/904) in June 2019.

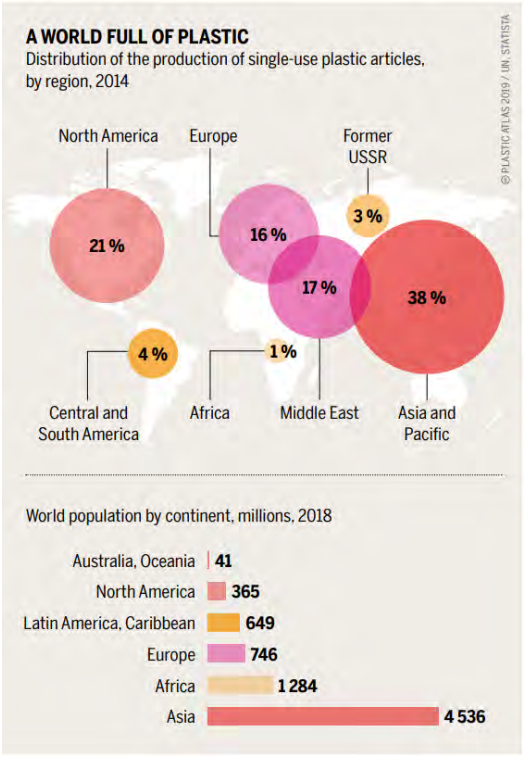


Figure 3: Distribution of single-use plastic production by region 2014 (Plastikatlas, 2019)

Starting point of the EU Plastics Directive was the investigation of pollution on European beaches. The most common items found there are disposable plastic and fishing equipment. The data show that disposable plastic accounts for almost half of all such items.

The SUP Directive covers a total of 15 disposable plastic products, which are addressed by a range of policy measures, including market restrictions, consumption reduction targets, design, collection and labelling requirements and extended producer responsibility. The measures and implementation dates depend on the subject matter and existing alternatives.

In this respect, the distinction between short-term & single-use vs. long-term & multiple-use is ideal for monitoring and evaluating the effects of specific avoidance measures since, for example, the introduction of the SUP Directive. Kershaw suggests such a simplified subdivision, illustrated in the following figure (Figure 4):

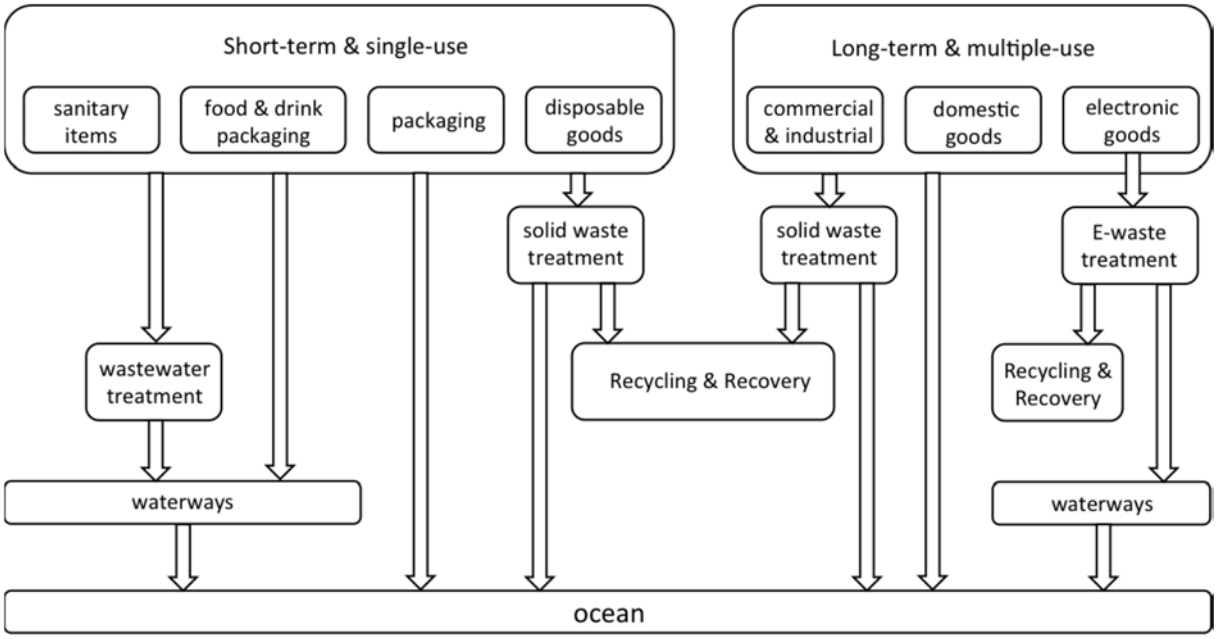


Figure 4: Land-based sources of macroplastics and pathways to the ocean (P. J. Kershaw modified by UNEP, 2016)

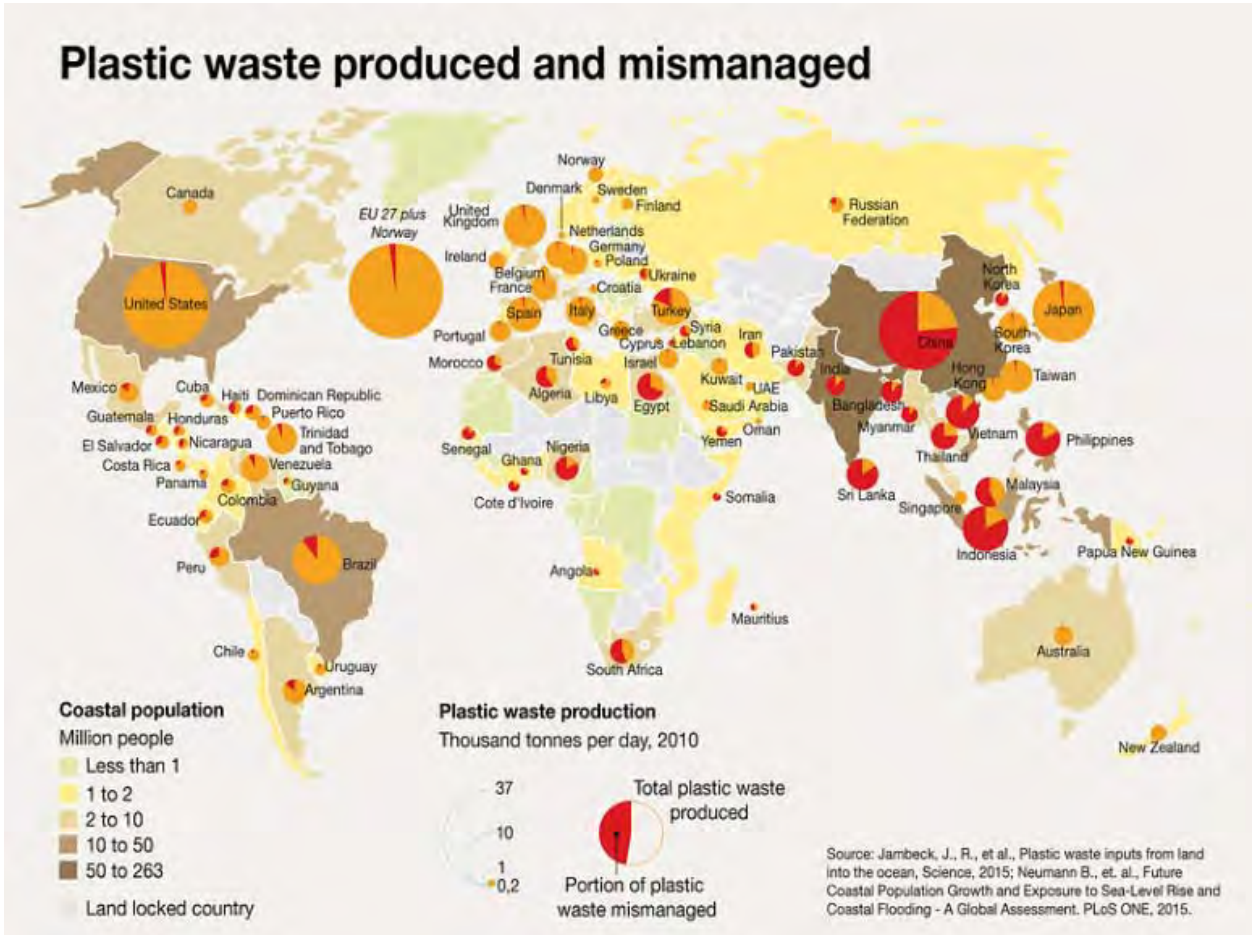


Figure 5: Global plastic waste produced and mismanaged (Pravettoni, 2018)

2.1.2.2. Packaging vs. Non-packaging

This classification approach is interesting insofar as almost 40% of all produced plastics are used as packaging (Fuhr and Franklin, 2019; PlasticsEurope, 2019). It is also a common subdivision of the plastic fraction in the context of residual/ municipal solid waste analyses. Subsequently, some examples of these standards are listed:

