MICROPLASTIC IN THE ENVIRONMENT

The Role of Municipal Wastewater Treatment Plants in Microplastic Removal and Environmental Protection

Bolzano - October, 2024

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Presentation Overview

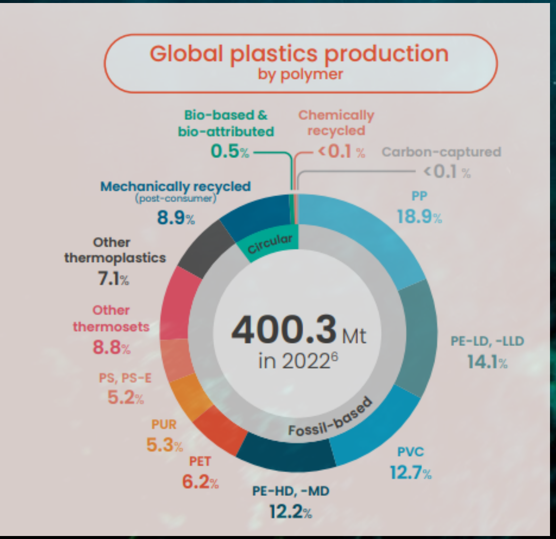
Introduction

- Plastic pollution
- Microplastic pollution, microplastics in WWTPs
- Analysis of microplastics in environmental matrices

Presented research

- Aims of the study
- Materials & Methods
- Results
- Conclusions and final considerations

Plastic pollution

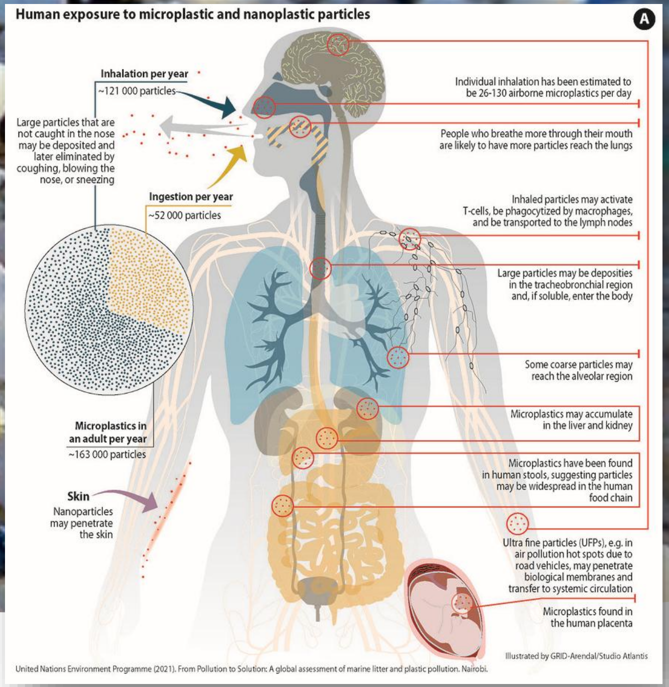


- 400,3 million tonnes of plastic produced worldwide, mainly PP, PE, and PVC from fossil fuels such as crude oil. In 2019, plastic **production** generated 3.4% of the global total greenhouse gas emissions .

- Two-thirds of the produced plastic materials soon become waste. Overall, 46% of plastic waste is landfilled, while 22% is mismanaged and becomes **litter**.

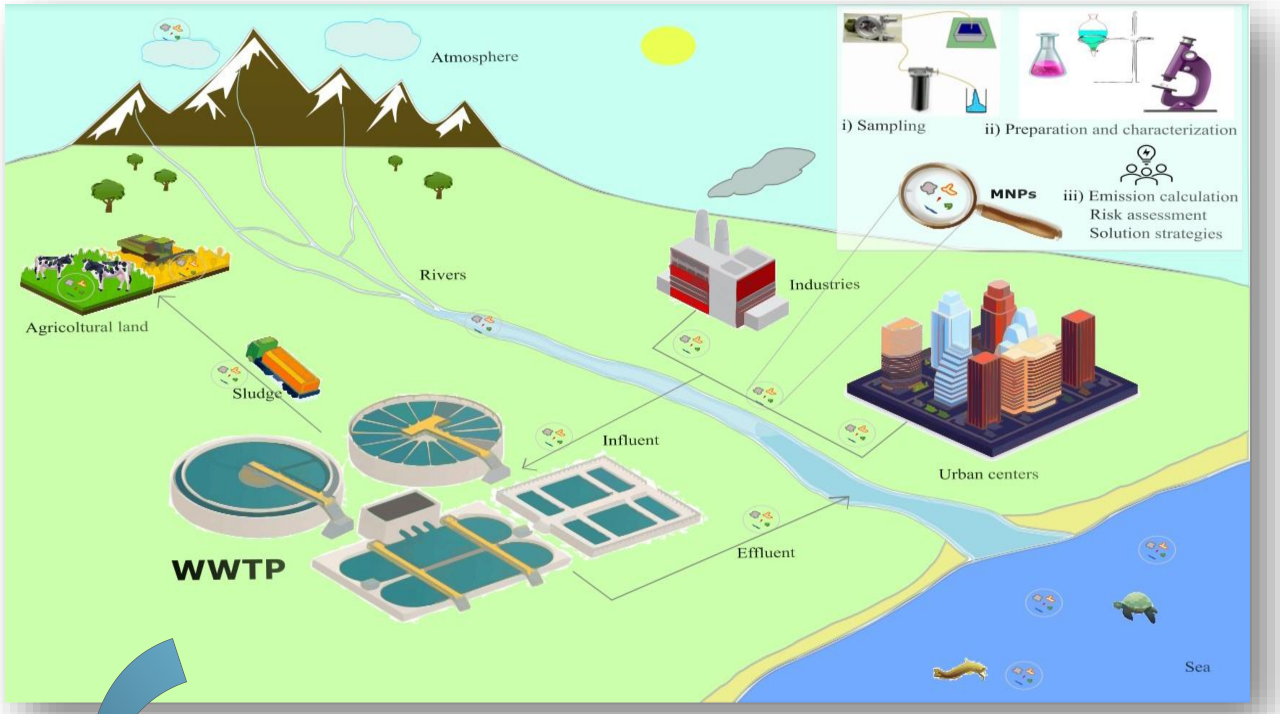
- Unlike other materials, plastic does not easily biodegrade. Plastic **pollution** damages wildlife, impacts on soil properties, and degrade freshwater quality.

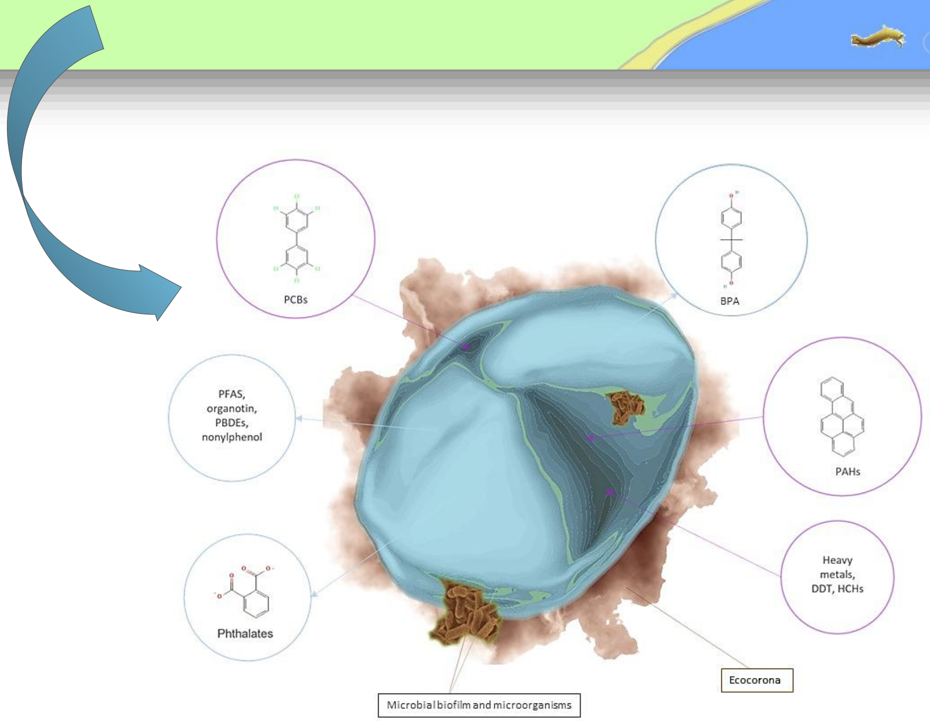
- Fragmentation of plastic litter: **Microplastics and nanoplastics**



Microplastics (MPs) pollution

- **MPs** can be defined as plastic particles ranging from 1 to 5000 µm in size. MPs can **intentionally** be produced as small particles or result from the **degradation** of larger plastic waste.
- Each year several tens of tonnes of primary MPs **end up in the environment**, while degradation of larger plastic materials are estimated to release hundred thousand tonnes a year to the surface waters.
- Accumulation along the **food chain**. MPs pose several **health risks**, including respiratory and digestive problems, sleep disturbances, obesity, and an elevated risk of diabetes, strokes, and heart attacks. Microbial biofilms on MPs may also enhance their ability to cross cell membranes.

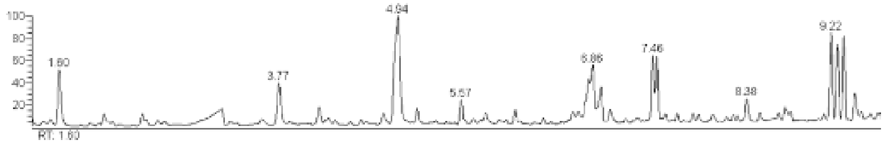




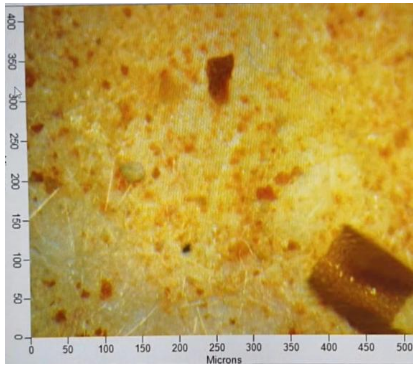
MPs in wastewater treatment plants (WWTPs)

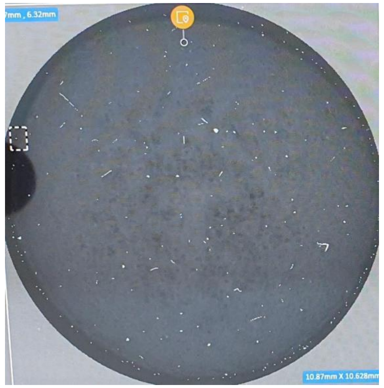
- **Sewages** are a major pathway for MPs entering aquatic environments. While WWTPs aren't designed specifically for MP removal, most MPs are **removed** during treatment processes, accumulating in **sewage sludge**.
- Although WWTPs remove most of the incoming MPs, the daily amount **released** into receiving water bodies remains significant.
- Since MPs exiting WWTPs can carry **contaminants**, pathogens, and antibiotic resistance genes, their monitoring as emerging hazardous contaminants is clearly warranted.

Analysis of MPs in WWTPs



- The study of MPs in WWTPs is challenging (e.g., sampling, MPs extraction). No standardized protocol currently available.
- MPs analytical methods include spectroscopic (FTIR, Raman, LDIR) and spectrometric techniques (Py-GC/MS, TD-GC/MS).



