Mapping microplastics flows for a model region

Summary of the output A2.3 of the FanpLESStic-SEA project

FanpLESStic-sea project 2021

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Introduction

This document is a summary of an output of the FanpLESStic-Sea project. The FanpLESStic-sea is an EU INTERREG Baltic Sea Region project aimed at decreasing and removing microplastics in the Baltic Sea. FanpLESStic-Sea envisaged outputs are:

- a model to map, understand and visualize microplastic pathways that will be applied to the partners' cities and/or regions;
- piloting of new technology i) for filtering out microplastics; ii) sustainable drainage solutions as means for removal of microplastics; and iii) to remove microplastics from storm water;
- defining innovative governance frameworks and engaging a large range of players for the implementation of coordinated and cost-efficient measures resulting in locally adapted investment proposals/plans for each partner's region; and
- dissemination of project results, including reports on barriers and ways forward, to increase institutional capacity on up-stream and problem-targeted methods to remove microplastics.

This summary concerns specifically the work package 2.3 in the project led by Sweden Water Research (SWR) on the estimation of flows of microplastics in an urban area. The aim of the work package is to understand, visualise, and communicate the sources, pathways, and recipients of microplastics in a flow model for a hypothetical model city. More specifically, the model focuses on the sources and pathways found in the literature as well as in the sampling performed in the work package 2.2 of the project.

The theoretical background for the model is provided in a report conducted by SWR. The report gives insights into how different sources of microplastics in urban waters can be calculated and what contextual information is needed to be able to perform such assessments. The report is accompanied with an Excel-based tool to ease the process of estimating each source.

The report further brings up other information related to each specific source, such as the polymers and the shapes that can be expected. The second part of the report focuses on estimating flows of microplastics in a semi-hypothetical city in the Baltic Sea area. The insights on source estimates from the first part of the draft report are combined with measurements taken in the project to assess flows to urban waters in a city.

The full report can be found in the project website.

Source estimations

There are different ways how sources of microplastics in wastewater and stormwater can be estimated. In some literature, stormwater sources are estimated to end up in a wastewater treatment plant (WWTP) due to combined sewers. However, due to the large differences regarding duplicate and combined systems, this is not assessed in this model and analysis on a general level, but it is assessed in relation to the flows of the model city. Stormwater is assessed as the final compartment for stormwater sources.

The general source estimates are connected to a calculation tool in Excel, which can be adapted to local conditions. There is a section below each source description named "information needed as input to the tool" which is the information that depends on contextual factors, and which needs to be included into the tool by the user. Information about the shape of the particles and the predominant polymer types, as well as the predominant pathways is also presented in connection to each source.

Sources and pathways of microplastics to wastewater

Households and enterprises are the main sources of microplastics in wastewater. Microplastics might also be present in tap water that is used by both, households, and enterprises.

The model mainly considers the following sources from households (see Figure 1):

- laundry
- dust
- personal care products (PCPs)
- cleaning products
- rinsing paint brushes
- other potential sources
- enterprises and other non-household related sources.