- EU (2004): Methodology for the Analysis of Solid Waste (SWA-Tool)
- USA (2008): Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste
- GER (2014): Directive on uniform waste analysis in Saxony
- GBR (2015): Guidance on the Methodology for Waste Composition Analysis
- AUT (2017): Guide for the performance of residual waste sorting analyses

Table 1: Categorisation of plastics – Extract of the SWA sorting catalogue (EC, 2004)

Primary Categories	Code	Secondary Categories	Code	Notes	Typical Examples
Plastics	PL4	Plastic Film –packaging	PL4 01	All packaging bags and refuse sacks	Biscuit wrappers; Cereal packets (inside box); Cling film; Compost/peat bags; Crisp packets; Frozen food bags; Packaging plastic film; Plastic food bags/pet food/non food bags; Sandwich bags
		Plastic Film – non packaging	PL4 02	All non packaging bags and refuse sacks	Cellotape; Garden sheets; Non-packaging film; Plastic bags; Refuse sacks; Shopping bags; Tarpaulins
		Dense Plastic Bottles/Jars (P)	PL4 03	All clear and coloured plastic bottles and jars	All plastic bottles/jars e.g.; Alcoholic drinks; Bleaches; Detergents; Household/pet/garden products; Laundry liquid; Milk; Oil; Soft drinks; Vinegar; Water
		Dense Plastic – other packaging	PL4 04	All other clear and coloured plastic packaging except bottles and jars	Appliance packaging; Cleaning tubes; Cosmetic tubes; Egg boxes; Food cartons; Food packing trays; Food tubes; Ice cream cartons; Margarine tubs; Plastic lids; Ready meal trays; Roll on deodorant bottles; Trays; Yoghurt cartons; Bottle tops
		Dense Plastic –non packaging	PL4 05	All non-packaging dense plastic items	Air freshener holders; Bank/credit cards; Buttons; CDs'; music cassettes; Cosmetic/glue/paint applicators; Disposable razor blades; Floor Linoleum (Lino); Floor Tiles (vinyl/plastic); Garden hoses; Gardening equipment; Hard plastic; Household/car/garden accessories; Lighters; LPs; Pens; Plant pots; Plastic curtain rails; Plastic frames; Plastic sunglasses; Plastic toys; Rulers; Rulers; Seed trays; Shoes (Plastic only); Toilet lids; Toothpastes; Tubes/pumps; Video cassettes; Washing up bowls/racks

Beverage and food packaging represent a substantial proportion of littered waste, as shown by many studies on coastal areas and beaches as well as clean-up events in the interior. This is not least because the consumption of these (fast food) products is often away from home and the packaging is not properly disposed of due to a lack of disposal infrastructure or for reasons of convenience, and thus ends up in the environment (OceanConservancy, 2013; GESAMP, 2016; OSPAR, 2010).

Unlike packaging, which has a short useful life and is usually only used once before it becomes waste, many non-packaging items remain in our technosphere for a longer period of time (e.g. in the construction sector, transport and traffic, electronics, industry). This is also evident with regard to the EU plastic waste generation. Here, *packaging* accounts for almost 60%, followed by *Others* (14%), waste of electrical and electronic equipment (WEEE) with 8%, and plastic waste from *automotive* sector, *agriculture* as well as *construction & demolition* at 5% each (PlasticsEurope, 2019).

2.1.3.Sources by sector

This classification of riverine or marine plastic litter directly addresses the source-sector. This approach is repeatedly because the waste can be often easier assigned to the respective emitter and prevention measures can be implemented in a more targeted manner.

GESAMP (2016) distinct the source in sectors by producer- & consumer responsibility during the lifetime of a plastic product following the value chain of plastic (Table 2). Beside the enumeration of some examples (description), typical entry point and the level of knowledge is also given. In connection with this classification GESAMP refers to the partly substantial regional differences in the relative importance of sources and entry points. In terms of the socio-economic aspects, citizen purchase behaviour (e.g. unpacked food), personal habits (e.g. use of reusable bottles/bags) and waste practices (littering, waste separation & collection) are key drivers of riverine and marine pollution.

Table 2: Sources of (macro) plastics by usage sectors identified by GESAMP (2016)

Category	Source Sector	Description	Entry points	Knowledge
Sectoral consumers	Agriculture	Greenhouse-sheets, pots, pipes, nutrient prills	Rivers, Coastline, Atmosphere	Low
	Fisheries	Fishing gear, packaging	Rivers, Coastline (e.g. ports), Marine	Medium
	Aquaculture	Buoys, lines, nets, PVC pipes	Rivers, Coastline, Marine	Medium
	Construction	EPS, packaging	Rivers, Coastline, Atmosphere	Low
	Terrestrial Transportation	Pellets, tyres, tyre dust	Rivers, Coastline, Atmosphere	Medium
	Shipping/ Offshore industry	Paints, pipes, clothes, miscellaneous, plastic-blasting, cargo	Rivers, Marine	Medium
	Tourism industry	Consumer goods, packaging, microbeads, textile fibres	Rivers, Coastline, Marine	High
	Textile industry	Fibres	Rivers, Coastline, Atmosphere	Low
	Sport	Synthetic turf	Rivers, Coastline, Atmosphere	Low
Individual consumers	Food & drink	single-use packaging containers, plastic bags, bottles, caps, cups, plates, straws, spoons, etc.	Rivers, Coastline	High
	Cosmetics & personal care products	Microbeads, packaging, toothbrushes, etc.	Rivers, Coastline, Marine	Medium
	Textiles & clothing	Fibres	Rivers, Coastline, Atmosphere, Marine	Medium
Waste management	Solid waste	Unmanaged or poorly managed waste disposal	Rivers, Coastline, Atmosphere	Medium
	Water & wastewater	Microbeads, fragments, fibres	Rivers, Coastline	Medium

The subsequent classification by UNEP (2016) targets the main sectors identified of potential land-based sources. This approach also provides different types of plastic products or waste and the typical entry points to the ocean (Table 3).

Table 3: Potential land-based sources of macroplastics by sector, examples of plastic waste, common entry points to the ocean and probable importance (UNEP 2016)

Sector	Description	Entry points	Relative importance[1]
Retail	Packaging, household goods, consumer goods	Rivers, coastal, atmosphere	High
Food and drink	Single-use packaging	Rivers, coastal, atmosphere	High
Households	Packaging, household goods, consumer goods	Rivers, coastal, atmosphere	High
Tourism industry	Packaging, household goods, consumer goods,	Rivers, coastal, atmosphere	High
Plastic recyclers	Packaging, household goods, consumer goods	Rivers, coastal, atmosphere	Medium
Construction	EPS, packaging,	Rivers, coastal, atmosphere	Low
Agriculture	Films/sheets, pots, pipes,	Rivers, coastal, atmosphere	Low
Terrestrial Transportation	End-of-life vehicles and tyres	Rivers, shorelines	Low

[1] qualitative estimate, likely to be regionally-dependent; variables include the extent and effectiveness of solid waste and wastewater collection and treatment, and storm water overflow capacity

2.2. Entry pathways of plastics

In general, the definition of sources includes the sector of society or industry responsible for releasing the litter into the environment, and pathway is defined by how litter finds its way into the aquatic environment (Sherrington and Darrah, 2014). Plastics which reached the environment can enter rivers via various pathways. Different studies refer that the differentiation between sources and pathways is not always clear (EC, 2012; UNEP, 2009). Additionally, precise assignments of (collected) plastics to pathways are even harder than to attribute them to a specific source. However, in some cases, there are pathways e.g. flushing of wet wipes with wastewater which can be more clearly attributed than others and can be targeted for abatement measurements. In literature several methods for categorisation of paths can be found. According Sherrington and Darrah (2014) there also exists certain litter attributes which can be used to concretise the term pathway, such as vector, intention or location. Unfortunately, a detailed definition or description of this attributes is not given. In our own understanding, the term 'vector' essentially covers the main distribution-medium of human, water and wind. 'Intention' in relation to pathways refers to whether waste is deliberately or accidentally released into the environment. 'Location or source' includes the sector or place of origin, while 'physical pathway' means the transport element by which the waste is discharged into the water body (e.g. inefficient sewage treatment plant, sewer/drain). Table 4 gives an overview about different distinctions including definitions and descriptions of possible marine litter pathways.

Table 4: Different methods for the definition of litter pathways (Sherrington and Darrah, 2014)

Method	Reference	Categories
By intention and source	UNEP (2009)	Negligent – Loss
		Negligent - System failures
		Negligent - Outdated and inadequate waste management practices
		Intentional - Public behaviours leading to illegal waste disposal/indiscriminate littering and dumping
By vector	UNEP (2009)	Human - By direct dumping
		Water - Transported by storm water, via drains and rivers towards the sea
		Wind - Blown into the sea.
By physical pathway, vector and source	UNEP (2009)	Wastes from legal and illegal dumpsites located on the coast or river banks
		Discharge via Industrial outfalls
		Discharge from storm water drains
		Discharge from municipal drains
		Untreated municipal sewerage
		Litter dropping close to waterways and wind/water transport across land/water threshold.
By physical pathway, vector and source	Arcadis (2012)	Direct (on site dumping)
		Diffuse (sewage)
		Diffuse (inland waterways and rieras)
		Diffuse (others)
By intention	Arcadis (2012)	Intentional, including negligence
		Accidental
By geography of origin	Arcadis (2012)	In situ generation
		Local (short distance)
		Long distance or transnational

Plastics which reached the environment can be transported over long distances by wind and water. Animals can also play an important role (e.g. birds picking waste out of trash bins). Transportation processes are influenced by shape, density and size of plastics (Schwarz et al., 2019).

