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D1.3 – EU27 matrix for bio-based input streams and NR technologies

WP1, T1.2 European status and barriers to Nutrient Recovery technologies and bio-based fertilisers

[Version 2 – 10/07/2023]

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Technical references

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Abbreviations

ABPR	Animal By-products Regulations
BBF	Bio-Based Fertiliser
BES	Bioelectrochemical systems
CMC	Component Material Category (see Annex II to the FPR)
COM	Commission
Co-WI	Co-incineration of waste
DS	Dry solids
EEA	European Environment Agency
E-PRTR	European Pollutant Release and Transfer Register
ESPP	European Sustainable Phosphorus Platform
FPR	The Fertilising Products Regulation 'Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laid down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003
IAS	Internal audit service
IED	Industrial Emissions Directive
INMAP	Integrated Nutrient Management Action Plan
LCP	Large combustion plants
MFC	Microbial Fuel Cells
MS	Member State
NR	Nutrient Recovery
OMBR	Osmotic membrane bioreactors
PFC	Product Function Category (see Annex I to the FPR)
REACH	Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals, establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC, OJ L 396, 30.12.2006, p. 1–850.
SIFF	Structured Implementation and Information Framework (SIIF)
UWWT	Urban Waste Water Treatment
UWWTD	Urban WW Treatment Directive
WFD	Waste Framework Directive - Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives, OJ L 312, 22.11.2008, p. 3–30
WI	Waste Incineration

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1 Executive Summary

The present deliverable comprises the first deliverable of WP1 – 'Mapping current nutrient recovery balance in European WW treatment systems'. It was carried out within Task 1.2– 'European status and barriers on nutrient recovery technologies and bio-based fertilisers'. This deliverable is representative of the continuously evolving attempts of the EU-matrix towards the closing of waste water (WW) and macro - (NPK) and micro - nutrients cycles, which is verified by the assessment of information updated by the European Commission in the previous 50 days.

The objective of this deliverable is to study, map and evaluate the current status in the EU-27 matrix of the:

- Bio-based input streams (Urban WW, sewage sludge, food, Industrial WW and brine).

- Nutrient Recovery technologies from bio-based input streams.

- Economically prime important nutrient resource-based products (i.e. Bio-based fertilisers).

As part of the contribution to Task 1.2, it was attempted to contact key stakeholders from each country, as part of an interview, to map the current status of the aforementioned aspects of the Nutrient Recovery Circle in the EU27 matrix. Due to personal data handling concerns and the publication of information regarding industries in the private sector, in the following sections, all publicly accessible official data sources will be presented and their content will be evaluated.

Addressing the obstacles that were faced during the mapping of EU's current status highlights the urgent need for the launch of an interactive platform (D1.5 and D1.6 (WP1)) to track and trace bio-based input streams and match the economically prime important nutrient resource - based products and recovered nutrients that derive from the application of Nutrient Recovery practices on them with Bio-based fertiliser applications.

Accordingly, the deliverable is structured in three semantically different sections.

Firstly, Section 3 and Section 4 are based on publicly accessible databases created by the European Commission. Even though these databases are detailed about the location and the waste and waste water quantity and mode of management (Table 3-5 to Table 3-9 and Table 4-10 to Table 4-12) it is necessary to be further updated, to cover the two-year gap of data (2020-2022) for the extraction of safe conclusions for the current status of the EU matrix. Regardless, with the increased Nutrient Recovery awareness and compliance, the need for the registration of small-scale industries whose pollutants (not valorised nutrients) effluent concentration is under the threshold of 50,000 kg/year for total nitrogen release in the water and 5,000 kg/year for total phosphorus emissions is highlighted. Mapping of the bio-based input streams predicts/controls/avoids according to the source (urban or industrial sector), the presence of potentially toxic elements, poly aromatic hydrocarbons, pharmaceutical residuals, microbiological pathogens etc. whose accumulation is hazardous in their valorisation as Bio-based fertilisers to be extensively discussed on Task 6.1 'Inventory and integrated assessment of the EU regulations related to production and application of Bio-based fertilisers' (WP6).

Secondly, in Section 5, the currently introduced Nutrient Recovery technologies in the EU matrix according to the European Sustainable Phosphorus Platform are presented. Their presentation includes the Bio-based input streams (Urban WW, sewage sludge, food, Industrial WW and brine) they can be employed to, the end-products that derive from them and are potential candidates for their utilisation as Bio-based fertilisers and their current operating status with details about the location. The presented information on Table 5-13, Table 5-14 and Table 5-15 sets the background for the identification of the preconditions and the factors that drive or hamper the deployment of Nutrient Recovery options in WW Treatment facilities for the Deliverable D1.4 'Barriers on Bio-based fertilisers development' of Task 1.2.