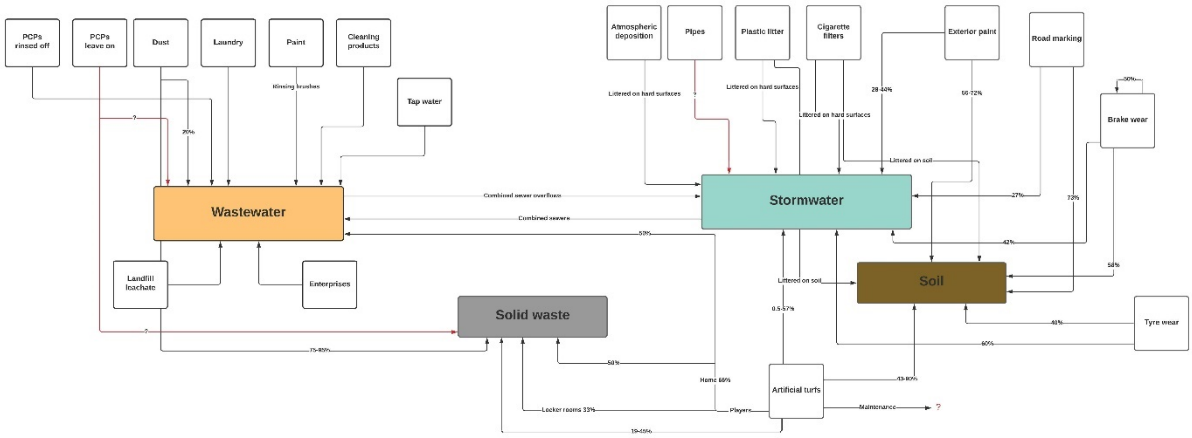

Figure 1 Overview of sources and pathways of microplastics in urban areas

As an example of how the sources are estimated, laundry, one of the major sources of microplastics in wastewater, could be pointed out. Microplastics, in the form of small fibres, are released from synthetic textiles when they are washed. The reported emissions of synthetic fibres during washing, vary greatly between studies.

Source estimate

The emissions from laundry ($E_{Laundry}$) are estimated in the following way:

$$E_{laundry} = (T_{washed} \times S_{share}) \times EF$$

where T_{washed} is the textiles washed in kg/capita/year, S_{share} is the synthetic share of the textiles washed, and EF is the emission factor. The EF can be obtained from different scientific studies that quantify release of fibres from laundry. If priority is given to studies that simulate real washing conditions in terms of loads, temperature, use of detergent, and cycle duration, as well as studies that report the results in mass (either using gravimetric methods or mass calculations), an EF of 33–399 mg/kg is obtained (Dalla Fontana et al., 2020; De Falco et al., 2019; De Falco, Gentile, et al., 2018; De Falco, Gullo, et al., 2018; Hernandez et al., 2017; Kelly et al., 2019). This EF is for polyester and can be used as a proxy for laundering of other textiles as well.

Information needed for input to the tool

- amount of textiles washed per capita per year. In Europe, one washing load is estimated to be 3–4 kg (Pakula & Stamminger, 2010) and the number of cycles washed per capita per week is between 1.2 and 1.5 depending on the country (Schmitz & Stamminger, 2014). See Table "input washing behaviour" in the Excel file for details; and

- the share of household textiles that are of synthetic origin. Hann et al. (2018) report that 34% of the clothes sold in Europe are of synthetic material. This does not give the full picture as other textiles, such as towels and bedlinen, are also washed frequently but can provide a rough estimate.

Polymer types and shapes

The polymer composition is dependent on the types of fabrics washed. In general, polyester is the most common synthetic material used in clothes in Europe, followed by acrylic and PA (Hann et al., 2018). The microplastics released during laundry is in the form of fibres.

Pathways

The emissions from laundry during washing is expected to, in full, be released to the wastewater.

The more detailed estimations for each source can be found in the full report.

Sources and pathways of microplastics to stormwater

There are approximately the same number of sources to stormwater and wastewater, but the pathways are more complex and challenging in stormwater (see Figure 1 above):

- atmospheric deposition
- artificial turfs
- littering of cigarette filters
- exterior paint
- road related emissions
- other sources to stormwater

One example to be pointed out is tyre wear, which is one of the main sources of microplastics in stormwater and forms part of the road-related emissions (with brake wear and road markings).

Two different approaches are typically used to estimate emissions from tyre wear. One approach uses emission factors per vehicle-km multiplied by the total mileage, and the other uses the number of tyres multiplied by the weight loss of these tyres during use (Kole et al., 2017). As wear is expected to be particularly high in urban areas due to more braking and accelerating (Knight et al., 2020), the emission-based method with emission factors for urban driving was determined as most appropriate for estimating city emissions.