If the human factor is left out of the equation and only the systems through which litter can be discharged into flowing waters are considered, these can essentially be rationalized into two entry paths: pathways via waterways and via atmosphere. Because this access seems essential with regard to the MFA model, the following section will touch upon it in more detail.

2.2.1.Pathways via waterways

With regard to the project-specific requirements of the MFA-model the following entry paths via waterways were essentially identified:

- Wastewater-related entries (incl. rainwater)
- Tributaries (direct input)
- Headwaters (direct input)
- Extreme rain & flood events

Sewage-related debris can enter the river systems basically through discharge of untreated waste water, the lack of sewage treatment plants or from sewer overflows or discharge from untreated storm water which entrains waste collected in storm drains into the rivers.

Transportation via **waste water** and surface water are likely pathways for the entry of macro plastics into the rivers. Toilets for example are not only used for their intended purpose, but unfortunately, also to dispose waste materials like hygienic products (cotton buds. sanitary towels, condoms etc.) or even toilet stones holders. **Rainwater** which is polluted with littered plastics on sealed surfaces (e.g. cigarettes) also can enter into rivers via rainwater sewage system or mixed sewage system.

Depending on population density and prevailing land use, **tributaries** can contribute greatly and directly to plastic pollution and significantly extend the catchment area for plastic waste. To estimate the contribution of the considered tributary to the riverine litter in the main stream, it would have to be regarded separately. Considering only the estuary stream, a determination of input quantities by the inflow is almost not feasible.

If the water is not observed from the source, litter is also discharged into the river section from the **headwater**. Similar to tributaries, an estimation of the pollution contribution of headwaters is difficult to determine without separate observation or measurement.

Extreme rain and **flood events** have a tremendous impact on plastic pollution and can multiply concentration of macro plastics in riverine ecosystems. Here, large quantities of available (plastic) items from surrounding areas are usually mobilized within a short period of time and transported over long distances. If the water level then sinks again, many of the debris carried along remain in the remote parts of the hinterland (e.g. floodplain forest, etc.), where they are not affected by clean-up operations.

2.2.2.Pathways via atmosphere

Jambeck et al. (2015) figured out that the most important contributor to the increasing plastic pollution in our oceans is mismanaged waste from particularly middle-income countries with rapidly growing economies and missing waste management infrastructure (see also Figure 6).

From a global perspective, **poor and improper** (plastic) **waste management** is the main reason why plastic debris enter running waters and finally end up in the marine environment (Moore, 2008; Sheavly and Register, 2007).

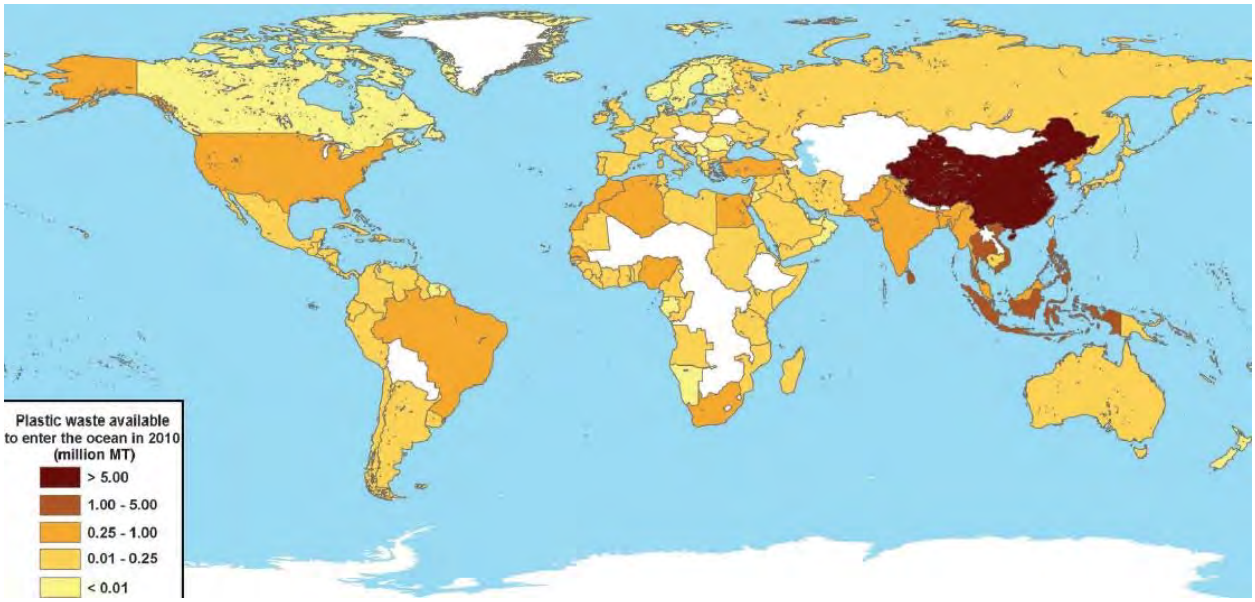


Figure 6: Global map with 192 countries coloured according to the estimated mass of mismanaged plastic waste (Mt) generated in 2010 by populations living within 50 km from the coast. White shaded countries are not included in the study (Jambeck et al. 2015)

In the project area, improper waste management (WM) plays a minor role due to the high WM-standards within the framework of European legislation. Treatment of waste (i.e. burning or removing of plastics) is mostly handled in buildings, therefore we expect them not to be a source of plastic pollution. As in European member countries municipal solid waste (MSW) is pretreated before landfilling, barely no plastics are landfilled anymore. Thanks to proper landfilling technology (e.g. surface coverings also at abandoned landfills) drifts into surrounding areas through **mismanaged landfill sites** can be excluded.

However, overflowing waste containers that are too rarely emptied, poorly anchored or constructed (e.g. drifts of waste or distribution by crows due to open construction; upset of containers due to strong winds) or vandalism can contribute to the entry of plastic waste into the environment.

Litter - usually as a result of carelessly throwing away and leaving waste at an unsuitable location- is difficult to assess in terms of amounts and pathways as it cannot be measured directly. Littering appears mainly in public places, at traffic hubs, along streets, near take-away restaurants, petrol stations, shopping centers and in natural recreation areas. Increased littering also occurs at major events (e.g. festivals, concerts, etc.) on and around the event site (UBA, 2020). A distinction can be made between direct and indirect littering. While **direct littering** involves active, conscious and deliberate action (throwing away a beverage bottle in the park), the actor – in case of **indirect littering** - accepts littering as a consequence by his actions. This can be, for example, insufficient protection of construction waste during transport (Breitbarth and Urban, 2014).

Illegal waste disposal is not the same as littering. In the case of illegal disposal, a conscious decision is made beforehand and it is to be regarded as a targeted action, for example, so to avoid having to pay a disposal fee. It usually concerns larger quantities/items or entire refuse sacks. Littering, on the other hand, involves smaller amounts of waste and smaller objects, such as an empty PET bottle or packaging.

2.3. Existing Studies for quantitative description

Breitbarth (2017) investigated the extent to which the rivers in Germany produce waste and the share to which the rivers contribute to the pollution of the oceans. For this purpose, the waste occurrence in and along different watercourses, distinguished between macro (>5mm) and micro (1-5mm) waste, was recorded and analysed with regard to product-related, material and size-related compositions.

The aim of this work was the investigation of selected German rivers and streams regarding the sources of waste inputs, the input and discharge paths into and from the flowing waters, the compositions of the waste regarding product types, materials and size distribution as well as the total volume. Breitbarth distinguishes between point and line sources with regard to the origin of the waste (see chapter 2.1.1.3). In addition, he divides the types of waste: 'waste' refers to general and unclassifiable trash, 'flotsam' includes floating debris and 'litter' refers to waste that can be assigned to the term “littering”.

Macro waste samples were collected via a) flotsam in and around the river, b) screenings from hydropower plants and a grid construction (for a small river and low water levels) as well as c) waste from riparian strips and adjacent areas, while micro waste was sampled with stationary nets (mesh size 1mm).