Next, follows the accurate definition of Bio-based fertilisers according to the WalNUT context in Section 6.

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Finally, the coverage of some topics regarding the association of economically prime important nutrient resource-based products that derive from the implementation of Nutrient Recovery practices on bio-based input streams with bio-based fertilisers in Section 7 is the predecessor for Task 6.1 'Inventory and integrated assessment of the EU regulations related to production and application of Bio-based fertilisers' in WP6 in which the compliance of bio-based fertilisers with the Reg. (EU) 2019/1009 to be implemented next month will be validated.

Keywords: Bio-based input streams, Nutrient Recovery Technologies

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2 Introduction

One of the goals of Task 1.2 of the WalNUT project is to produce a description of the EU27 matrix of the Bio-based input streams (Urban WW, sewage sludge, food, Industrial WW and brine) i.e. the current status of the type and volume of industrial effluents entering municipal waste water treatment plants (WWTP) that are the potential candidates for nutrient recovery practices. In Sections 3 and 4, the most relevant major flows of urban WW and key industrial sectors WW flows were assessed and a more focused inspection of the accessible data on their treatment was performed. As part of their extensive interviews that will be presented in D1.4, key industrial sectors companies were asked for industrial WW contracts or environmental permits regarding pre-treatment of their WW, cooperation with local WWTPs or waste handling companies as well as the set limits regarding pollutants. In mid-2022, municipalities and industries become increasingly aware of the Nutrient Recovery (NR) concept. It is always in the context of environmental friendliness (e.g. reduction of the carbon footprint and resource recovery) that we hear of the implementation of NR practices. Phosphorus is removed in order to meet (the progressively stricter) effluent disposal limits and protect local water bodies from nutrient pollution (Preisner, et al., 2022). It is however, due to intensive research regarding e.g., the reduction of struvite maintenance expenses or mitigation pipe/pump/digester struvite build-up, the improvement of dewaterability, the avoidance of extra sludge generation and the waste disposal costs, that NR practices can in some cases achieve a 100 % return of investment in less than 10 years (Srivastava, Vaish, Singh, & Singh, 2020). Nevertheless, apart from the reduction of operational costs, total influent phosphorus can be converted into premium market-ready fertiliser with a compensating yield (Mini-paper – End-user requirements for recycled and biobased fertiliser products, 2022). Researchers assist this circular economy approach by focusing on the development of high-value market-ready fertilisers. The time is ripe now with the implementation of the EU Circular Economy Fertilising Products Regulation 2019/1009 that market ready fertilisers can derive from the implementation of Nutrient Recovery technologies.

Even though phosphate rock along with magnesium (micronutrient needed for the growth of plants) are listed as Critical Raw Materials (European Comission, 2022), the macronutrients NPK (needed for food-crop cultivation) cycle remains open. The fertiliser production market uses 80% of natural, non-renewable phosphorus resources in the form of phosphate rock. By 2025, 25,000 tons/year of phosphate from the phosphate ores will have to be replaced by phosphate from secondary raw materials.

The sustainable circular economy concept involves the implementation of Nutrient Recovery / Bio-based fertiliser manufacturing technologies for the conversion of phosphate-rich (P_2O_5) local flows into competitively priced sustainable products (P_2O_5 and K_2O). 3.3 % of the global natural gas production and 1 % of the global energy consumption and attendant greenhouse gas emissions are used for the industrial extraction of the (atmospheric) nitrogen via the energy-intensive Haber-Bosch process. The need for nitrogen extraction from sewage sludge, nitrogen recovery from biological sludge drying process air and recovery from sewage sludge as ammonium sulphate is urgent.

These nutrients are introduced into the food chain and ultimately end up in municipal WW treatment plants. When separated from stormwater, total phosphorus (regardless of the P-form) concentration can be ~5.6 mg/L and is removed as a phosphate-rich (relatively dilute) sludge to control eutrophication. Total nitrogen (as N) concentration can be ~35 mg/L and the nitrogen-containing compounds are converted to stable nitrogen gas via nitrification-denitrification. At the same time, in food processing industries, nutrients leach and runoff into the water bodies from where it is impractical to recover. In some cases, nutrients remain disused in industrial waste even after the implementation of strict pollutant (not valorised nutrient) disposal limits after waste water treatment.

1. Handling the increased cadmium and uranium content due to the rapid ore consumption involves the investment in additional purification technologies. P and other nutrient recovery on a local scale is sustainable and has become feasible because emissions, transport costs and purification (cadmium, uranium) in the deriving end-products are avoided (Tur-Cardona, et al., 2018). The utilisation of such end-products does not entail risks to human and animal health and the environment.