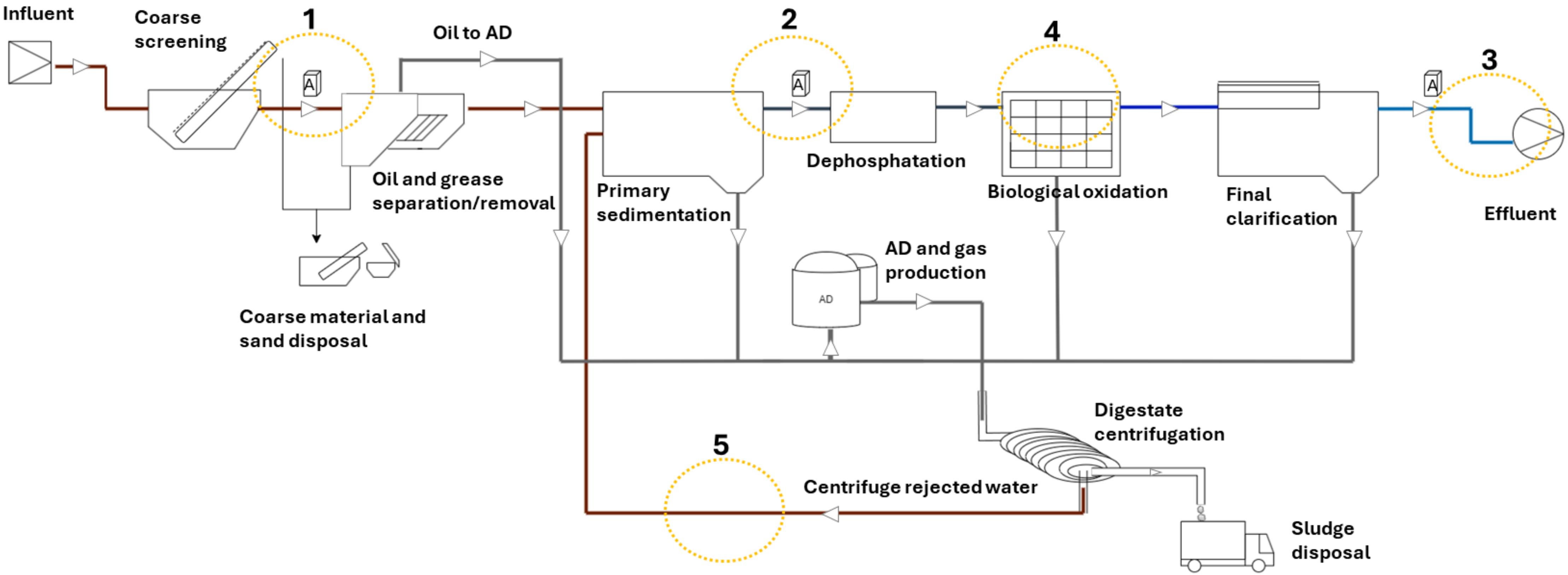


Aim of the study (1)

- This research aims to **identify, characterise, and quantify MPs** in samples collected from a municipal WWTP at various stages of treatment through a **multi-analytical approach** (FPA micro-FTIR, LDIR, and TD-GC/MS).
- The results are used to assess the **fate of MPs within the plant** and the **environmental emission factors** attributable to the WWTP under investigation. The different analytical techniques are discussed and compared, highlighting the critical challenges and advantages of each method.

M&M_1

- **Description of the WWTP:** designed to serve 450000 PE. 42294 m^3 of wastewater per day (2021). Preliminary treatments, primary sedimentation, biological oxidation and final clarification. Anaerobic digestion for biogas production. Mechanical dewatering of digested sludge by centrifugation.
- **Sampling points:** Influent (1), after primary sedimentation (2), effluent (3), activated sludge (4), centrifuge rejected water (5).

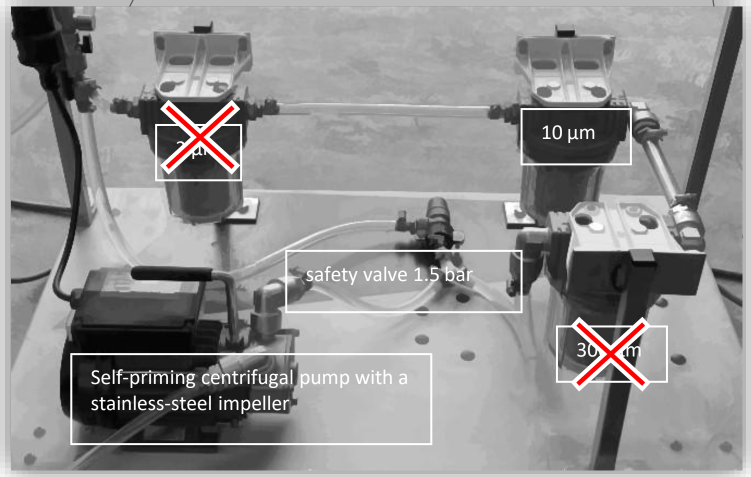


M&M_2

MPs sampling: Influent wastewater (1) and the sample after primary sedimentation (2) were collected using an automatic sampler already installed at the WWTPs and filtered *in-situ*. *The* effluent sample (3) was accumulated for 24 h in a 400 L ss tank, and then filtered *in-situ* until filter clogging. Activated sludge (4) and the centrifuge rejected water (5) were grab-sampled.

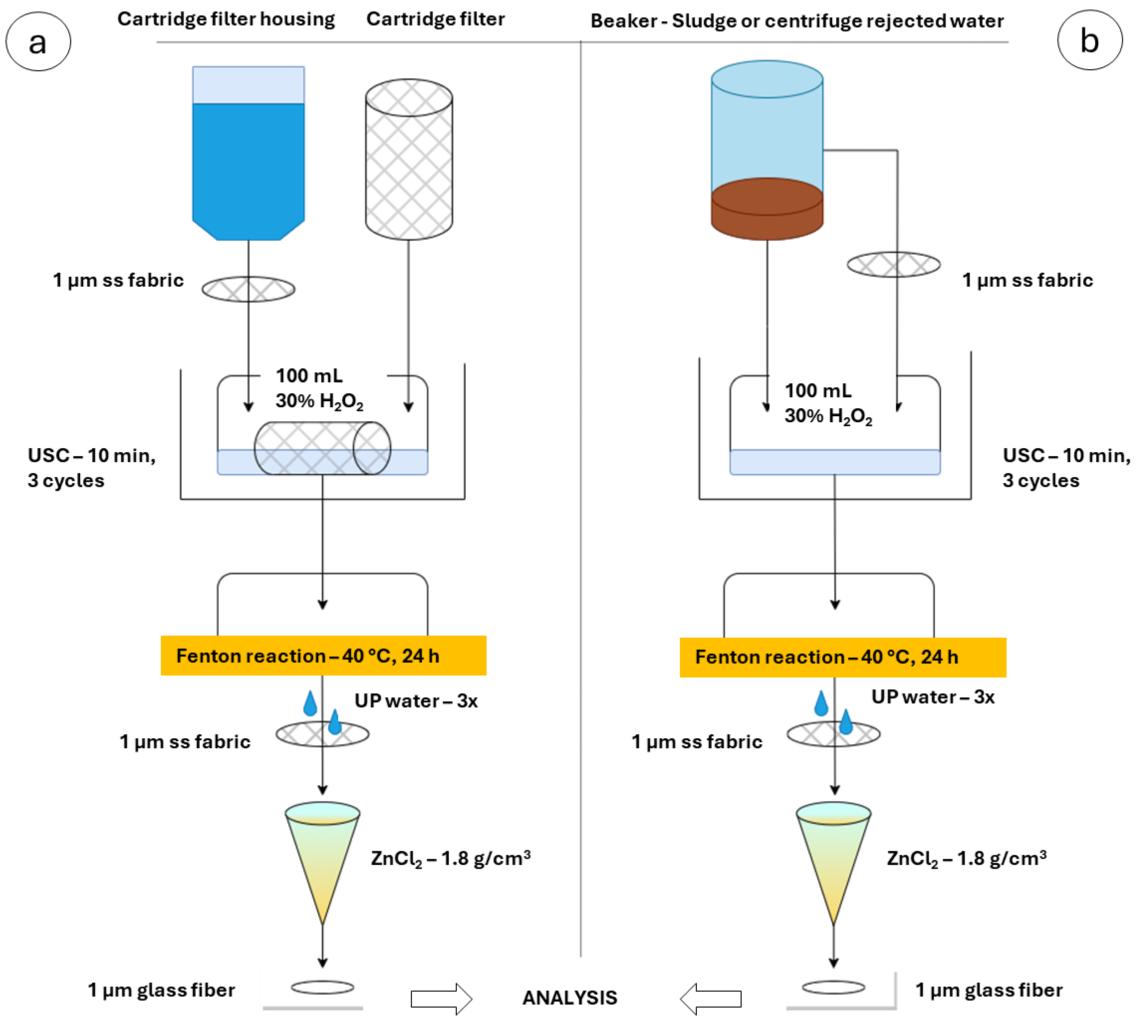
Table 1 Final sampled volumes and sampling times in the different stages of wastewater treatment (1=influent, 2 =after primary sedimentation, 3= effluent, 4=activated sludge, 5=centrifuge rejected water). N/A=not applicable.

Sampling point	(1)	(2)	(3)	(4)	(5)
Sampling time	T_0	T_0 + 1,5 h	T_0 + 34 h	N/A	N/A
Volumes sampled [L]	3	6	200	1	1
Sampling interval [h]	24	24	24	N/A	N/A



M&M_3

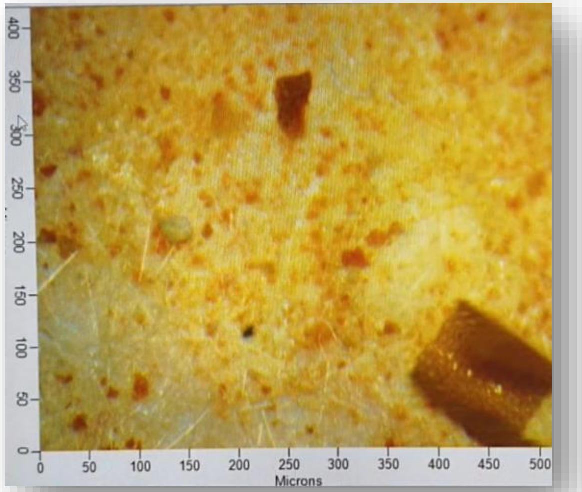
- **MPs extraction:** H_2O_2 in USC, Fenton reaction, and 48-h density separation. The floating particles were thoroughly rinsed with UP water and captured on a glass fiber filter.

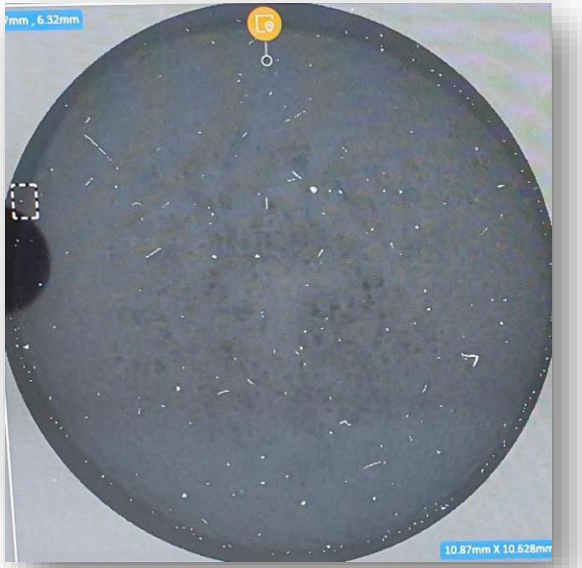


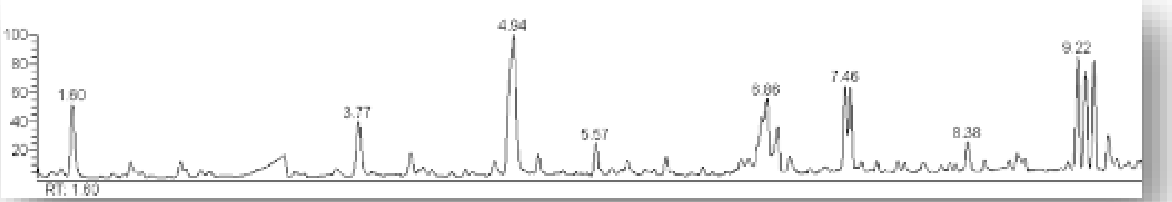
M&M_4

- **QA & QC:** Glass and stainless-steel equipment, cotton lab coats, and colored gloves to minimize and control self-contamination. Sample preparation occurred under a fume hood in a clean environment. Experimental blanks at each extraction.