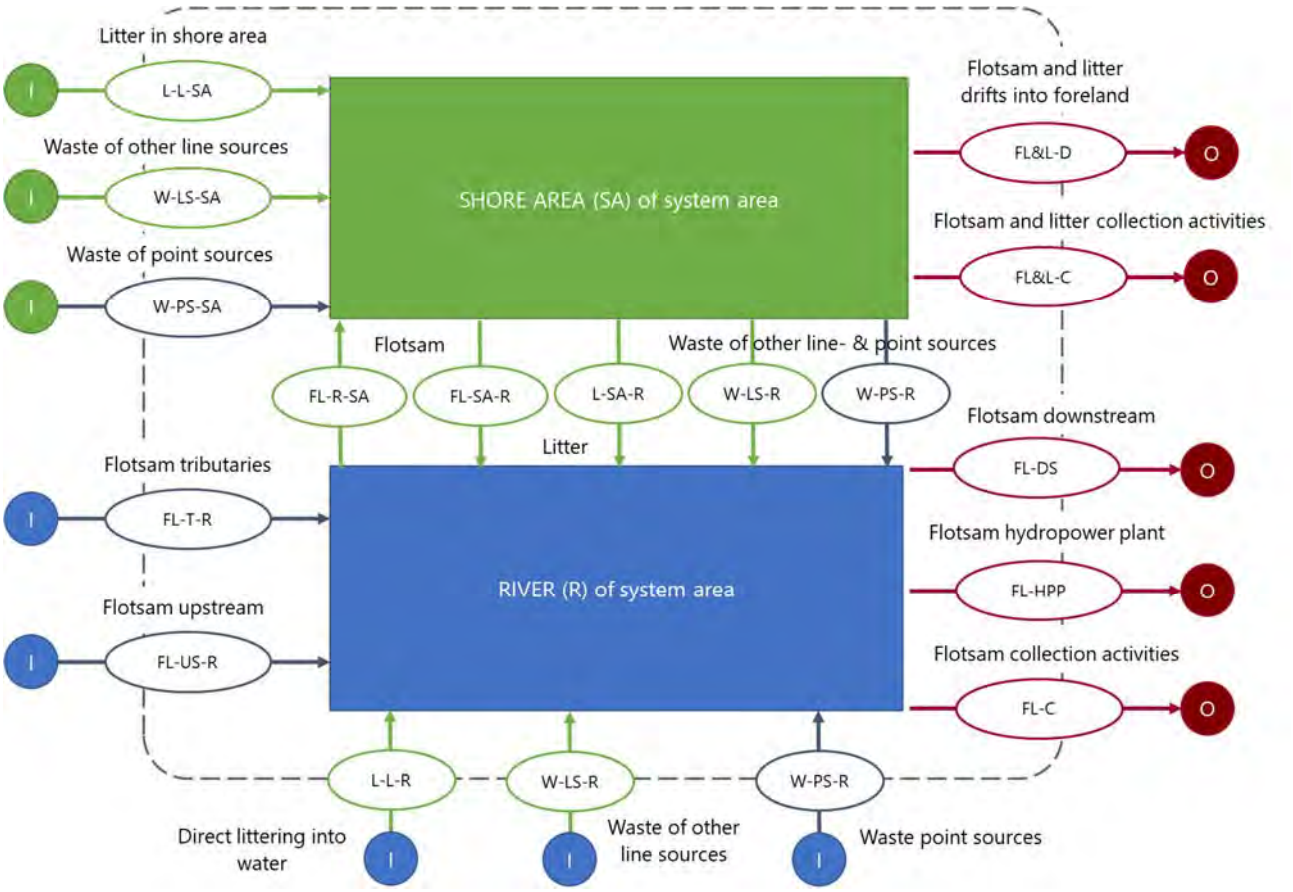
The waste samples, usually collected on a monthly basis, were sorted and projected over the annual discharge of the respective river. In all investigated rivers (Rhine, Saale, Fulda, Haune, Ahna, Werra) a contamination with wastes could be detected. For macro wastes it was determined that, in terms of mass, packaging (44 mass-% in the Saale) and in terms of quantity, due to fragmentation in the water, films, sheets and bags (50 pieces % in the Saale) or building materials with predominantly EPS fragments (60 pieces % in the Werra) are the most frequent product classes. In terms of material, the main part of the waste consists of plastics (88 p.c. % / 49 wt.% in the Saale). A comparison of the waste compositions in the water bodies with the waste compositions at the shore area shows that the predominant input of the macro wastes enters the water via drifts and floods.

The waste input into the seas and oceans via the five main rivers Rhine, Elbe, Danube, Weser and Oder was estimated at 153.4 t/a (42.5 million pieces) for macro waste and 148.4 t/a (49.6 billion pieces) for micro waste. For the estimation the absolute quantities over the 5 main German rivers Rhine, Danube, Elbe, Oder and Weser were extrapolated on the basis of the respective average discharges of these rivers. As a basis the average concentration of macro wastes determined over one year in the Saale by masses and numbers of pieces related to the discharge [kg/mio. m3 and pcs./mio. m3] were simply transferred to the discharges of bigger streams. As the analyses are exclusively based on the data of one power plant in the river Saale, where already from the one power plant the loads of the whole river were deduced (without taking into account whether all plastics could be recorded), the results for the average waste volume in the river Saale (based on 12 days of investigation) of 0.9 kg per 1 million m3 of water should be regarded with caution. Current and well-founded data on the total waste discharge into the North Sea, the Baltic Sea and the Baltic Sea and the Black Sea are not known

Already 1995, the OSPAR commission estimated an total waste input of around 20,000 t per year into the North Sea (UBA, 2010), thus, Germany's relevance to waste input into the world's oceans via running waters

can be considered very low. However, the ecological effects of the waste on running waters are largely unclear.

The figure beside shows the underlying MFA model, which was developed by Breitbart to illustrate the relevant sources and pathways in German rivers.



I... import / entry pathway
O...output / discharge pathway

→ Point source
→ Line sources
→ Discharge

Structure of the abbreviations: type of waste - source/sink – part of system area

Type of waste:	**W**-Waste; **FL**-Flotsam; **L**-Litter; **FLL**-Flotsam with Litter
Sources:	**PS**-Point Source; **LS**–Line Source; **US**–Upstream; **L**–Littering; **T**-Tributaries
Sinks:	**DS**-Downstream; **C**-Collection/cleaning; **D**-Drifts; **HPP**-Hydropower Plant (screenings)

Figure 7: General material flow model for input and output paths of macro wastes in a delimited system area of a watercourse (Breitbarth, 2017; modified)

In a recent study, Kawecki and Nowack (2019) modelled the emissions of macro- and microplastics for seven polymers in Switzerland. In form of a probabilistic material flow analysis they completely analyse the flows from production, manufacturing and use to end-of-life. Based on a previous model on European Plastic Flows in general already based on modelling only with high uncertainties they appraise the plastic entry into the Swiss environment at 200 ± 120 g/cap/a of polyethylene terephthalate (PET), 126 ± 43

g/cap/a of polypropylene (PP), 94 ± 34 g/capita/year of low-density polyethylene (LDPE), 98 ± 50 g/cap/a of high-density polyethylene (HDPE), 24 ± 13 g/cap/a of polystyrene (PS), 16 ± 12 g/cap/a of expanded polystyrene and 65 ± 36 g/cap/a of polyvinyl chloride (PVC). Regarding plastic emissions, the macro-plastic input into soil exceeds that of micro plastic by a factor of 7.5 with 540 ± 140 g/cap/a (all surveyed polymers combined), the macro-plastic entry into fresh water is with 13.3 ± 4.9 and g/cap/a about 7,6 times higher than the micro-plastic. No evaluation of the model was performed on real data.

Kawecki and Nowack cite also that most of the pollution is due to littering for both terrestrial and aquatic environments. Furthermore, they argue that more attention should be paid to mass flows into the soil, as they are estimated to be 40 times larger than those into waters. The uncertainty has to be explicitly mentioned to be very high. In general it could be shown that most of the plastic end up at soil and not in the water. Interactions between primary littering and subsequent cleaning were not consideredIn their study they also emphasize the importance of referring to specific polymers instead of just “plastics”.

The following figure exemplarily shows the structure of the underlying MFA-model by Kawecki and Nowack.