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The valorisation of bio-based input streams (Urban WW, sewage sludge, food, Industrial WW and brine) into marketable fertilising products or components is urgent and is guided and directed by accurate legislation for such products to enter the EU market.

2.1 European Sustainable Phosphorus Platform Position and recommendations

Quite recently, on 26th April 2022, the European Sustainable Phosphorus Platform (ESPP) highlighted that the escalation of the ongoing since 2014 Russo-Ukrainian War on 24 February 2022 is to have considerable impacts on fertiliser supply, and so ultimately on food production in Europe and global food security. The conflict makes it urgent to reduce import dependency on the EU-listed Critical Raw Material 'Phosphate Rock' and on natural gas for nitrogen fertiliser production.

ESPP has welcomed the progress towards integrating EU nutrient policies, with the development of Integrated Nutrient Management Action Plan (INMAP). ESPP supports the Green Deal objective to reduce nutrient losses by 50% without deteriorating soil fertility, as fixed by the Farm-to-Fork and Biodiversity Strategies, in synergy with nutrient recycling. Towards this end, ESPP mentioned that 'The emphasis of INMAP must not only be to reduce nutrient losses (N and P losses to water, ammonia air pollution and nitrogen oxides climate emissions, as in the proposal) but also Nutrient Recovery and recycling, and sustainable and healthy diets. Dietary choices are a key driver of fertiliser use, livestock production and nutrient pollution, as well as food security.

INMAP should not be limited to water policy, climate change and Critical Raw Materials policies, but should include:

- *"Targets for nutrient recycling and avoidance of nutrient losses in food waste and food processing, defined at EU Member State (MS) and regional levels*
- *Integrating nutrient recycling into the revision of the Urban WW Treatment and Sewage Sludge Directives, the Algae Initiative*
- *Ensure that chemicals and pharmaceuticals policies reduce contaminants in nutrient flows and so enable safe recycling*
- *R&I inc. nutrient flow data, demonstration projects*
- *Social awareness of nutrient use, recycling, losses*
- *Adapting the Common Agricultural Policy to monitor nutrient flows and to incentivise Nutrient Use Efficiency, optimised fertilisation, nutrient recycling and Nutrient BEMPs (Best Environmental Management Practices).*

Member State initiatives within the existing Common Agricultural Policy will not be sufficient without such changes."

ESPP notes that an estimate of the costs of the phosphorus losses by the EU Commission (COM) is needed. ESPP suggests that INMAP should include an assessment of CAP to identify where policy changes may be needed to ensure the achievement of the Green Deal nutrient loss reduction target (including "exported" nutrient losses), covering both EU policy and MS implementation plans. INMAP should fix the objective to reduce and then end EU import dependency for the CRM 'Phosphate Rock' and for natural gas for nitrogen fertiliser production, and should define and implement regulatory, fiscal and other policy actions to achieve this.

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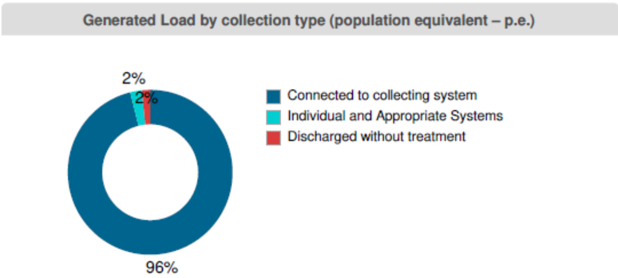
3 EU27 matrix for bio-based input streams (Urban WW)

After a rapid web-based survey, one can verify the steps towards the registration of WW in EU-27. Although EU-27 is still in a transitional phase regarding this matter, it was possible to collect valuable information on the mapping of EU-27 Urban WW streams. On the Beta edition of the dissemination platform of the 'Urban WW Treatment Directive, UWWTD)' (Urban Waste Water Treatment Directive: dissemination platform, 2022) one can have access to graphs for European statistics generated from the 10th reporting of the countries (2016). The graphs depicted in Figure 3-1, Figure 3-2 and Figure 3-3 are interactive and can be accessed in full definition here.

According to Figure 3-1, only 1.6 % of the generated load (9,661,451 pe) was discharged without treatment in 2016. 96.1 % is connected to a collecting system and the rest 2.3 % is collected in individual and appropriate systems.



Collection type	2016
Connected to collecting system	583,935,547 pe (96.1%)
Individual and Appropriate Systems	14,015,026 pe (2.3%)

Figure 3-1: Graph of EU-MS generated load of urban WW by collection type in 2016.

In Figure 3-2 an attempt to specify the destination of urban WW in each of the 28 EU-MS was made. Differentiation of the load not connected to a collecting system but reported to the Internal Audit Service (IAS) was made to showcase that in 2016, Romania (7,434 kpe) < Italy (565 kpe) < Hungary (552 kpe) < Bulgaria (412 kpe) < Spain (305 kpe) < Cyprus (175 kpe) < Poland (108 kpe) were the EU –MS with the highest loads not destined neither at a collecting system nor at a system reported in the IAS.