Source estimate

Emissions from tyre wear are estimated in the following way:

$$E_{tyres} = (T.A._{vechicle\ type} \times \text{urban share}) \times EF_{urban}$$

where $T.A._{vechicle}$ type is the traffic activity for different types of vehicles and *urban share* is the share of that vehicle type that is driven in urban areas. This information can be found in national or European databases. The European average of shares of different vehicle types driven in urban areas is presented in the Excel file. EF_{urban} is the wear rate on urban roads and is set to 0.06-0.85 depending on the vehicle type (details in the Excel file) as reported by Hann et al. (2018). Further, sometimes the whole particle can be considered as microplastics and sometimes only the rubber content is considered. The rubber content in car tyres is between 40 and 60% (Wagner et al., 2018).

Information needed as input to the tool

- the traffic activity for different types of vehicles in the city.

If this is not available, Sieber et al. (2020) made an approximate calculation of 1.29±0.45 kg/cap./year for Switzerland. It should be noted that this value is only for the rubber part of the particle and not the whole tyre particle.

Polymer types and shapes

A car tyre can contain both synthetic and natural rubber. Heavy vehicles, such as buses and trucks usually have tyres with more natural rubber, while passenger cars have more synthetic rubber (Wagner et al., 2018). Styrene butadiene rubber (SBR) is a common synthetic rubber. In terms of shapes, tyre wear particles commonly show a slightly elongated shape (Knight et al., 2020).

Pathways

The pathways of tyre wear particles can be context dependent and therefore it can be challenging to draw general conclusions. For example, in the Netherlands porous asphalt is very common, which led Kole et al. (2017) to estimate that over 50% is trapped in asphalt, but porous asphalt is not common in the rest of Europe (Hann et al., 2018). In general, the majority of the particles released will be deposited close to the road. For the studies that take the pathway to air into account, the share was estimated to be 1-7% (Kole et al., 2017; Sieber et al., 2020; Verschoor et al., 2016). However, Sieber et al. (2020) point out that these particles will probably enter soil or water in a short period of time and hence do not see this as the final compartment. For urban areas the share to stormwater has been estimated to 60% and soil 40% (Verschoor et al., 2016).

More detailed estimations for each source can be found in the full report.

The semi-hypothetical case city

In order to use the several measurements that have been taken in different countries in the FanpLESStic-sea project, the flows of microplastics are estimated for a semi-hypothetical case city. The characteristics are primarily set to the real cities where the samples were taken. When literature values were used, it was evaluated whether to choose data from studies that were most similar to already set characteristics of the case city or to base them on a European average.

Characteristics of the case city

The characteristics of the city are described in Figure 2. The city has approximately 100 000 inhabitants. The average temperature is 9°C. Most of the precipitation falls as rain, while 10% falls as snow. The city centre has an area of about 26 km^2. This area consist of 44% hard surfaces and the rest are green areas, agricultural areas, or water. Out of the hard surfaces, most are buildings (37%), followed by roads (26%), and parking lots (11%). The rest consists of miscellaneous hard surfaces.

There are 12 artificial turfs in the area that all use SBR granulate infill and polyethylene (PE) pile. There is no snow ploughing of the fields in the winter. Half of the fields are used 30h/week and the other half are used 25h/week. The fields are used 40 weeks per year and there are, on average, 16 players per game. One game is between 60 and 120 minutes long.

The city receives drinking water from a large drinking water plant that also supplies other cities in the region. All inhabitants in the city are connected to a WWTP. The WWTP has mechanical treatment, an activated sludge process and post-precipitation with ferric chloride. The WWTP treats about 11 million m^3 per year. The recipient is a river. The combined sewers in the city cover an area of 9% of the city area and 20% of the wastewater at inlet is inflow and infiltration. Approximately 3000 m^3/year is discharged due to combined sewer overflows. This water consists of 91% stormwater, 7% grey water and 2% black water. There are some industries connected to the WWTP, but none that release water that can be expected to contribute with microplastics.