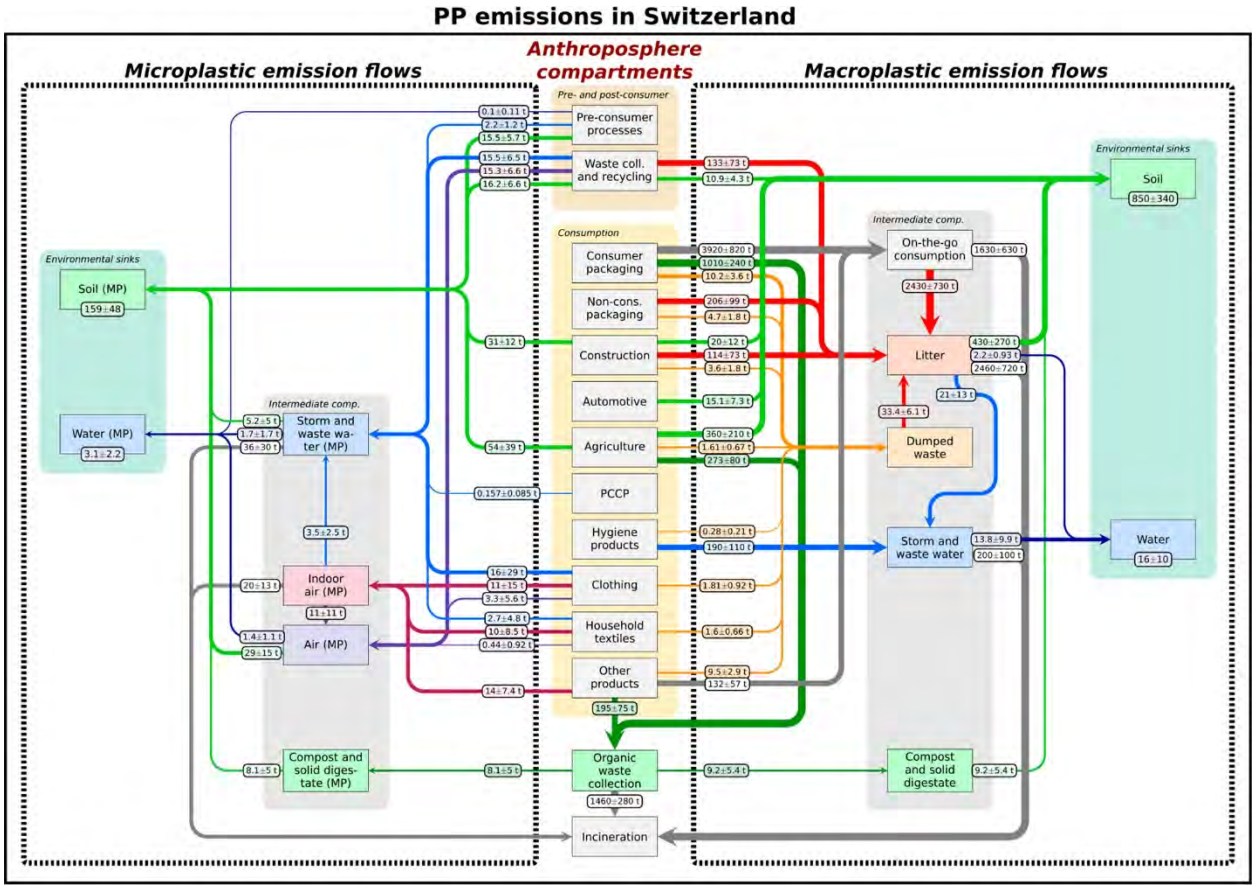


Figure 8: Aggregated emissions flows for Polypropylene (PP) in tonnes per year for macro- and microplastic in Switzerland 2014 (Kawecki and Nowack, 2019).

Both possibilities the extrapolation of measurement data as well as the modelling approach have shown their weaknesses and therefore both approaches can only be used to estimate orders of magnitudes. They are more relevant to recognise differences for specific materials than to estimate the overall plastic input in the sea by rivers.

3. DEVELOPMENT OF A METHODOLOGY

For the identification, structuring and quantification of sources and paths of plastic waste in rivers (or here with focus on the Danube), it is important to proceed systematically. A feasible methodology, which was developed and implemented in the course of the "PlasticFreeDanube" project, is outlined in the figure beside. This cascading method should serve as a starting point and basis for future projects dealing with the pollution of river systems. Moreover, this methodological approach could also be used for other types of pollution beyond the plastic issue.

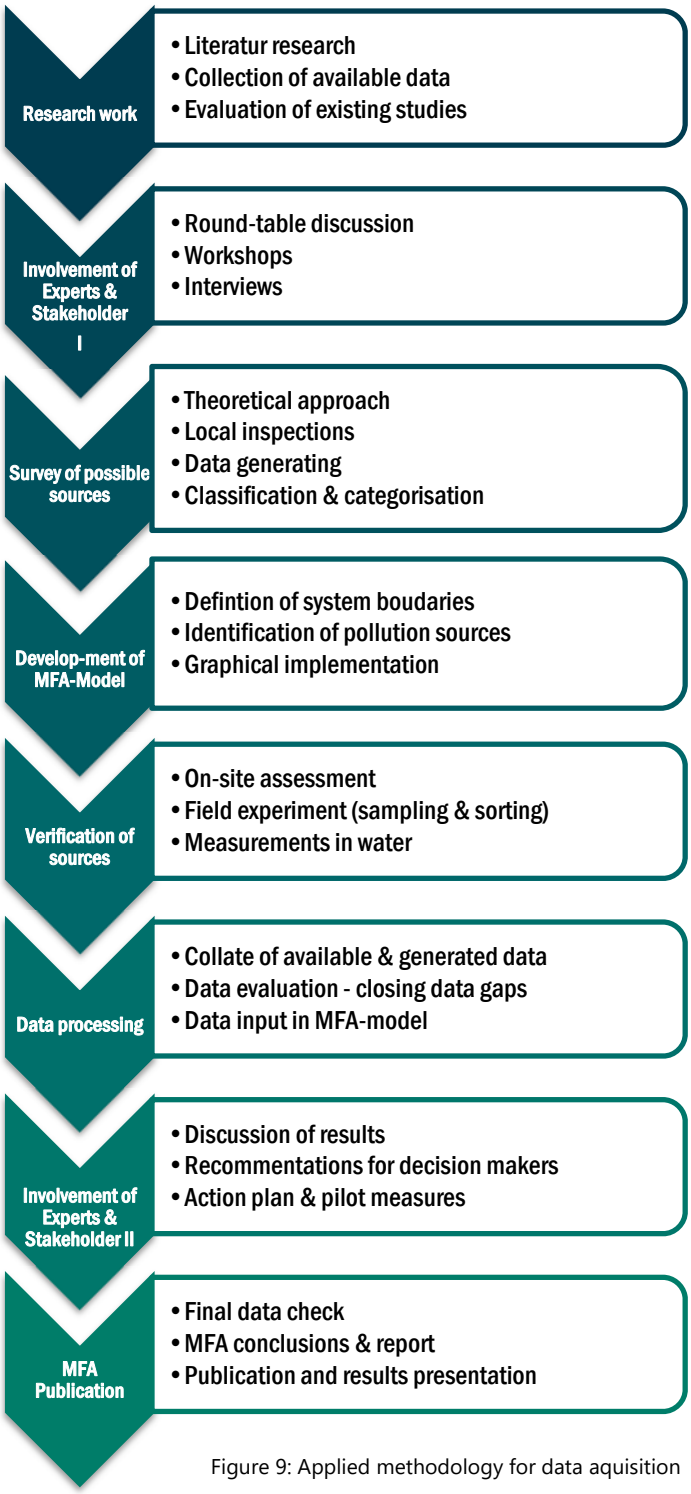


Figure 9: Applied methodology for data aquisition

Each step is described in detail below. In the next chapter the necessary data for estimating, evaluating and quantifying the plastics situation in the Danube are compiled in a list.

Step 1: Literature research

The starting point for each project/initiative is a detailed **literature research**. The current state of knowledge is examined and the most essential information is compiled. Simultaneously, it is useful to **gather available and relevant data** as well as **evaluate** already published **studies** whether applied methods could be appropriate. In summary, a valid desktop research lay the foundation to get an overview of the plastic pollution in the observation area.

Step 2: Involvement of Experts & Stakeholder

After subsequent screening of the existing material, the involvement of experts & stakeholder increases the value of the knowledge acquired and promotes the **exchange of expertise** within the framework of **interviews**, **round-table discussions**, **workshops**, or similar events. The achieved inputs should be implemented in the further process.

Within PFD a joint strategic partner meeting and two separate expert workshops in Austria and Slovakia were held in the first project phase. A prerequisite for hosting such events or meetings is the **identification of relevant stakeholders**. Addressed stakeholder include public authorities (ministries, state agencies, etc.), research institutions & consultancies, municipal waste management associations, educational institutions, NGOs, companies and other actors operative in this field.

The participation in subject-specific conferences in the course of the project also accelerates the knowledge transfer and information exchange between the individual actors as well as the further training of the internal project partners.

Step 3: Survey of possible sources

3.1.1.Theoretical approach

In many cases (size of the study area, external study), an estimation of which sources occur in the investigation area cannot be verified directly on site. Therefore, a theoretical approach can be used. On the one hand, already described sources are used and evaluated from previous studies or surveys (secondary data). On the other hand, the examination and evaluation of aerial photographs, online maps, GIS maps, or land use plans may provide -depending on the resolution of visuals and grade of pollution - further information on sources of pollution. For such materials it is important to note that they are up-to-date.

3.1.2.Local inspection

Since in very few cases the entire course of the river can be considered (possible exception: small stream/ creek), attention must often be paid to a specific river section. The challenge is to find or select segments that are as representative as possible and whose findings can be transferred to the remaining parts of the river system. Concrete recommendations for the choice of such river sections are given in the PFD Handbook for Sampling & Sorting (D 4.1.2).

A (regular) local inspection of selected areas or riding (e.g. by bike, boat, etc.) on partial routes can provide information about possible accumulation hotspots that have not been identified or classified as such. Variations over time or any local environmental factors that may influence the pollution on site should be noted. Inquiries do not always have to take place at a constant location, in some cases randomly inspections are more useful. Selective inspection of more frequented leisure areas or adjacent public areas such as bathing areas, playgrounds, camping and pick-nick sites, fire places, etc. is also essential to be able to estimate the actual pollution potential.