Mass recovery test on MPs (500–2000 μm) showed a recovery rate > 90% for the tested polymers.





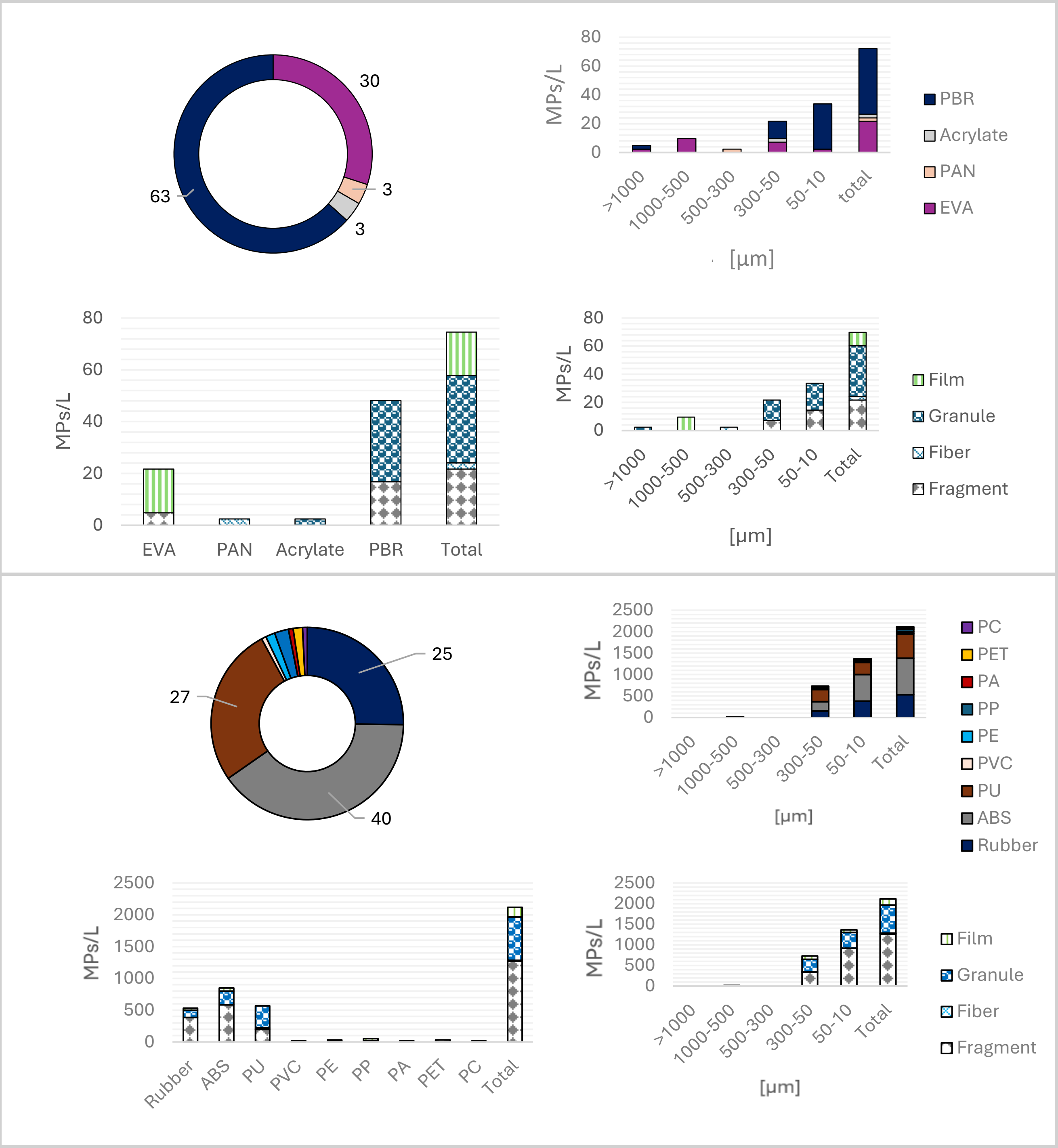


Results_1

Influent

- FTIR 72 MPs/L, most of them PBR and EVA. LDIR 2117 MPs/L, most of them ABS, PU, Rubber.

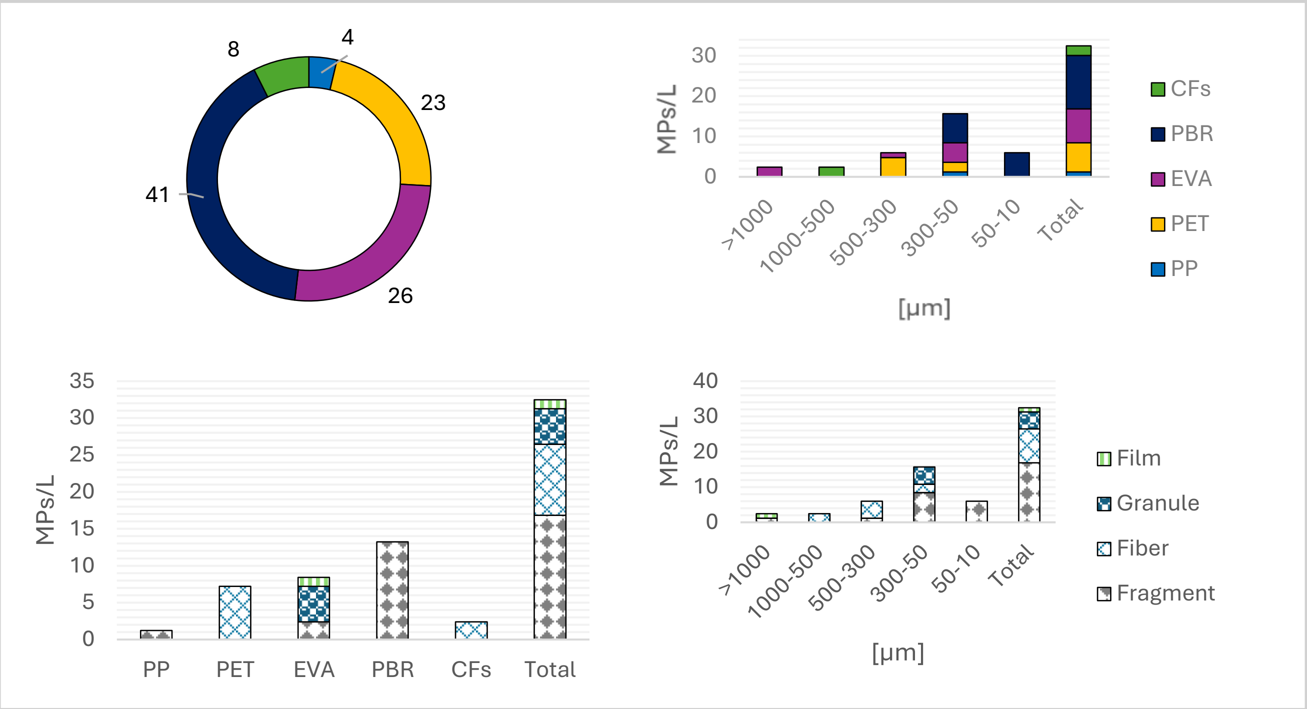
- FTIR and LDIR: most of the MPs between 300 and 10 µm (granules and fragments).

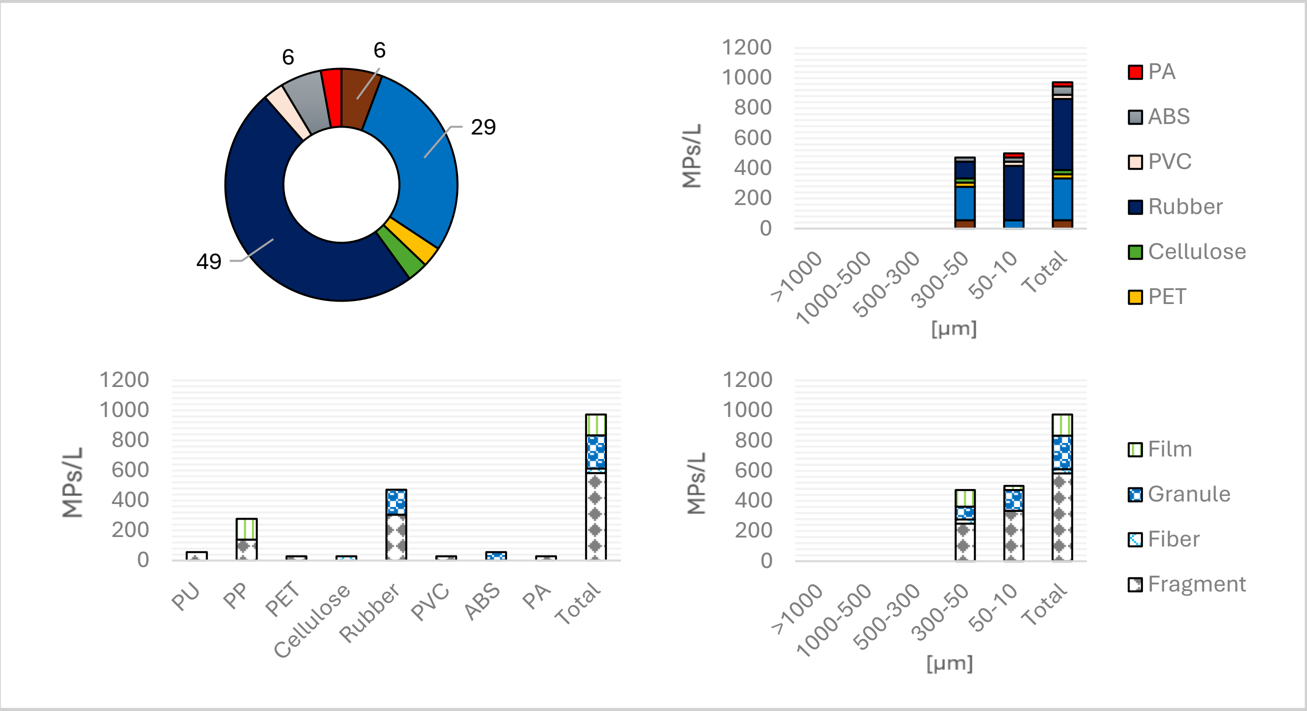


Results_2

After primary sedimentation

- FTIR 32 MPs/L, most of it PBR, EVA, and PET. MPs removal IN/after primary sedimentation = 55%. LDIR 944 MPs/L, most of which Rubber, PP, PU, and ABS. MPs removal = 54%.