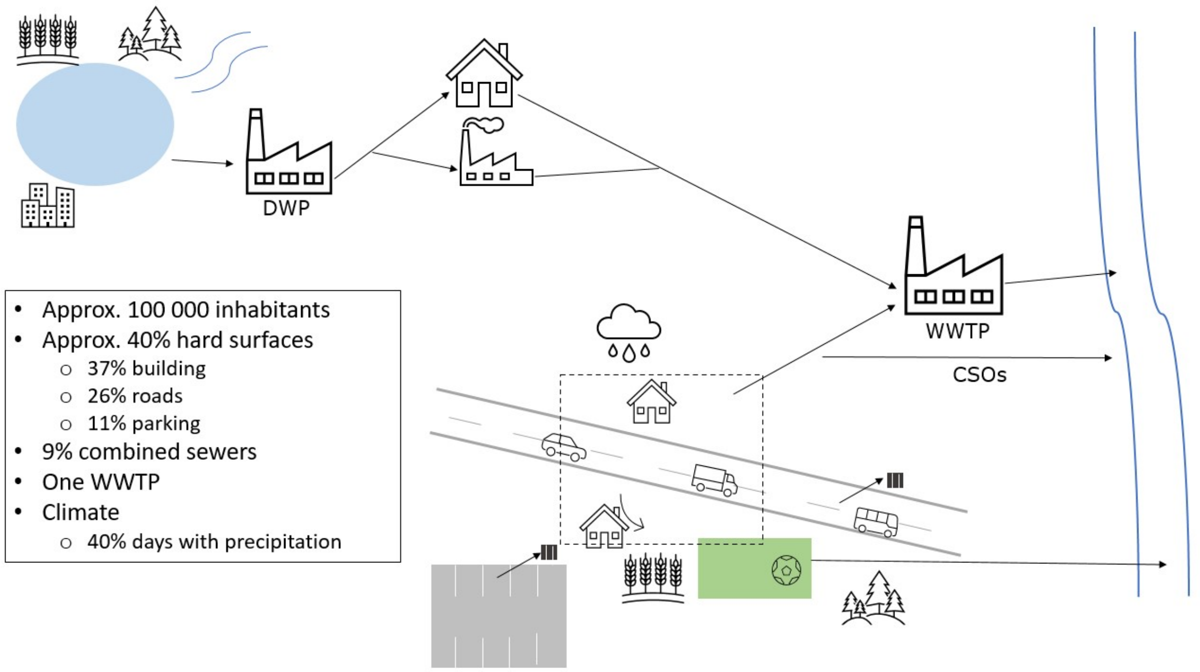

Figure 2 Charasteristics of the hypothetical city.

Description of control measures

There are different control measures that can be implemented in a city. The measures include both upstream (preventive) and downstream (treatment) categories. Examples of upstream measures are microplastic bans that avoid the introduction of microplastics to the system and a more efficient waste management as an example of avoiding the introduction of microplastics to the urban waters. Table 1 below summarizes the control measures considered in the model for the hypothetical city.

Table 1 Summary of control measures implemented in the hypothetical city

Category	Measure	Source	Builds upon
Preventive	Ban on microbeads	Rinse-off PCPs	Swedish legislation
Preventive	Ban on all intentionally added microplastics	PCPs, cleaning products, behaviour change for paints	EU restriction proposal
Preventive/ decentralised	Limit dispersal to 7g/m^2/year	Artificial turfs	EU restriction proposal
Decentralised	Filter in laundry machine	Washing of synthetic textiles	Literature
Centralised	Large stormwater treatment facility	Stormwater	Summary of emissions + measurement in the project
Centralised	Disc filter at WWTP	Wastewater	Literature + measurement in the project.
Centralised	Biofilter at WWTP	Wastewater	Literature + measurement in the project

Method for estimating flows in the semi-hypothetical city

Mapping of microplastic flows and pathways is not a simple task and includes many challenges and uncertainties. Also, the lack of harmonized sampling methodologies makes it difficult to compare studies. The Fanplesstic-Sea project used a cut off size of 10 µm, however, this is not the case in all studies. The table below (Table 2) shows the cut-off sizes used for the estimations of the different sources for the model city.