3.1.3.Classification & Categorisation

To counteract the problem of riverine litter and to develop appropriate, application-oriented and pragmatic measures, sources of plastic pollution need to be classified. In this context, it is important to use a categorisation system that is adapted to the question at hand. The classification shall be adapted according to the individual needs or the requirements of the study. However, the comparability with other studies should be taken into account as well as the practicability of the implementation. Possible classifications are summarized in chapter 2.1 and 2.2. The PFD division based on an intersection of sources by sector (see chapter 2.1.3), detected pathways and locations of possible plastic-release into environment. As the project-

specific focus of *PlasticFreeDanube* is on the prevention of plastic pollution, therefore, avoidance measures can be implemented in a more targeted manner. However, in case of many plastic debris, it cannot be clearly proven or determined where the item came from and where it entered the nature. Therefore, this access should include all potential entry possibilities and aspects (origin, path, location) and thus provides a higher information content.

The applied classification (Table 5) is based on the following three pillars: i) sources and pathways mentioned in the literature, ii) the classification of the EU plastic waste generation and iii) the identification of those emitting sectors and pathways in the investigation area which are expected to have a potential impact on the river system or which have been identified by initial sorting analyses.

Table 5: Classification of pollution sources, entry locations and pathways

Source (WHO?)	Location of release into environment (WHERE?)	Examples of plastic items (WHAT?)	Pathway[1] into river system (HOW?)
Households (private and commercial end user)	Housing	Household goods and appliances, garden furniture and tools, office supplies, beverage and food packaging, non-food packaging etc.	Littering[2] and illegal waste disposals;
		Personal care and cosmetic products like hygiene articles, cotton sticks, wet wipes, toothbrush, etc.	Discharge via wastewater system
	Sport, Leisure and Recreation	Toys, sport items, camping equipment, single-use tableware, beverage and food packaging as well as sanitary waste (e.g. wet-wipes for picknick), etc.	Littering[2]
	Street & Transportation	Beverage and food packaging, car parts like tyres, car accessories and automotive products (e.g. plastic packaging of engine oil)	Littering[2]; discharge via rainwater sewer
	Fishing[3]	Fishing gear like rod and line, bait box, fishing nets, etc.	Littering[2]
Waste and wastewater management	Landfills, waste treatment or recycling plants, etc.	Waste that was originally disposed of properly but was generated from inefficient operation or treatment (losses from waste operation & transportation)	Discharge via rain- & wastewater system
Construction sector	Building and construction sites (private & commercial)	Insulating material (e.g. EPS or XPS insulation panels), tools, plastic building materials like tubes, pipes, etc. (incl. the packaging)	Littering[2]; discharge via rainwater sewer
Industry and commercial sector	Industrial and comm. enterprises, include trade sector & service	Waste generated during manufacturing processes, branch-specific waste, packaging waste, etc.	Discharge via Industrial outfalls
Agriculture & Forestry	Fields, cultivated landscape, managed forests	Agricultural (packaging) films in e.g. the production of silage, greenhouse cover, plastic mulch for vegetable cultivation, growth protectors for trees, etc.	Littering[2]
Inland navigation	Harbour, Docks, landings, river	Buoys, fender, ropes, etc. and "tourism-litter" like beverage and food packaging	Littering[2]

[1]based on the UNEP (2009) classification but only caused by human impact; "natural influences"/entry pathways like wind, (extreme) rain, animals or flood events are explicitly excluded because they can directly influence any source or location of release

[2]definition according to Breitbart und Urban (2014): includes direct (active, conscious) and indirect littering (accepting of losses)

[3]is assigned to households within this project because commercial fishing is not permitted (Donau-Auen National Park) in most of the Danube river section under consideration

A number of different places where plastic waste can end up in nature have also been identified, referred to as "locations of release into environment" (see list in chapter 4). All this "point sources" were also implemented in the project-specific output of a GIS based "map of pollution". This map - with focus on the project region of PlasticFreeDanube - describes the situation regarding economy, population, land use and waste management system and contains information about possible pollution hotspots. The results of the GIS-map a summarized in the *report on GIS analysis of the project area (D 3.1.1.)*.

3.1.4.Compile a list of possible sources, origin and pathways

Finally, it can be helpful to summarize all potential sources of pollution and entry paths that have been identified in the project area in a list. It facilitates the verification of which sources or paths are actually responsible for the plastic input into the system. How such a list can look like is explained in chapter 4. This list summarizes all the possible pollution sources as well as locations of release into environment identified in the project area between Vienna and HPP Gabčíkovo. Based on defined indicators (availability of individual sources in the project area, general pollution potential due to increased plastic waste generation or lack of actions/measures, established cleaning measures or retention barriers, etc.), a pollution potential can be determined, which is visualised in the form of a traffic light system for the project region.

Step 4: Development of MFA Model

A Material Flow Analysis (MFA) is an important systematic assessment tool to illustrate interactions between society and environment (here in relation to plastic pollution in and along rivers). With the help of the MFA, an attempt is made to map the relevant stocks, sources, flows and sinks of plastic pollution in the project area in the best possible way and thus to depict them to political and strategic decision-makers or to make them accessible to a broad public.

The modelling of such an MFA requires special attention – among other things – to the definition of the system boundary in space and time (includes geographical; content-related limitations, etc.), detection of all relevant processes concerning the "plastic circuit" and the identification of appropriate plastic flows (mass input/output) as well as stocks and sinks. The detailed description of the technical terms and the overview of the MFA-procedure are summarised in chapter 5, while the list of pollution data has served as a basis for the MFA modelling.

Step 5: Representation of actual pollution sources

Following the bottom up and top down approach, the theoretical sources should be assigned to the actual pollution objects found. On the one hand, we can divide plastic waste into categories according to the polluter-pays-principle and thus allocate the found plastic items to the pollution sector. On the other hand, there are potential polluters, we have identified within the literature research and the own assessment in the project area. In between there are various distribution pathways. With the MFA we want to connect the potential polluters with the actual amounts remaining in the environment.

At this step the actual sampling and assessment of plastic pollution through sorting analyses takes place. An important prerequisite is an appropriate sampling and evaluation strategy. Since there is no uniform procedure for the evaluation of plastic waste in and along rivers yet, this project tried to create a

standardized and thus in the future comparable sampling methodology. For this purpose, a sampling and sorting protocol that meets the underlying requirements was developed. A detailed description of the developing process and the methodological approach is given in the *PFD Handbook for sampling and sorting (D 4.1.2)*. The handbook also contains information regarding the correct handling of the sampling and sorting protocol.

Step 6: Data processing

The collected data in the course of the collection/sampling and sorting activities should help to **close major data gaps**. Beside the statistical evaluation of generated data, the **valuation and transformation** into the corresponding unit (e.g. t/yr or kg/(cap*yr)) take place. Subsequently, all available data are assigned to the respective mass flow and entered into the MFA-model. According to the mass-balance principle, the sum of all (plastic) input quantities into a process equals the sum of all (plastic) outputs of this process plus a storage term that regards accumulation or depletion of plastics in the process. The **graphical representation** of material flow systems serves to highlight and clarify conditions and processes in order to point out specific data and weak points and to be able to assess them more easily.

Various mathematical representation methods can be used to illustrate the generated information (assignment table, from-to-matrix, etc.), but also graphical representation methods like the Sankey diagram are very suitable to demonstrate material flows by quantity.

Step 7: Involvement of experts & stakeholder II

At the end of the evaluation phase, the corresponding experts and relevant stakeholders are again involved. The results are first presented to a selected audience before they are made available to the general public. The aim of the discourse is to obtain general response on the MFA study, to eliminate any ambiguities, and to check the plausibility of the results. The feedback received should be considered and incorporated into the report. Finally, these findings will serve as a further component of the action plan in addition to the recommendations derived from the project and can also be implemented in the pilot measures.

Step 8: MFA presentation & reporting

Finally, it is important to present the relevant results of the MFA in an easily comprehensible manner and to collate the findings to a clear and compact message. According to Brunner and Rechberger (2016) the main objective of the MFA presentation is "*to stage this message to make it clear, understandable, reproducible, and trustworthy.*" Furthermore, it should be considered that there are two crucial audiences for an MFA study: on the one hand scientists and technical experts who have the appropriate basic knowledge and on the other hand, stakeholders who are not intimate with MFA terminology and procedures. The latter target audience is often more important to reach as it is involved in policy and decision-making. In this respect, a language understandable to the general public has to be chosen for the presentation and the MFA results should be prepared and visualized in a clear and transparent way.