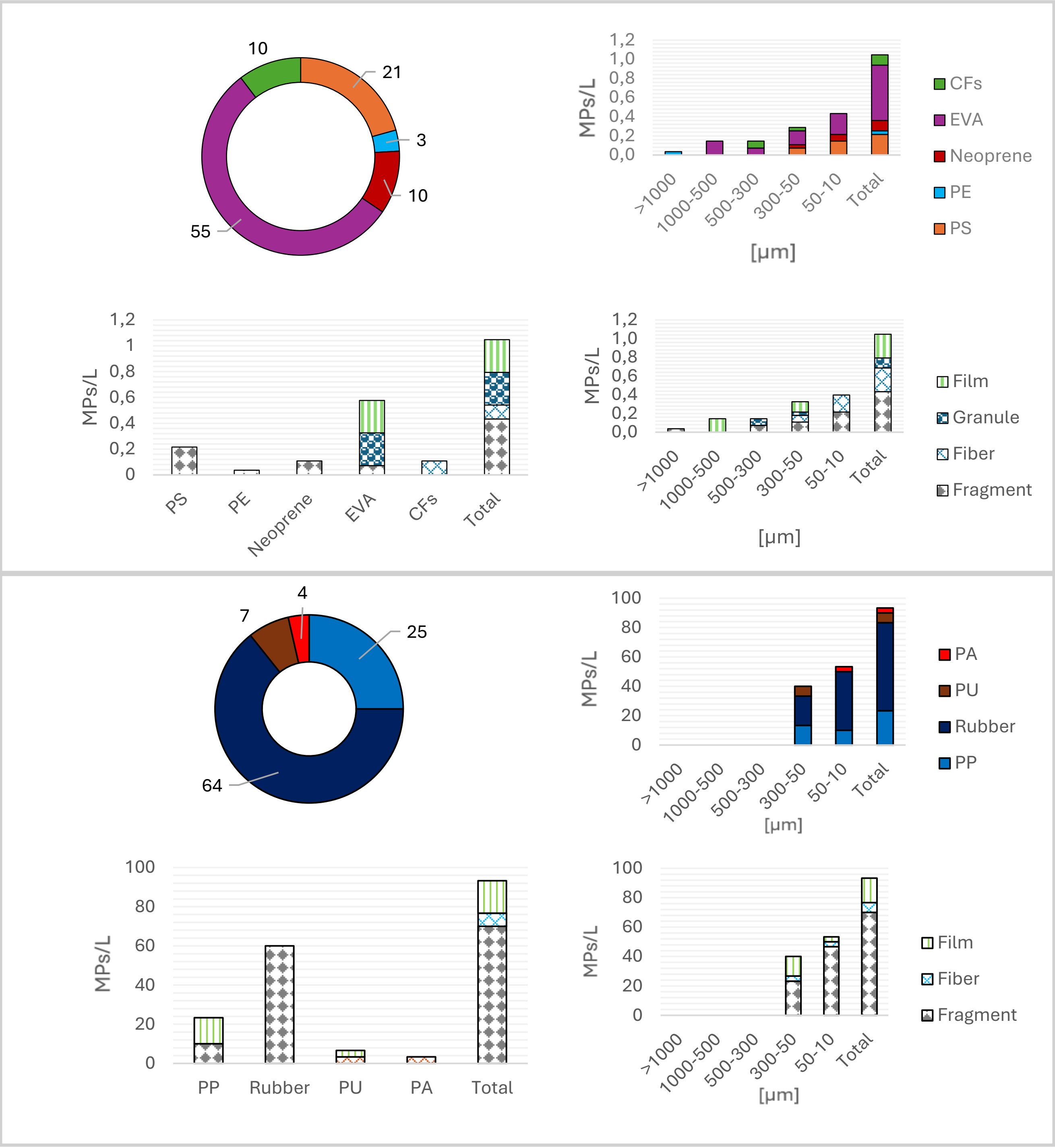


Results_3

Effluent

- FTIR 1.05 MPs/L (98% total removal). Most abundant polymers EVA, PS, Neoprene, and cellulose. LDIR 93 MPs/L (96% total removal), most of which Rubber, PP, and PU.

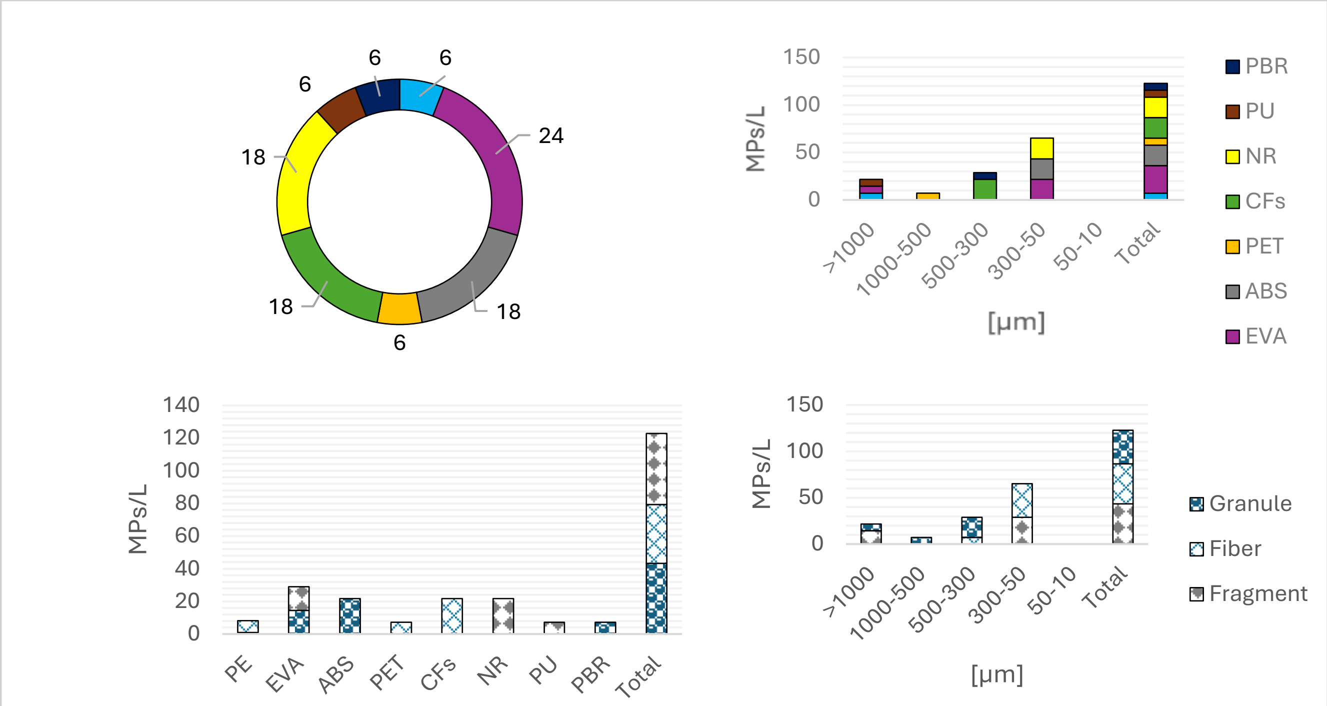
- FTIR and LDIR: size class 50-10 um the most abundant, mainly fragments.

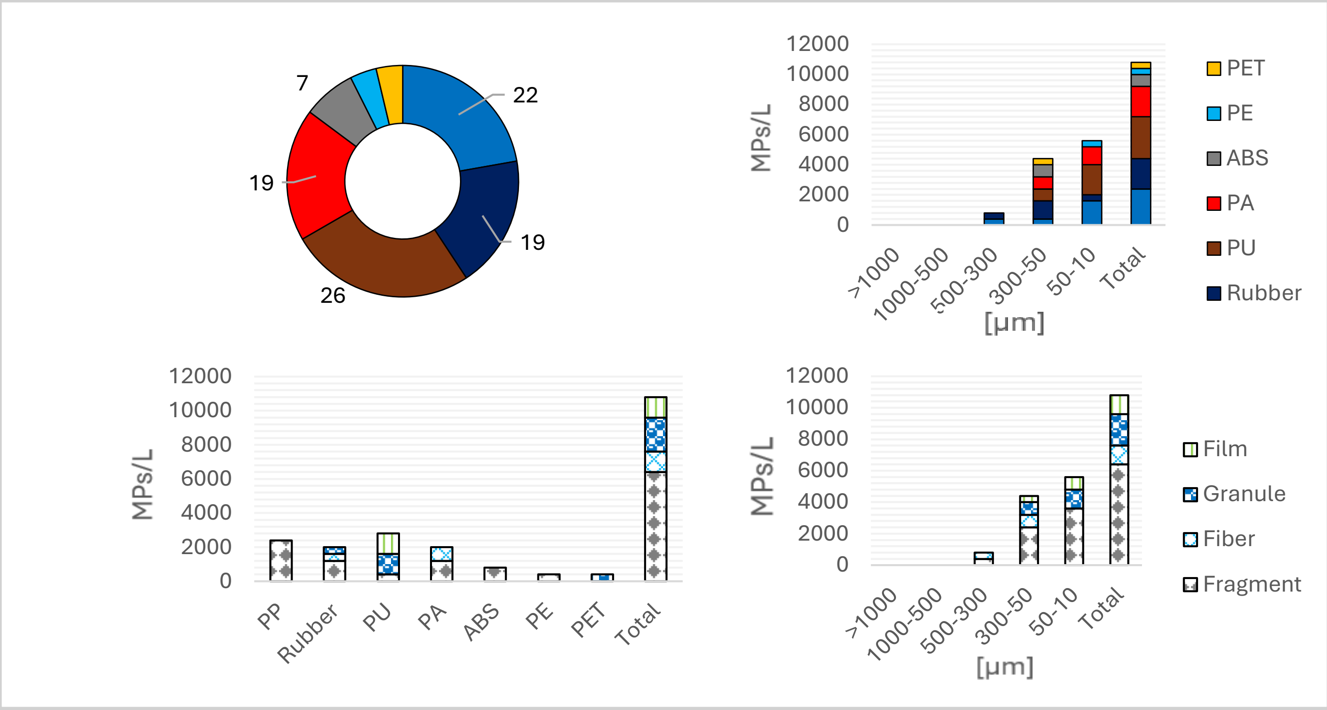


Results_4

Activated sludge

- FTIR 123 MPs/L, most of which EVA, Nitrile rubber, ABS, and cellulose. LDIR 10800 MPs/L, mostly PU, PE, Rubber and PA.
- FTIR: large MPs, equally distributed fragments, fibers, and granules. LDIR: MPs in the size class 50-10 um, mainly fragments.