Table 2 Background information of the estimated flows in the semi-hypothetical model city

Source	Cut-off size	Year	Method	Reference	Assumptions and other notes related to calculating flows in the semi-hypothetical city
Tap water	10 µm	2019	µFTIR whole sample (10-500 µm) ATR-FTIR (500-5000 µm)	Measurement in this project	• Transport from the outlet of the drinking water plant to the tap was assumed to not affect microplastics concentrations. • All microplastics in the tap water enter the wastewater, i.e., the uptake in humans and the amount that might be used for purposes where it does not become wastewater (e.g., watering plants) was assumed negligible.
Laundry	40 µm	N/A	Light microscope, scanning electron microscope, ATR-FTIR. Gravimetric mass estimate	(Dalla Fontana et al., 2020)	• Number of cycles and weight of a load was based on the country where the sampled WWTP was located. • European average of synthetic textiles in clothes was used.
	20 µm pore size	N/A	Gravimetric mass estimate	(Kelly et al., 2019)	
	5 µm pore size	N/A	Scanning electron microscope and image software. Calculated mass estimate	(De Falco, Gullo, et al., 2018)	
	20 µm pore size	N/A	Gravimetric mass estimate	(De Falco et al., 2019)	
	20 µm pore size	N/A	Gravimetric mass estimate	(De Falco, Gentile, et al., 2018)	
	0.45 µm pore size	N/A	Microscope and image software. Calculated mass estimate	(Hernandez et al., 2017)	
Dust	50µm	2019	Stereomicroscope, fluorescent microscope, FTIR	(Soltani et al., 2021)	• Average living area was derived from the city where the sampled WWTP was located.

PCPs	1 µm	2015	Information from industry	(Amec Foster Wheeler, 2017)	• Amec Foster Wheeler (2017) provides the most recent data, includes all products put on the market, and provides estimations at a European level, this is why this data was used for the source estimates. • For leave-on products, it was assumed that 50% enter wastewater and 50% enter solid waste. The amount that will wear off when the product is used was assumed to be negligible.
Cleaning products	1 µm	2015	Information from industry	(Amec Foster Wheeler, 2017)	• Amec Foster Wheeler (2017) was chosen as they include most of the products.
Rinsing paint brushes	1 µm	2015 Sales data: 2019	Information from industry	(Amec Foster Wheeler, 2017) (Sveff, 2021)	• Sales data for private paint consumption was taken from the country where the sampled WWTP was located and for the same year as when the WWTP was sampled.
Artificial turfs	N/A	2018	Material flow analysis µFTIR whole sample (10-500 µm) ATR-FTIR (500-5000 µm) Py-GCMS	(Hann et al., 2018) Measurements in the project	• The annual refill was not known for the fields sampled within the project. Therefore, the method based on pitch size was used. • Size, maintenance, and playing time was derived from the sampled fields.
Cigarette filters	N/A	2020	Litter quantification campaign	(Swedish Environmental Protection Agency, 2020).	• The sampled week was assumed representative for the whole year.
Exterior paint	N/A	Sales data: 2020	Material flow analysis	(Hann et al., 2018; A. Verschoor et al., 2016). (Sveff, 2021)	• Sales data were taken from the country where most stormwater samples were taken and for the year when stormwater samples were taken.
Road related emissions	10 µm	2020	µFTIR whole sample (10-500 µm) ATR-FTIR (500-5000 µm) Py-GCMS	Measurement in this project	• Yearly precipitation from the sampled city was multiplied with the area sampled and the runoff coefficient 0.8 (Swedish Water and Wastewater Association, 2016).