4. LIST OF POTENTIAL POLLUTION SOURCES

		1.household (private & comm. End-user)	2. Construction sector	3. Industry and trade sector	4. Agriculture & forestry	5. Inland navigation	6. Waste and wastewater management	Source is located within project area	Collected plastics could originate from respective source	Pollution potential is considered to be relevant due to high amounts and missing measures like regularly cleaning/protection through fences/ measures in WWTPs etc.	Cleaning, sweeping by municipality, private operator, etc.?	Retention barriers (fences, noise barriers, windbreaks, etc.)	Collected plastic can be assigned to source	**Pollution potential in project region of PFD**
Area	**Location of release into environment**	**Sources**						**I**	**II**	**III**	**IV**	**V**	**VI**	
infrastructure	road network (open roads, highways, streets)	✓	✓	✓	✓		✓	✓	✓	✓	yes	~	⊘	
	public places	✓						✓	✓	⊘	yes	⊘	⊘	
	railways	✓		✓				✓	⊘	⊘	yes	✓	⊘	
	cycle path	✓						✓	✓	⊘	partly	⊘	⊘	
	railway-, underground stations	✓						✓	✓	⊘	yes	⊘	⊘	
	parking spaces	✓						✓	✓	✓	partly	⊘	⊘	
	airports	✓		✓				⊘	✓	⊘	yes	✓	⊘	
	industry harbour	✓		✓		✓		✓	✓	⊘	?	⊘	~	
	marinas / yacht harbour	✓				✓		✓	✓	⊘	?	⊘	~	
	landing stages for passenger vessels	✓				✓		✓	✓	⊘	yes	⊘	~	

resid. & comm. property	residential area: households and (allotment) gardens close to the river, household like facilities like offices	✓						✓	✓	✓	no	~	✓	
	building and construction sites	✓	✓					✓	✓	✓	no	~	✓	
Cultivated area	agricultural and forest land / area	✓		✓	✓			✓	✓	⊘	no	~	~	
On water	cargo vessels	✓				✓		✓	✓	⊘	no	⊘	~	
	passenger vessels	✓				✓		✓	✓	⊘	no	⊘	~	
Industrial area	plastic production and processing plants	✓		✓				✓	✓	⊘	no	✓	⊘	
	industrial and commercial companies (incl. recycling plants)	✓		✓				✓	✓	⊘	no	✓	⊘	
Recreation & leisure areas	sports facilities	✓						✓	✓	⊘	yes	✓	~	
	camping sites	✓						✓	✓	⊘	Yes	✓	~	
	restaurants	✓						✓	✓	⊘	Yes	~	~	
	beaches and swimming sites	✓						✓	✓	⊘	partly	⊘	~	
	public outdoor pools	✓						✓	✓	⊘	yes	✓	~	
	nature reserve	✓						✓	✓	⊘	yes	~	⊘	
	fireplaces	✓						✓	✓	✓	yes	~	⊘	
	picknick sites	✓						✓	✓	✓	yes	~	⊘	
	playgrounds	✓						✓	✓	✓	yes	✓	~	
	dog areas	✓						✓	✓	✓	yes	~	⊘	
	park areas (incl. public green area)	✓						✓	✓	✓	yes	~	⊘	
	festival & event sites	✓						✓	✓	✓	yes	⊘	⊘	

	popular fishing places	✓						✓	✓	⊘	no	⊘	✓	
Waste Management infrastructure	waste treatment and recycling plants						✓	✓	✓	⊘	no	✓	⊘	
	landfills						✓	⊘	✓	⊘	no	✓	⊘	
	waste collection centers	✓					✓	✓	✓	⊘	yes	✓	⊘	
	waste collection sites	✓					✓	✓	✓	⊘	yes	~	⊘	
	public waste bins	✓					✓	✓	✓	~	yes	⊘	⊘	
	waste water treatment plants (incl. CSO combined sewer overflows)	✓					✓	✓	✓	~	no	~	✓	

5. MFA- MODELLING

5.1. MFA terms and definitions

According Brunner and Rechberger (2016) material flow analysis (MFA)*" is a systematic assessment of the state and change of flows and stocks of materials within a system defined in space and time."*

MFA connects the sources, the pathways and the intermediate and final sinks of a material. Because of the law of conservation of matter, the results of an MFA can be controlled by a simple mass balance comparing all inputs, stocks, and output of a process. An MFA delivers a complete and consistent set of information about all flows and stocks of a particular material over timer within a spatially defined system (Brunner and Rechberger, 2016). In the following, the terms used are partly explained in more detail than they actually appear in our MFA model. This could serve as a starting point for further MFAs of plastic pollution in riverine systems.

While a **process** involves the transformation, transport or storage of materials and implies that something is altered in its quality (e.g. feedstock become product and waste), a **stock** is defined as processes in which the material remains for a while before it is finally transported further, so it mainly changes its quantity (Baccini and Brunner, 1991). Examples of processes could be plastic production, transport and distribution of plastic goods, the collection and treatment of plastic waste or the input of plastic items into nature or the water body itself. Relevant stocks are the separate collected plastic waste or quantities of plastic debris collected through volunteer's collection campaigns.

Sources are defined as processes where (plastic) emissions are generated. This was examined in detail at the beginning of the report anyway and different classifications were listed. **Sinks** are processes in which the material either remains forever or is destroyed (Cencic and Rechberger, 2008). In this context, a landfill, waste incineration plant but also the discharge of litter from the river and its accumulation in inaccessible areas of the hinterland (e.g. alluvial forests), where plastic remains (at least for a very long time), can be seen as a sink.

The terms flow and fluxes have been often used in the same way, but they differ significantly. A **flow** is defined as a "mass flow rate" (= ratio of mass per time through a system, e.g. conductor; units might be given in kg/S or t/y). A **flux** is defined as a flow per "cross section" (units kg s^{-1} m^{-2}) and can be considered as a specific flow. Commonly used cross sections are geographically limited areas, a person, or an entity such as a private household or a company. Regarding the PFD-MFA model, the actual exchange of plastic determined for our project region (=cross section) is designated as a flow (t/yr), while the specific flux, for example, would be the plastic demand or consumption per inhabitant (kg/c x yr).

5.2. Procedures of MFA

An MFA starts with the definition of the issue and of adequate objective. Next step is the selection of relevant and appropriate system boundaries, processes, and goods. Then follows the assessment of the mass flows of goods and – depending on the issue - substance concentrations in these flows. It is important to consider uncertainties by calculating the substance flows and stocks. The results should be presented in a suitable way. Visualizing the conclusions and highlighting the core statements help to facilitate the implementation of target-oriented decisions. Brunner and Rechberger (2016) emphasize that the MFA procedure (Figure 10) does not have to be executed strictly sequentially, but should rather be understood as an iterative optimization process.

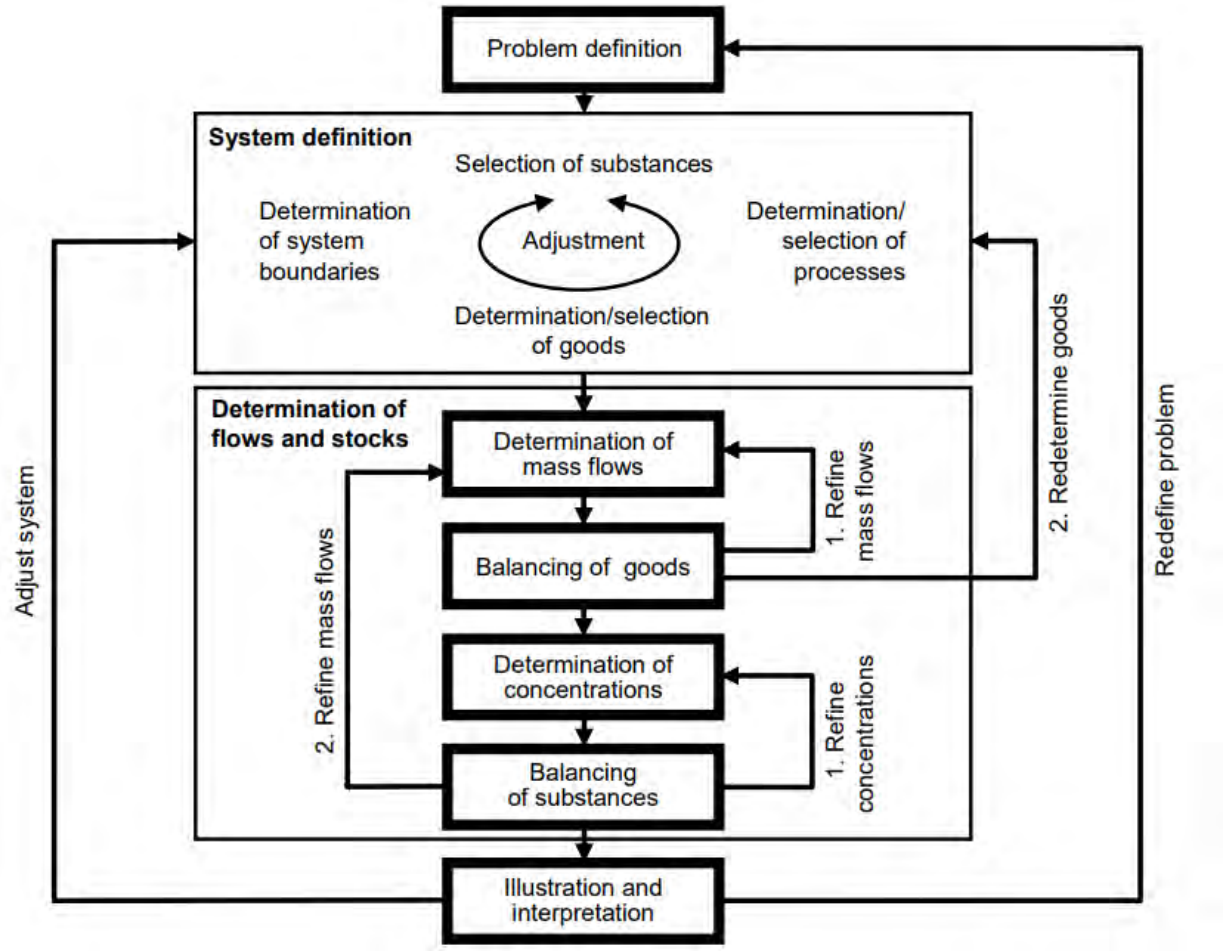


Figure 10: Procedures for MFA – MFA is to be understood as an iterative process, selection of elements and accuracy of data have to be checked with regard to the objective of the investigation (Brunner and Rechberger, 2016)