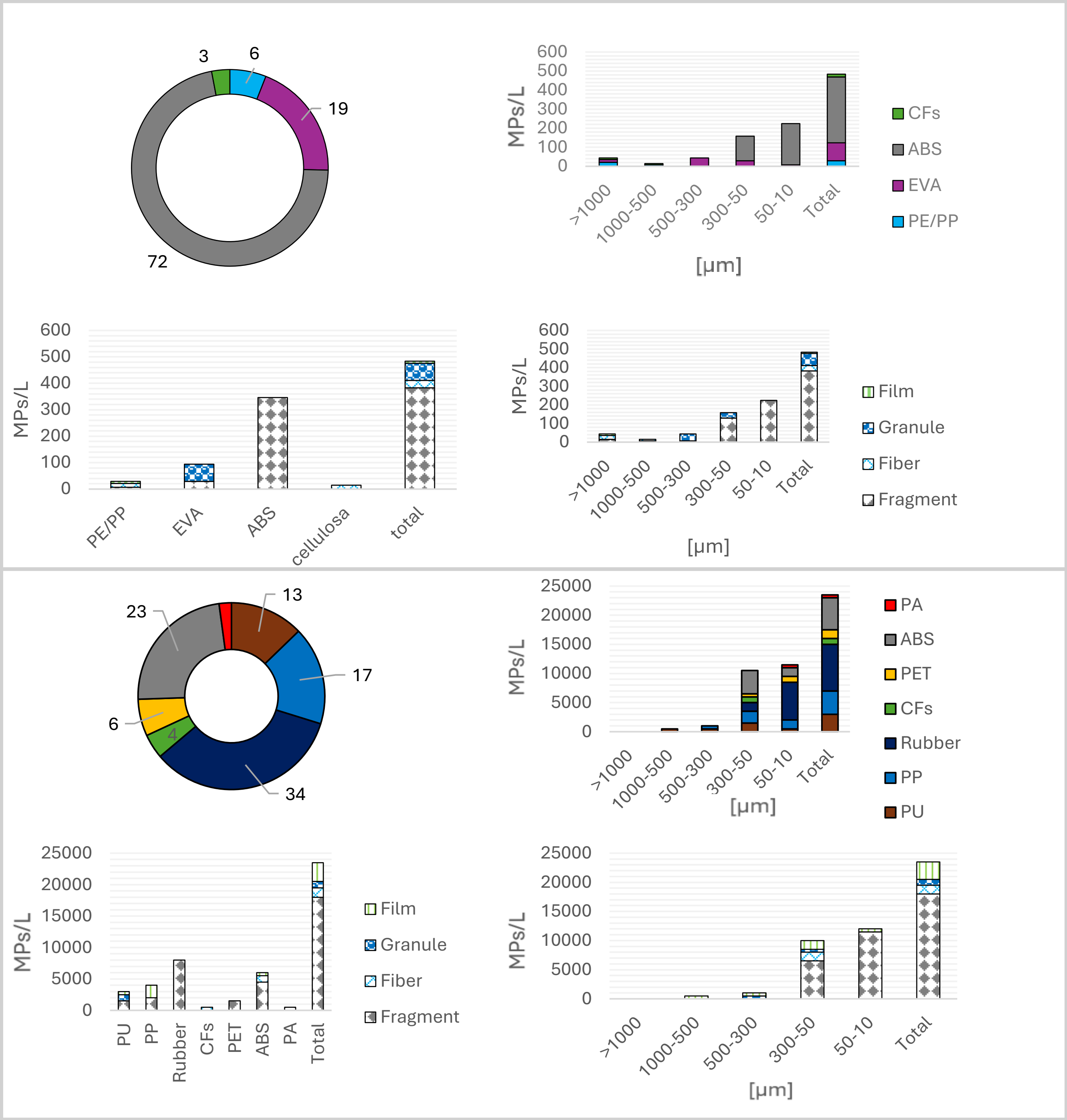




Results_5

Centrifuge rejected water

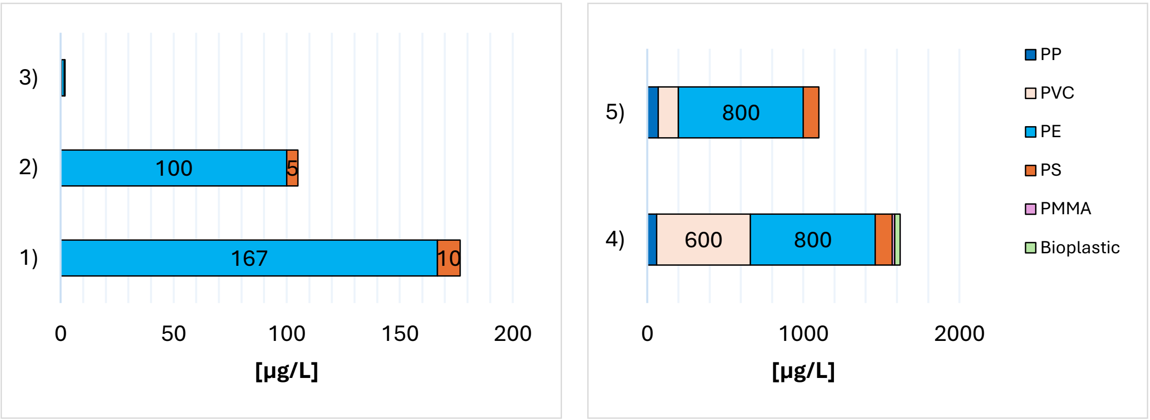
- FTIR 484 MPs/L, most of which ABS, EVA, PE/PP copolymers. LDIR 23000 MPs/L, mainly Rubber, ABS, PP, and PU.
- FTIR and LDIR: most MPs fragments in the 300-10 um size class.



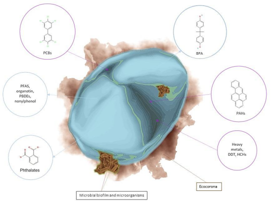
Results_6

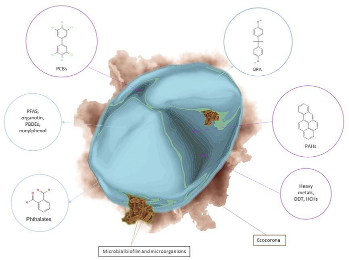
- PVC, PP, PE, PS, ABS ~~tires~~, PMMA, and bioplastic.
- 177 ug/L in the influent, mainly PE and PP. After primary sedimentation, C_{MPs} 105 µg/L (41% removal). In the effluent 2 µg/L (99% removal)
- Activated sludge the highest C_{MPs} (1620 µg/L), with PE the most abundant, followed by PP, PS, PMMA and bioplastics. Centrifuge rejected water: 1100 µg/L total MPs.

TD-GC/MS - MPs mass concentration



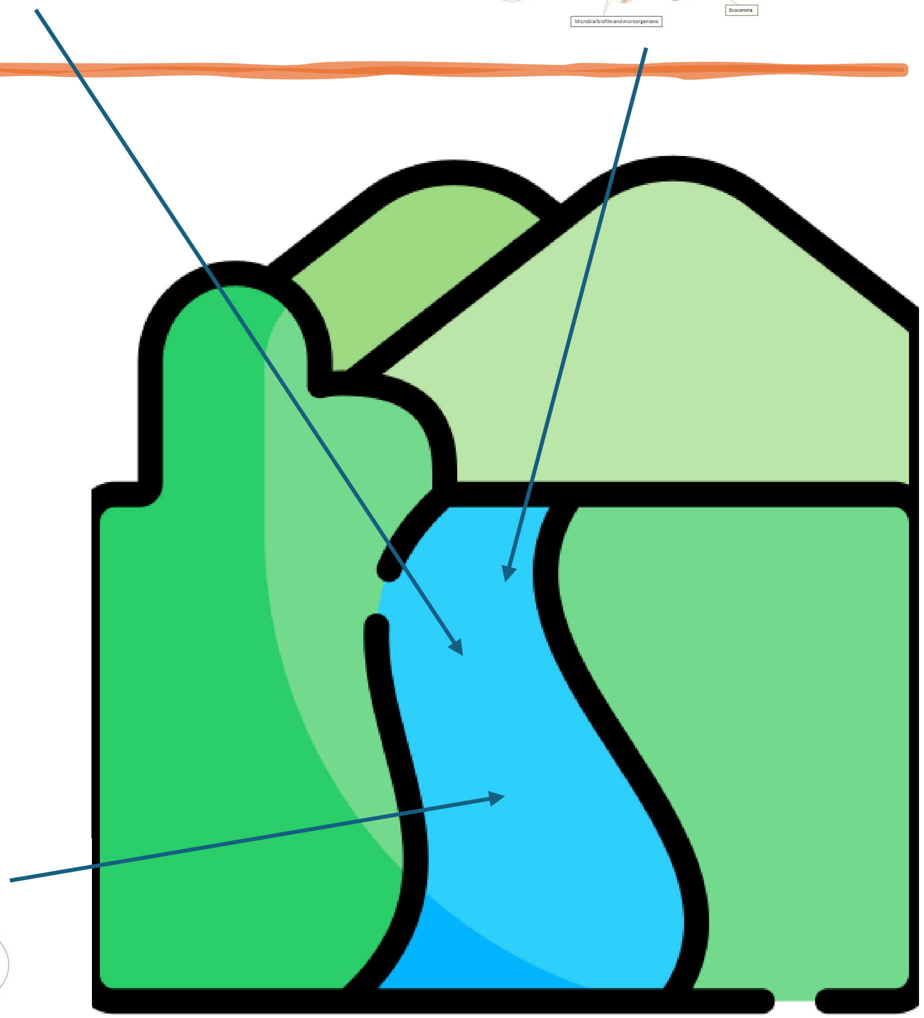
Results_7

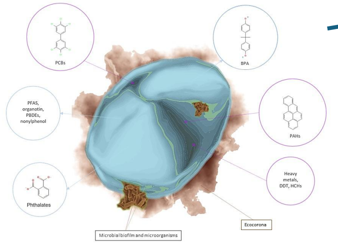




Environmental emission factors – LDIR and TD-GC/MS (no CFs)

- 4×10^{9} MPs/day (11,700 MPs/PE*day) emitted by the WWTP into the receiving water body, primarily rubber and PP fragments < 300 µm. All six polymers detected by TD-GC/MS in the effluent sample. About 75 grams of total MPs released into receiving water body daily, most of which was PE and PVC.
- MPs levels in final dewatered sludge was not directly measured but estimated using plant operator data and mass/flowrate balance → 8.6×10^{6} MPs/kg (dw) dewatered sludge; 0.75 g MPs/kg dw.
- 447 m^3/day of centrifuge extracted water (90% centrifuge capture efficiency). $\sim1\times10^{10}$ MPs re-enter the wastewater line daily (11% of the MPs entering through the influent) , or ~0.5 kg/day.



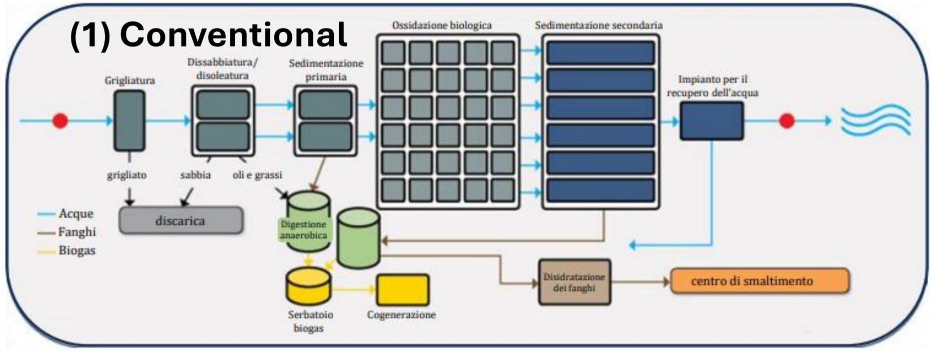


Aim of the study (2)

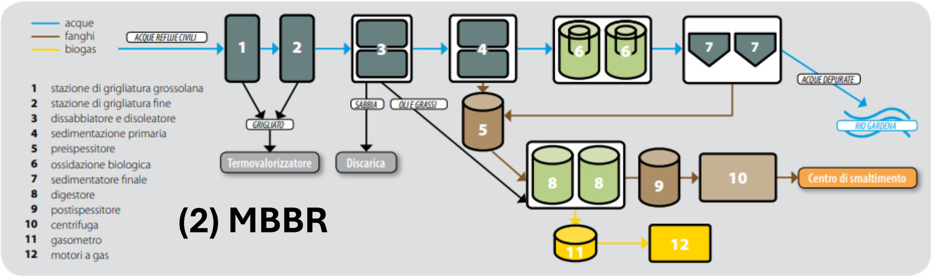
- Apply a systematic method for sampling, preparation, and analysis to identify and quantify selected polymers in the influent and effluent of WWTPs with different treatment technologies.
- Evaluate the specific performance for each plant.
- Use the analytical data to calculate environmental emission factors, expressed as the mass of microplastics released daily into the environment by each plant.