Parking lots	10 µm	2020	µFTIR whole sample (10-500 µm) ATR-FTIR (500-5000 µm) Py-GCMS	Measurement in this project	• Yearly precipitation from the sampled city was multiplied with the area sampled and the runoff coefficient 0.8 (Swedish Water and Wastewater Association, 2016)
Roof runoff	10 µm	2020	µFTIR whole sample (10-500 µm) ATR-FTIR (500-5000 µm)	Measurement in this project	• Yearly precipitation from the sampled city was multiplied with the area sampled and the runoff coefficient 0.9 (Swedish Water and Wastewater Association, 2016)

Microplastics in the semi-hypothetical model city

Flows of microplastics

For wastewater, laundry had the highest contribution, and tap water and dust had the lowest contributions (see Figure 3). For dust, the majority instead ends up in solid waste. The total load (from all household sources and microplastics, excluding tyre particles) to the WWTP was estimated to 1 200-5 800 kg/year of which the stormwater from the combined sewers contributes with 540-670 kg/year. The load to recipient waters from combined sewer overflows was estimated to approximately 1kg/year. The effluent water of a WWTP was sampled and an extrapolation of the measurement gives a yearly load in the effluent of 7.2 kg. Other studies, that use the same method and the same laboratory, report effluent values from 2.6-73 kg/year (Ljung et al., 2018; Simon et al., 2019; Tumlin & Bertholds, 2020). If the influent and effluent values are compared, it suggests a retention of 99%. Such a high retention capacity is not uncommon (Habib et al., 2020). The size of the plant may impact yearly loads, but there is no clear pattern between size and yearly load in effluent.

Tyre wear particles were estimated to contribute with approximately 1 500 tonnes/year from roads in the city and about 600 tonnes/year from parking lots. The roads in the city cover a larger area than parking lots, but if the emissions are compared per square metre, the average emissions from parking lots and roads are both approximately 480 g/m^2/year for tyre wear particles. For other microplastics, the parking lots had a higher contribution per square metre than roads (26 compared to 16 mg/m^2/year).

The introduction of control measures could reduce the contribution of different sources to the overall microplastic load. Rinse-off personal care products (PCPs) including microplastics is prohibited in several countries. If this measure was implemented in the model city, it would lower the microplastics load from households with 3-24% and the total load at the inlet of the WWTP with 3-13%. Another example is from paints. If all inhabitants in the city would stop rinsing the equipment (paint brushes) in water, and the other uses would be prohibited[1], this would lower the total load from households with 9-49% and the total load at the inlet would be reduced with 8-28%. The largest wastewater-related source in the model city was from laundry, which was estimated to stand for 45-91% of the total load from households and 25-81% of the total load in the influent water to the WWTP. There are several technologies that have been tested on washing machines (filters and devices) to reduce microplastic emissions from laundry with varying efficiencies. Napper et al. (2020) reported retention between 21% (washing bag) and 78% (a filter). Browne et al. (2020) ended up with a retention

[1] Intentionally added microplastics and paint stand for 9-55% of the load to the WWTP from households and 8-30% of the total load of microplastics at the inlet.

efficiency of 74% for a similar filter. Overall, if one of these methods was applied, the laundry emissions would decrease from 290-4 700 kg/year to 64-1 200 kg/year.

If all the above-described measures (ban on rinse off PCPs, leave on PCPs, cleaning products, stop rinsing paint equipment and filter in washing machines) were implemented and the inhabitants continued to vacuum before they wet wash their floors, the total load to the WWTP would decrease from 1 200-5 800 kg/year to 600-1 900 kg/year.

For control measures to stormwater, the pilot technique that was tested in this project showed a high retention of microplastics (93%) and a moderate retention for car tyre particles (47%). The pilot technique has the possibility to treat all stormwater in the city, which means that there is the potential to lower the microplastics emissions to the recipient from 13 000-17 000 to 940-1 200 kg/year for microplastics and from 2100 to 1100 tonnes/year for car tyre particles.