5.3. The PlasticFreeDanube MFA Model

5.3.1. MFA objective

Objective of this MFA (model) is to visualize the main sources and pathways of plastics in Danube river for the project region between Vienna and Gabčíkovo. The material flow diagram includes information on quantities produced by different sources, disposal routes, as well as entry points for plastic waste into the Danube, which are indicators for major sources and pollution hotspots. The results of the material flow analysis are partly included in the action plan (D 6.2.2) and communicated to the stakeholders as well as decision makers in the conferences for strategic partners (D 6.2.1).

5.3.2.System boundaries

5.3.2.1. Geographical boundaries

Concerning the emergence of (littered) plastic waste, the project area has been defined as the territory of the Danube river and wetlands, as well as adjacent river banks between the metropolitan areas of Vienna and Bratislava down to hydropower plant Gabčíkovo in Slovakia (downstream border of the project area). As catchment area for direct plastic pollution within the cities a uniform distance of 250 m from the shoreline was defined, in rural areas (e.g. farmland etc.) a distance of 500m. The width of the study area was chosen as compromise between manageable effort of investigations and necessary accuracy and aims to cover relevant pollution sources. Along the Danube Canal the distance is chosen to be only 100m, because that is the distance to the residential areas (Figure 11). Within this distances, transportation of plastics by wind, strong rain or floods seems to be likely although no figures about transportation pathways and distances of plastics by wind and runoffs exist. We assume, it cannot be ruled out that, especially during single events such as heavy rain or storms, plastic waste may be carried into Danube river from a long distance and is not considered in this MFA. The chosen study area in general does not reflect the contribution of indirect plastic pollution by e.g. waste water treatment plants, as this would include for example total Vienna or tributaries.



Figure 11: GIS-Map of project area (Austria) (HQ100 overlap with 500m area)

5.3.2.2. Content-related boundaries

MFA is limited in terms of content, starting with the use phase of plastics. Although the "new" plastics brought onto the market can be related to the inhabitants of the study area, however, it is not possible to determine all plastics currently in use (installed, used, stored, etc.). Consequently, the MFA can only include the end-of-life phase in the modelling, where at least a reasonably well documented database is available.

5.3.3.Data limitations

Possible data limitations include a precise breakdown of how many plastics are actually in the use phase or what types and quantities of plastic products are brought to market in the project area (in the literature, for example, only the plastics demand of the domestic industry is given). Furthermore, there is a lack of detailed information and assessments on national littering quantities that actually remain in the environment. In this respect, only very inaccurate estimates of the collected litter amounts are available. Data gaps can also remain if existing data from e.g. authorities may not be used for this investigation. The *report on available data concerning plastic pollution* (D 3.3.1) summarized all data limitations in more detail.

Data uncertainties also exist in the extrapolation of the collected and analysed samples along the banks, in the hinterland or the measurements in the water. Furthermore, many of the analysed plastic parts cannot be directly attributed to a specific source.

5.4. MFA-model

As mentioned above, the material flow model (Figure 12) starts with the **end-of-life phase** of plastic products. This level (**waste collection**) is essentially divided between the properly collected and managed plastic waste, which is then treated in an appropriate way (e.g. recycling or thermal utilisation → level **treatment & disposal**) and plastic debris that enter and remain in the environment due to littering, illegal waste disposal or "mismanaged or improper" handling of waste (e.g. sewage-related debris, etc.) In some cases, it will be possible to assign certain plastic debris to a specific source sector while other quantities are summarized as "general waste" because it is simply not feasible to identify the origin. The latter plastic waste is considered in more detail in the MFA: With regard to the input of plastic waste into the system, a distinction is made between **direct input** into water bodies (**Danube river**) and **indirect** input (**shore area**).

Various processes (wind, flood, etc.) influence the input and output of plastic litter into the system or the exchanges between the considered balance areas (river & shore area). Starting from the "pollution stock" (orange and blue boxes), the individual plastic flows are assigned to the land-based (yellow lines) or river-based (blue lines) input and discharge sources (red arrows). It can be assumed that most of the analysed plastic wastes (in course of sampling and sorting activities) cannot be assigned to a specific or individual source, so these debris were broadly summarized in the model.

The MFA-model was created with the software STAN (subSTance flow ANalysis).

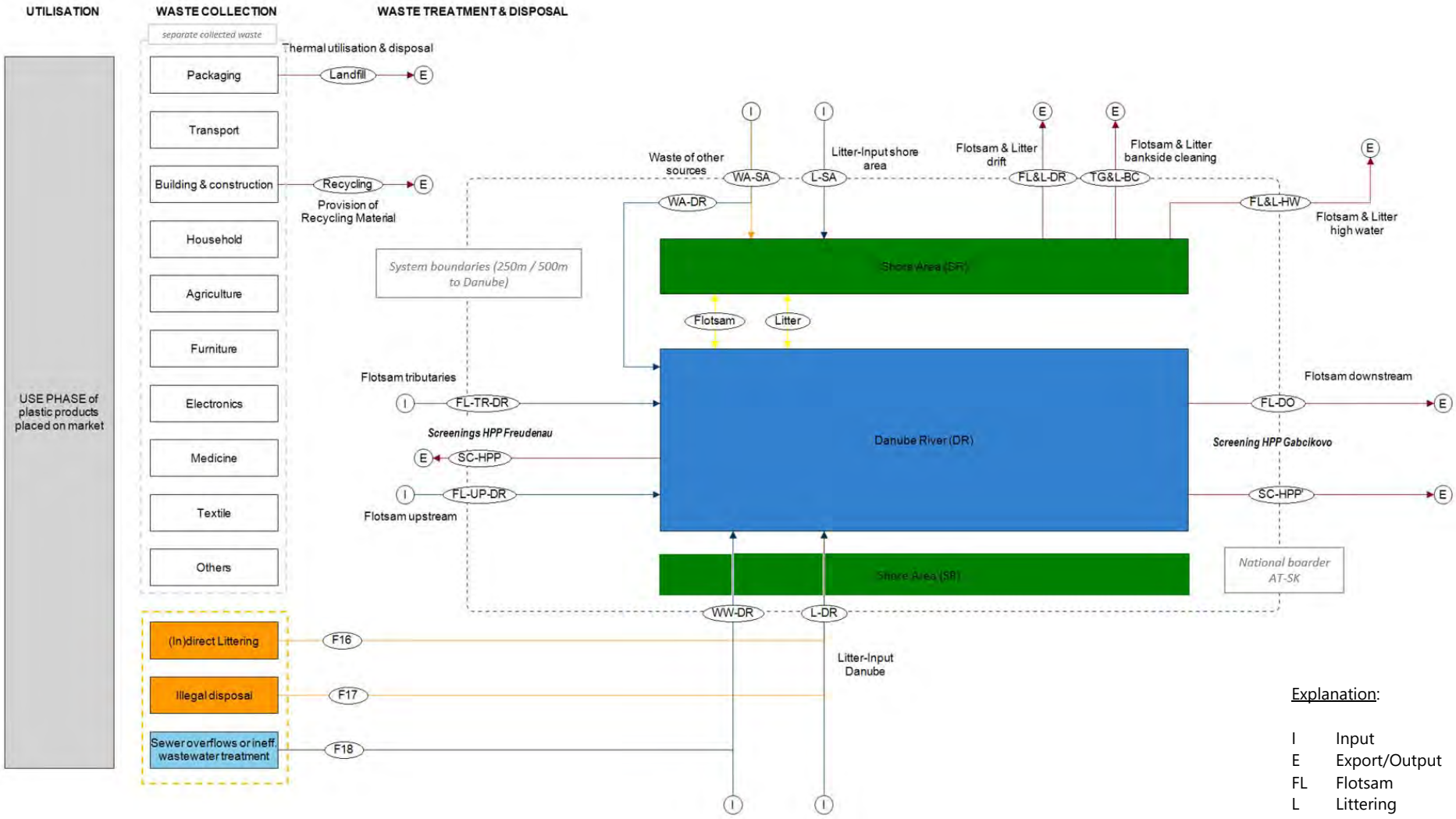


Figure 12: MFA-Model of the main plastic sources and entry paths in the project region of "PlasticFreeDanube" with software STAN

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