M&M_1

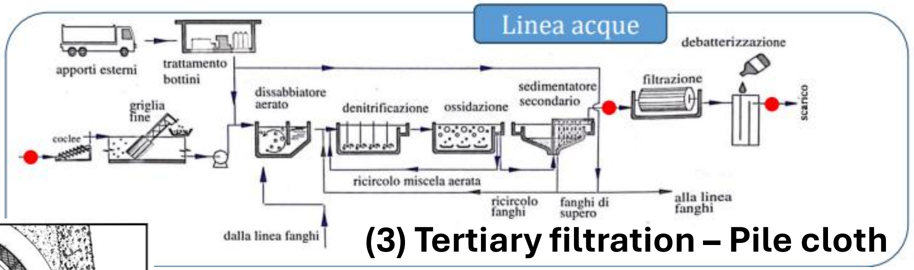
Investigated WWTPs



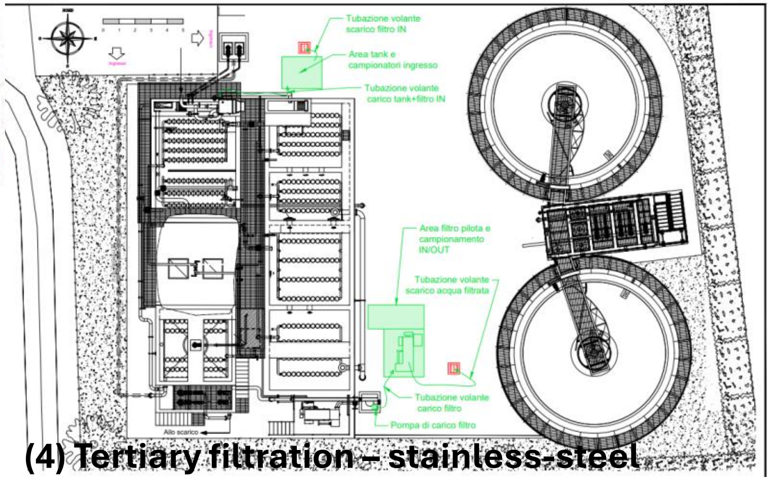
(1) Conventional



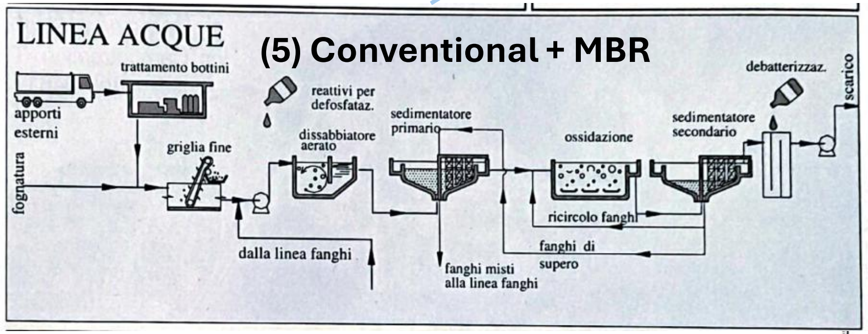
(2) MBBR



(3) Tertiary filtration – Pile cloth



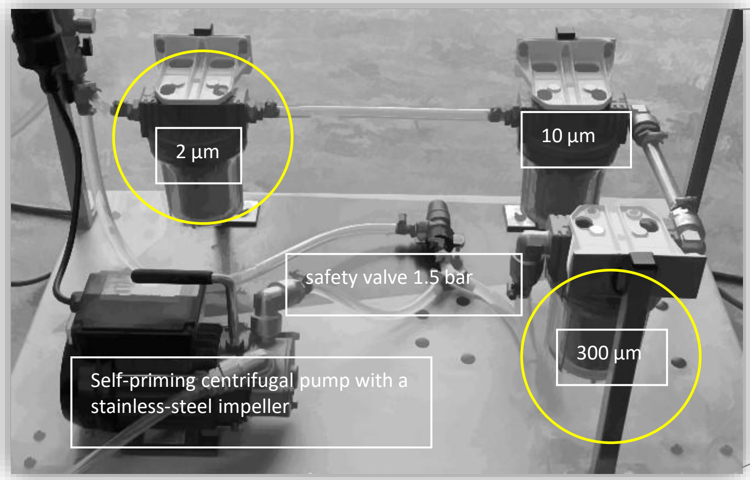
(4) Tertiary filtration – stainless-steel

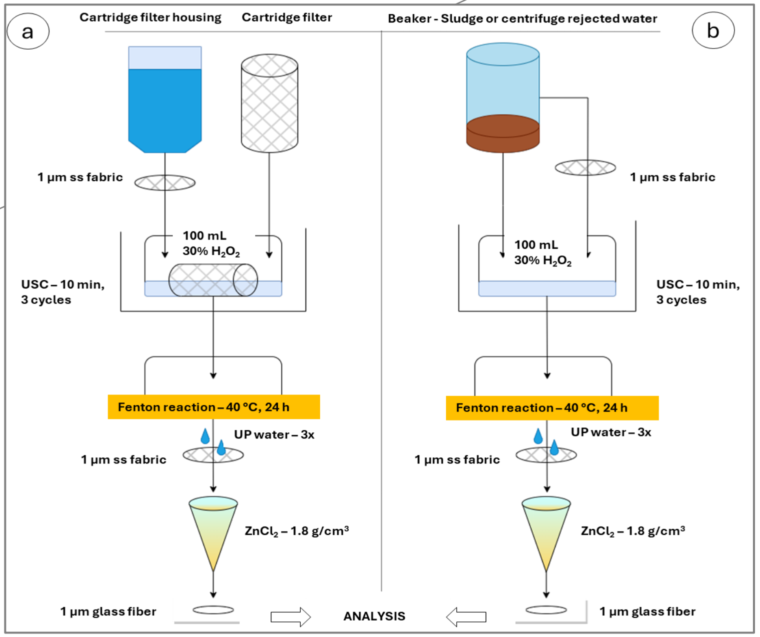


(5) Conventional + MBR

M&M_2

MPs sampling: Influent and effluent wastewaters were sampled the same way described in STUDY 1, but three ss cartridge filter were used to collect MPs.



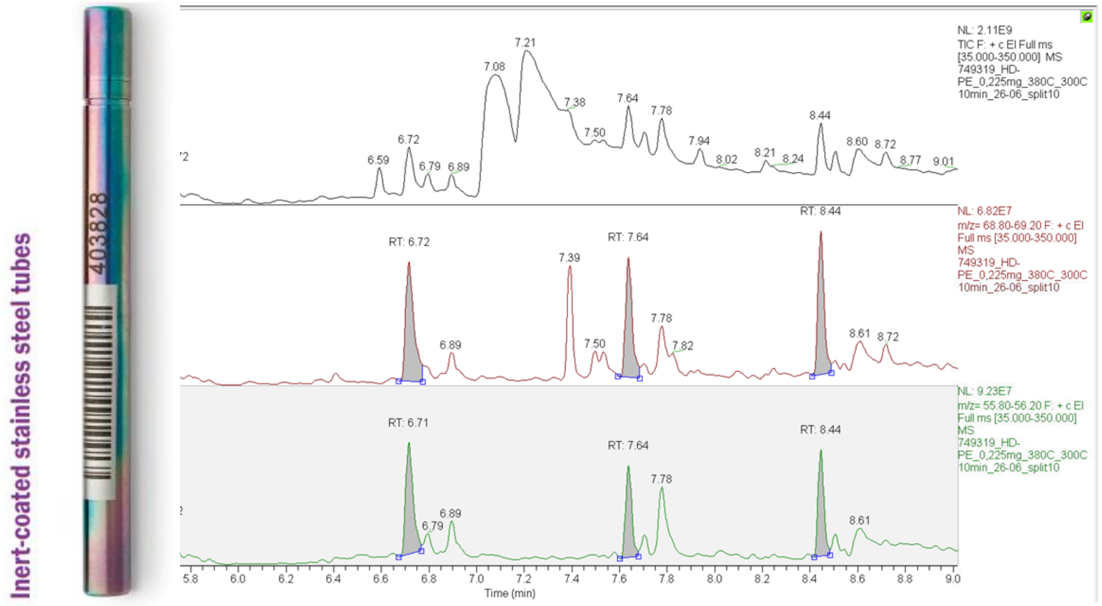


MPs extraction: same as STUDY 1

M&M_3

TD-GC/MS analysis

The glass fiber filters, containing the extracted MPs, were directly analyzed by rolling the filters into sample tubes and thermally desorbing them for GC/MS analysis. Polymers investigated: PVC, PP, PE, PS, PMMA, and bioplastics.



QA & QC

Glass and stainless-steel equipment, cotton lab coats, and colored gloves to minimize and control self-contamination.

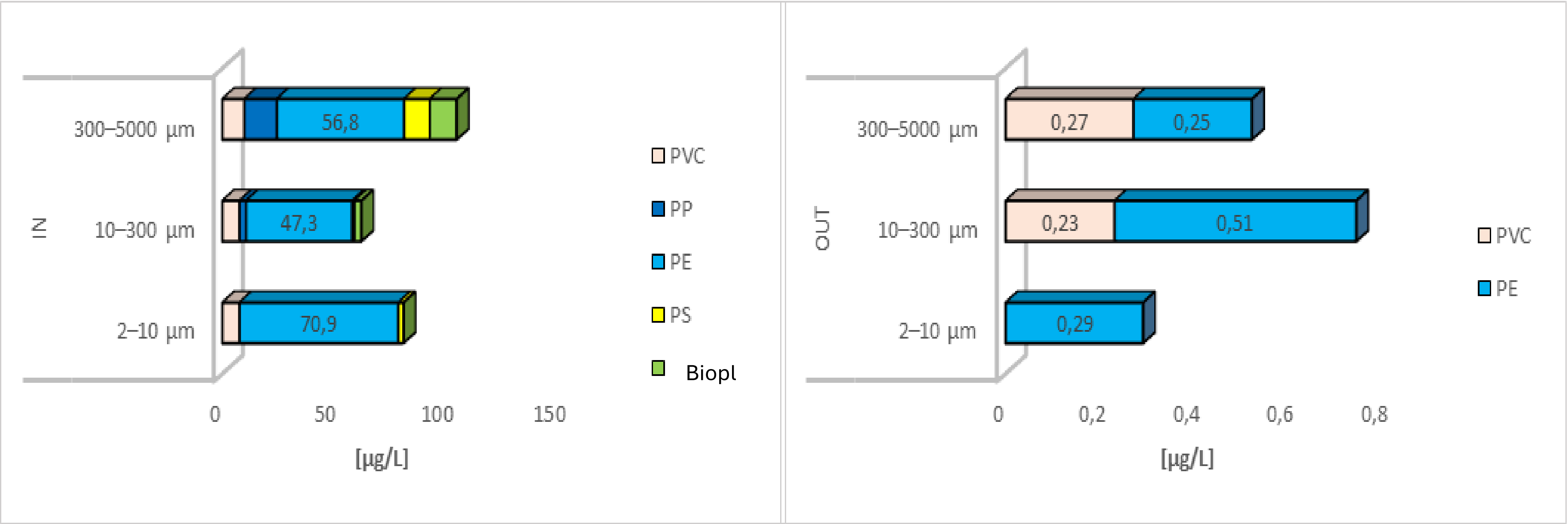
Sample preparation occurred under a fume hood in a clean environment. Experimental blanks at each extraction (open beaker of UP water).

Recovery test on MPs (500–2000 μm) showed a recovery rate > 90% for PVC, PET, PP, and HDPE.

Type of Polymer	Source	Weight [mg]		Mass loss (%)	Recovery rate (%)
		Before	After		
PVC (fragments)	Pipe	18,63	18,58	0,27	99,73
PET (sheets)	Water bottle	10,00	9,50	5,00	95,00
PP (sheets)	Food-grade bag	8,80	8,00	9,09	90,91
HDPE (fragments)	Bottle stopper	14,75	14,35	2,71	97,29

Results_1

Conventional



<u>Influent</u>

- Total MPs concentration 247.4 µg/L.
- PE (71%), PVC (10%), PP (7%), bioplastic and PS (6%).
- 42% of total MPs in the largest size class (300–5000 µm).

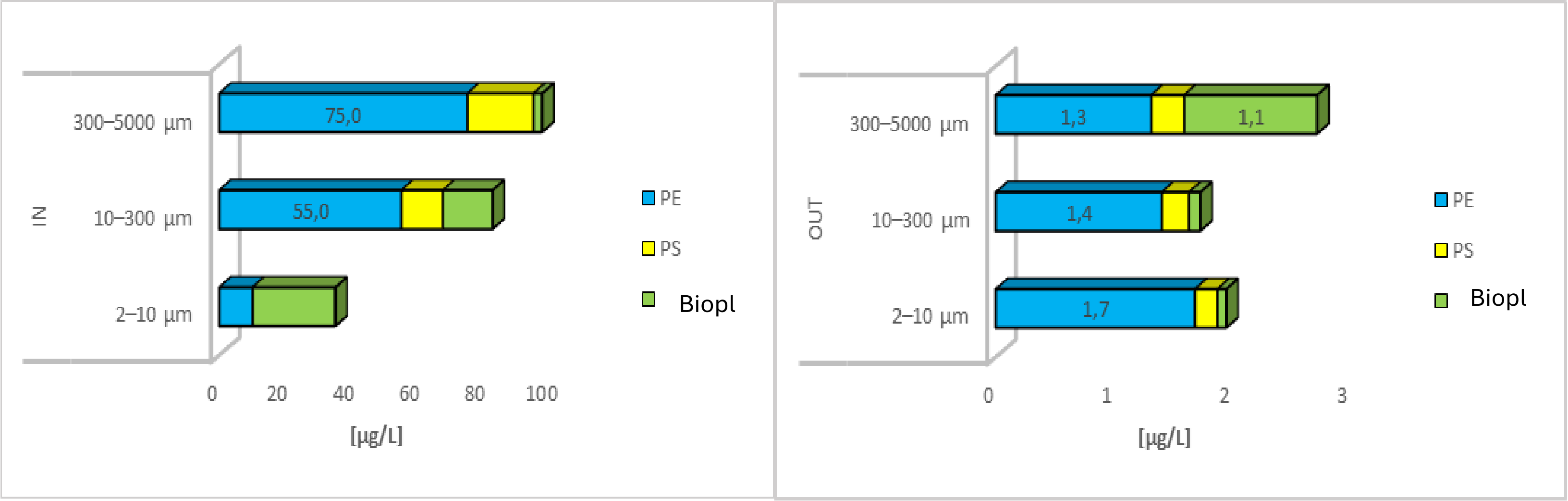
<u>Effluent</u>

- 1.55 µg/L (~99% removal).
- PE remains most common in the effluent (68%), primarily in the 10–300 µm size class.
- PP, PS, and bioplastic were completely removed, with bioplastic potentially biodegraded due to low initial concentration.