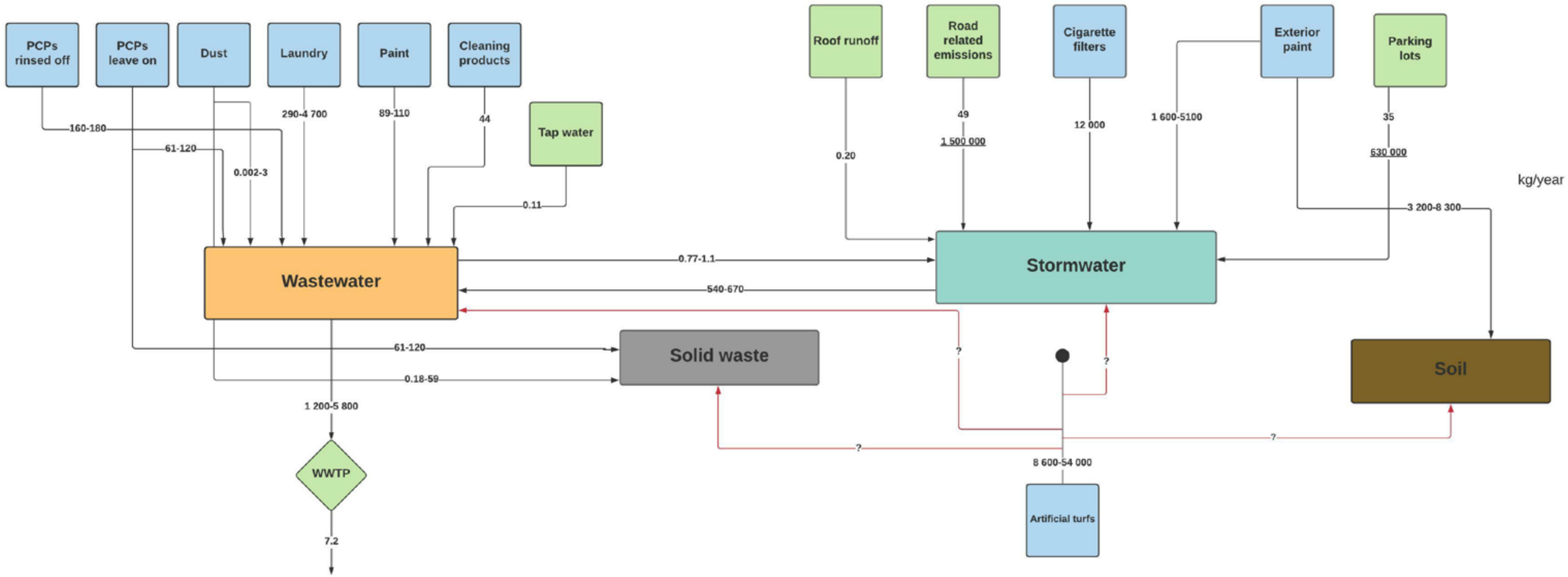

Figure 3 Flows of microplastics in the semi-hypothetical city in kg/year. The underlined values are tyre wear particles in kg/year whereas the blue boxes are source estimates, and the green ones are estimated by extrapolating measured values.

Conclusions

One of the goals of the FanpLESStic-Sea project was to increase the knowledge on where microplastics come from and their transport pathways. By combining strategic measurements with source estimates the flows were visualised for a model city in the Baltic Sea. The largest source in urban areas is tyre wear particles. For wastewater the highest load came from laundry. Tap water, dust, and roof runoff all made a small contribution to the overall load to urban waters. The emissions to recipient waters were higher from stormwater than wastewater, even if only pathways where measurements were taken were considered.

Several policy interventions have been proposed, mostly for wastewater sources and if all these are implemented there is the potential to cut emissions to WWTP with 30-50%. For stormwater, more research is still needed into the techniques that would be most efficient and if it should be handled at source or rather centralised in large scale facilities.

There are still several uncertainties related to source estimates and the agreement between the source estimates and the polymers found when measuring is often not consistent. This raises the question if some sources are missed, while other are overestimated. Microplastics in water have been studied more than microplastics in other environments, which means that there is still a lack of knowledge on whether the emissions at source are overestimated, or whether it is only the share to stormwater. In the future, microplastics in urban soils and sewage sludge would benefit from receiving increased attention.

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