Conventional wastewater treatment processes effectively removed MPs, including those in the smallest fraction (2–10 µm).

Results_2

MBBR



Influent

- Total MPs concentration 215 µg/L.
- Only PE, PS, and Bioplastic were detected. PE the most abundant polymer, most in the 300–5000 µm size range.
- Most of the Bioplastic was in the smallest size fraction (2–10 µm).

Effluent

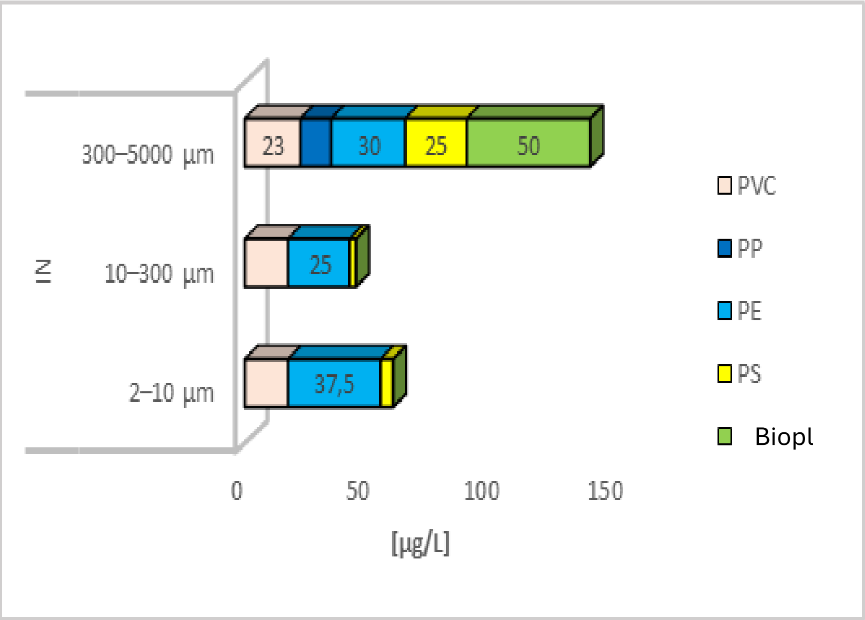
- 6.4 µg/L MPs (97% removal).
- PE (69%), Bioplastic (20%), and PS (11%).
- 2–10 µm sized PS in the effluent. MPs fragmentation?

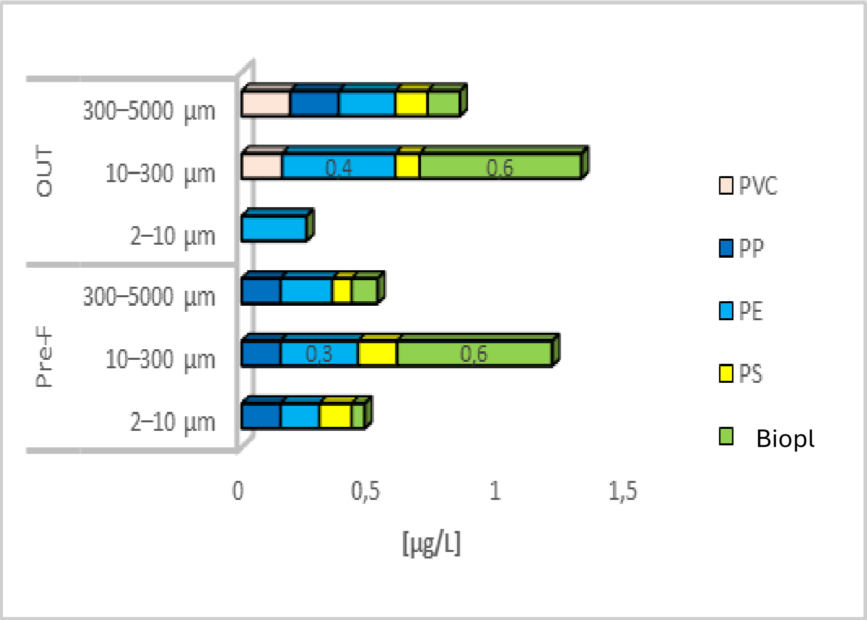
Bioplastic also present in the effluent, indicating possible resistance to biodegradation.
High concentration of PE in the effluent: MBBR element degradation?

Results_3

Tertiary filtration

Pile cloth filter





Influent

- Total MPs concentration 245 µg/L.
- PE is the most prevalent, followed by PVC (23%), Bioplastic (20%), PS and PP.
- 300–5000 µm MPs the most abundant.

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Pre-tertiary filtration

- 99% of total MPs removed after preliminary, biological, and final clarification stages.

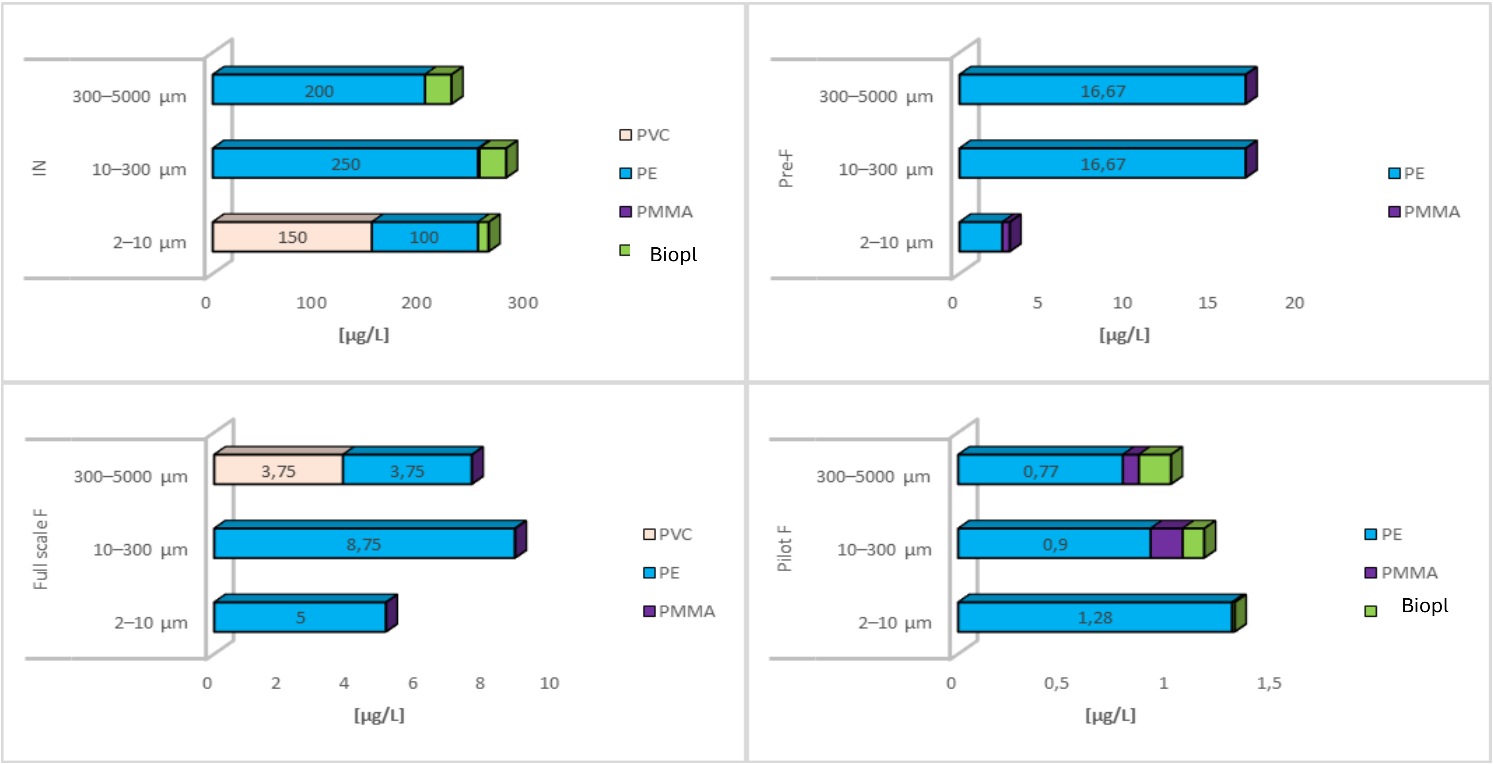
Effluent

- No additional MP reduction in tertiary filtration stage: MPs content increased from 2.2 µg/L to 2.4 µg/L after pile cloth filtration. Release during backwashing / filter degradation?

Results_4

Tertiary filtration

Stainless-steel filter



<u>Influent</u>

- Total MPs concentration 761.5 µg/L (higher compared to others).
- PE is the most prevalent polymer (72%), followed by PVC (20%) Bioplastic (8%), and PMMA.

<u>Pre-tertiary filtration</u>

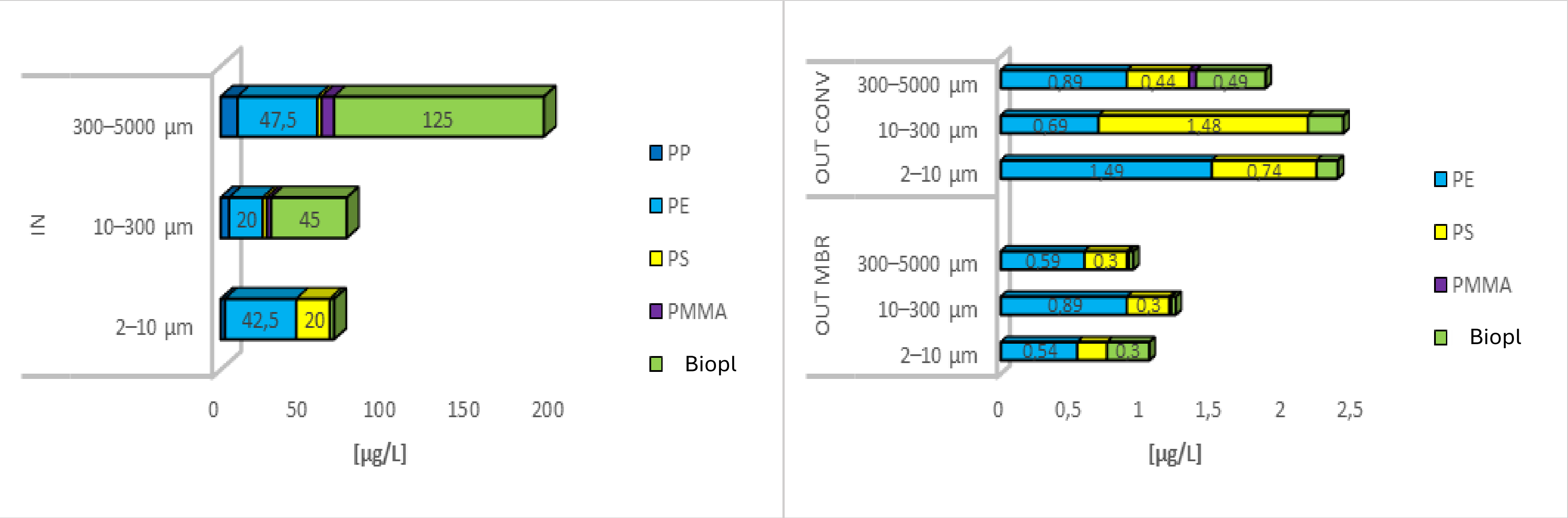
- 95% of MPs removed before final filtration (PVC and Bioplastic completely removed).
- PE remains the dominant polymer, followed by a small amount of PMMA (1.2%).
- Effective MP removal by activated sludge process.

<u>Effluent</u>

- Full-scale filter removed additional 41% of MPs. Total reduction of 97%. Most abundant size fraction is 10–300 µm.
- Pilot filter removed additional 91% of MPs. Total reduction 99.6%. Most abundant size fraction is 2–10 µm.

Results_5

MBR

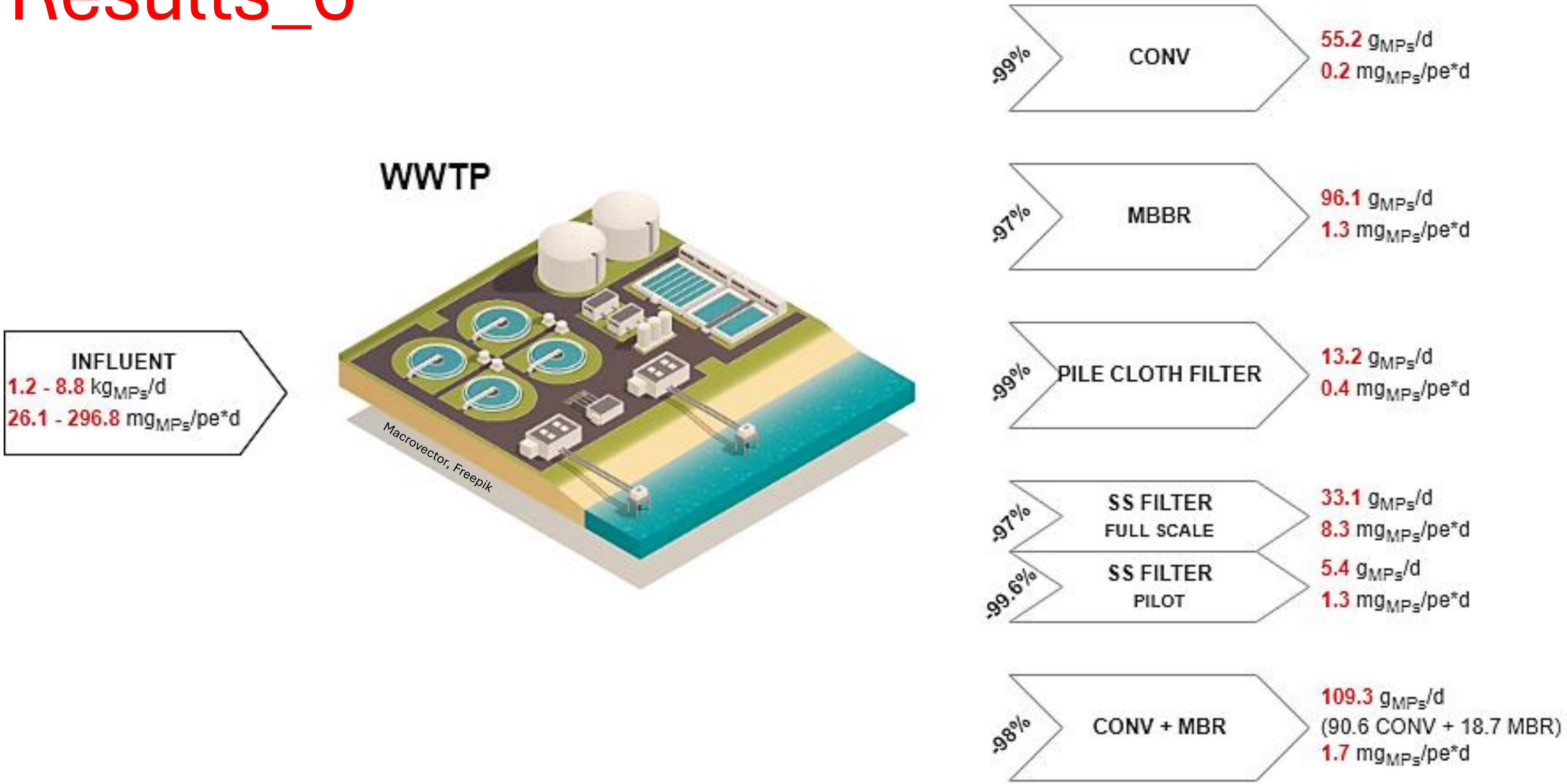


<u>Influent</u>
- Total MPs concentration 335 µg/L.
- Bioplastic is the most abundant polymer in the 300–5000 µm size fraction.
- PE (33%), PS (7%), PP, and PMMA (9%) mostly in larger size fractions.

<u>Conventional treatments</u>
- 98% of MPs removed (similar to conventional WWTP 1).
- Largest size fraction removed by 99%. Smaller fractions removed less efficiently (96-97%).

<u>MBR treatment</u>
- MBR treatment removed MPs more efficiently (99% removal).
- Potential deterioration of membrane modules? System design and configuration could affect MBR efficiency.

Results_6


WWTP
INFLUENT
1.2 - 8.8 kg_{MPs}/d
26.1 - 296.8 mg_{MPs}/pe*d
Macrovector, Freepik
-99%
CONV
55.2 g_{MPs}/d
0.2 mg_{MPs}/pe*d
-97%
MBBR
96.1 g_{MPs}/d
1.3 mg_{MPs}/pe*d
-99%
PILE CLOTH FILTER
13.2 g_{MPs}/d
0.4 mg_{MPs}/pe*d
-97%
SS FILTER
FULL SCALE
33.1 g_{MPs}/d
8.3 mg_{MPs}/pe*d
-99.6%
SS FILTER
PILOT
5.4 g_{MPs}/d
1.3 mg_{MPs}/pe*d
-98%
CONV + MBR
109.3 g_{MPs}/d
(90.6 CONV + 18.7 MBR)
1.7 mg_{MPs}/pe*d

Conclusions and Future Outlooks_1

STUDY 1:

- **LDIR** efficiently processes samples but requires trained personnel for accurate polymer identification, especially for degraded samples. LDIR detected more MPs due to its ability to identify particles as small as 5 µm, while **FPA-microFTIR** struggled with particles smaller than 20 µm. **TD-GC/MS** offers polymer mass data but requires meticulous calibration to analyze a broad spectrum of polymers. Sample purification, and expert interpretation of mass spectra are essential.
- An integrated approach using multiple analytical techniques provides a **more comprehensive view** of microplastic contamination.
- Although WWTPs remove over 96% of MPs, **significant amounts** still enter the environment. Proper **sewage sludge management** is crucial, since if reused in agriculture, it could reintroduce MPs and other contaminants into the environment, increasing human exposure. MPs released during **sludge centrifugation** are recirculated within the plant, posing a risk of environmental dispersion.

STUDY 2:

- **MPs** concentrations, size class and chemical composition **varied** across the five WWTPs.
- **MBR** and 5 µm **stainless-steel tertiary filtration** systems removed 99% or more of MPs; the **conventional plant** (WWTP 1) also showed comparable efficiency. **MBBR** treatment may **release** PE, and **pile cloth** filters could **degrade**, releasing polymer fibers. More studies are needed to confirm these findings.
- Further research should consider **other polymers** (e.g., nylon, PET), while **integrative analysis** on MP physical characteristics and number quantification would provide a more comprehensive information.

Conclusions and Future Outlooks_2

GENERAL

- The analytical **method** effectively allowed to collect, characterize, identify and quantify **MPs in the 2–5000 µm size range.** Sample preparation efficiently removed organic and inorganic substances for accurate polymer analysis.
- A longer monitoring **campaign, with replicates**, is recommended, along with investigations into alternative **treatment methods,** such as sand filtration (and constructed wetlands for very small decentralized WWTPs).
- Investigations on the **fate and environmental mobility of MPs accumulated in sewage sludge.**
- **Nanoplastics and micro-and nanoplastics associated pollutants** also require further exploration due to potential increased emissions and risks to ecosystems and health.

Thank you for your attention

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References

- PlasticsEurope. (2024). *The Circular Economy for Plastics – A European Analysis*. https://plasticseurope.org/knowledge-hub/the-circular-economy-for-plastics-a-european-analysis-2024/
- UNEP 2024, https://www.unep.org/news-and-stories/story/everything-you-need-know-about-plastic-pollution
- ECHA 2024, https://echa.europa.eu/hot-topics/microplastics
- Ee-Ling Ng, Esperanza Huerta Lwanga, Simon M. Eldridge, Priscilla Johnston, Hang-Wei Hu, Violette Geissen, Deli Chen, An overview of microplastic and nanoplastic pollution in agroecosystems, Science of The Total Environment, Volume 627, 2018, Pages 1377-1388, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2018.01.341.
- Albert A. Koelmans, Nur Hazimah Mohamed Nor, Enya Hermsen, Merel Kooi, Svenja M. Mintenig, Jennifer De France, Microplastics in freshwaters and drinking water: Critical review and assessment of data quality, Water Research, Volume 155, 2019, Pages 410-422, ISSN 0043-1354, https://doi.org/10.1016/j.watres.2019.02.054.
- National Oceanic and Atmospheric Administration (NOAA), What are microplastics?, https://oceanservice.noaa.gov/facts/microplastics.html
- Paul, M. B., Stock, V., Cara-Carmona, J., Lisicki, E., Shopova, S., Fessard, V., Braeuning, A., Sieg, H., & Böhmert, L. (2020). Micro- And nanoplastics-current state of knowledge with the focus on oral uptake and toxicity. *Nanoscale Advances*, *2*(10), 4350–4367. https://doi.org/10.1039/d0na00539h
- Rahman, A., Sarkar, A., Yadav, O. P., Achari, G., & Slobodnik, J. (2021). Potential human health risks due to environmental exposure to nano- and microplastics and knowledge gaps: A scoping review. *Science of the Total Environment*, *757*. https://doi.org/10.1016/j.scitotenv.2020.143872
- Leslie, H. A., Velzen, M. J. M. van, Brandsma, S. H., Vethaak, A. D., Garcia-Vallejo, J. J., & Lamoree, M. H. (2022). Discovery and quantification of plastic particle pollution in human blood. *Environment International*, *163*. https://doi.org/10.1016/j.envint.2022.107199
- Elseblani, R., Cobo-Golpe, M., Godin, S., Jimenez-Lamana, J., Fakhri, M., Rodríguez, I., & Szpunar, J. (2023). Study of metal and organic contaminants transported by microplastics in the Lebanese coastal environment using ICP MS, GC-MS, and LC-MS. *Science of The Total Environment*, *887*, 164111. https://doi.org/10.1016/j.scitotenv.2023.164111
- Galafassi, S., Sabatino, R., Sathicq, M. B., Eckert, E. M., Fontaneto, D., Dalla Fontana, G., Mossotti, R., Corno, G., Volta, P., & Di Cesare, A. (2021). Contribution of microplastic particles to the spread of resistances and pathogenic bacteria in treated wastewaters. *Water Research*, *201*, 117368. https://doi.org/10.1016/j.watres.2021.117368
- Kopatz, V., Wen, K., Kovács, T., Keimowitz, A. S., Pichler, V., Widder, J., Vethaak, A. D., Hollóczki, O., & Kenner, L. (2023). Micro- and Nanoplastics Breach the Blood–Brain Barrier (BBB): Biomolecular Corona's Role Revealed. *Nanomaterials*, *13*(8), Article 8. https://doi.org/10.3390/nano13081404
- Braun, M., Mail, M., Krupp, A. E., & Amelung, W. (2023). Microplastic contamination of soil: Are input pathways by compost overridden by littering? *Science of The Total Environment*, *855*, 158889. https://doi.org/10.1016/j.scitotenv.2022.158889
- Cavazzoli, S., Ferrentino, R., Scopetani, C., Monperrus, M., & Andreottola, G. (2023). Analysis of micro- and nanoplastics in wastewater treatment plants: Key steps and environmental risk considerations. *Environmental Monitoring and Assessment*, *195*(12), 1483. https://doi.org/10.1007/s10661-023-12030-x