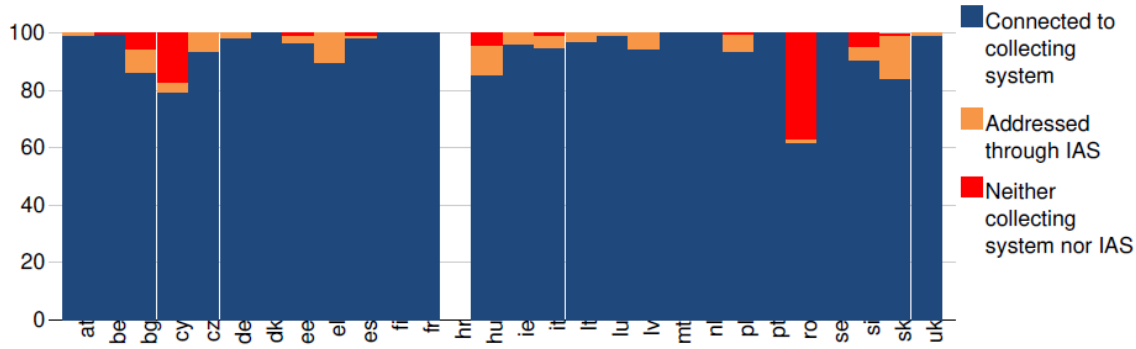


Figure 3-2: Graph of EU-MS evolution of the urban WW load destination in Kilo population equivalent (kpe)

In Figure 3-3, an 'MS level: Sewage Sludge production and destination' graph is included, describing the sewage sludge production in T DS/year and its destination. The creators decided to include the % sewage sludge.

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- re-used in 'soil and agriculture'
- re-used in 'other practices'

'Other practices' of sewage sludge refers to recycling routes applied in Europe in the present. Such routes include the use of sludge in forestry and silviculture as well as in land reclamation.

Storage of sewage sludge fulfils two main purposes: regulation of the flows to be re-used in 'soil and agriculture' and homogenisation of its composition. 'Long-term storage of sewage sludge has a disinfecting property, reducing the number of viruses and bacteria in sludge. Its efficiency depends on the duration of the storage. However parasites are the most resistant pathogens and it has been reported that long term storage would not affect their infectious potential. In cold climates, this process does not enable to reach a sufficient level of disinfection' (European Commission, 2022).

- disposed of in landfills

Landfill operation generates emissions into the air (mainly greenhouse gases like methane and carbon dioxide, reduced when biogases are collected and burnt), and into the soil and water at dumpsites (various compounds such as ions, heavy metals, organic compounds and microorganisms in leachate). The operation of a landfill also generates other impacts in terms of noise and dust from the delivery vehicles, as well as odours, land use, disturbance of vegetation and the landscape (European Commission, 2022).

In waste water treatment (both urban and industrial), energy requirements are of great importance. In some cases, the utilisation of produced on-site biogases and steam as energy sources (i.e. in boilers to maintain a temperature around 35 ˚C or for the production of electricity on the plant) can reduce them to a great extent.

- disposed of for incineration
- disposed of in 'other practices'

WalNUT targets the inclusion in 'other practices' of valorisation of waste water – based products as fertilisers.

- with not sorted destination

'Not sorted destination' refers to the quantity of sewage sludge whose destination has not been reported in the Urban Waste Water Treatment Directive dissemination platform. According to Table 3-1, the origin of such sewage sludge is in Denmark, Poland, Italy and Portugal.

According to the information provided by EU-MS to the EU-COM (European Commission, 2022)

• In Luxembourg, sludge is digestible then conditioned with lime or iron salts. Mechanical processes are used for dewatering. Polyelectrolytes are added to sludge that has not been conditioned so as to facilitate dewatering.

• Within the Walloon region of Belgium, sludge is digestible, aerobically stable, automatically or thermally dried, or conditioned with lime or polyelectrolytes.

• In Denmark, sludge is digested in a heat digestion chamber or a bioreactor, stabilised by aeration, composted (in controlled conditions for two weeks at a temperature of 55 ˚C), conditioned with lime or pasteurised at a temperature of 70 ˚C for one hour.

• In France, sludge is subjected to prolonged aeration, aerobic or anaerobic stabilisation, lime conditioning, thermal drying or composting.

• In Portuguese Republic, the technologies used are drying beds (drainage on sand bed and evaporation of humidity), thickening, mechanical dewatering (band filters, filter presses, vacuum filters or centrifuge) and numerous stabilisation processes.

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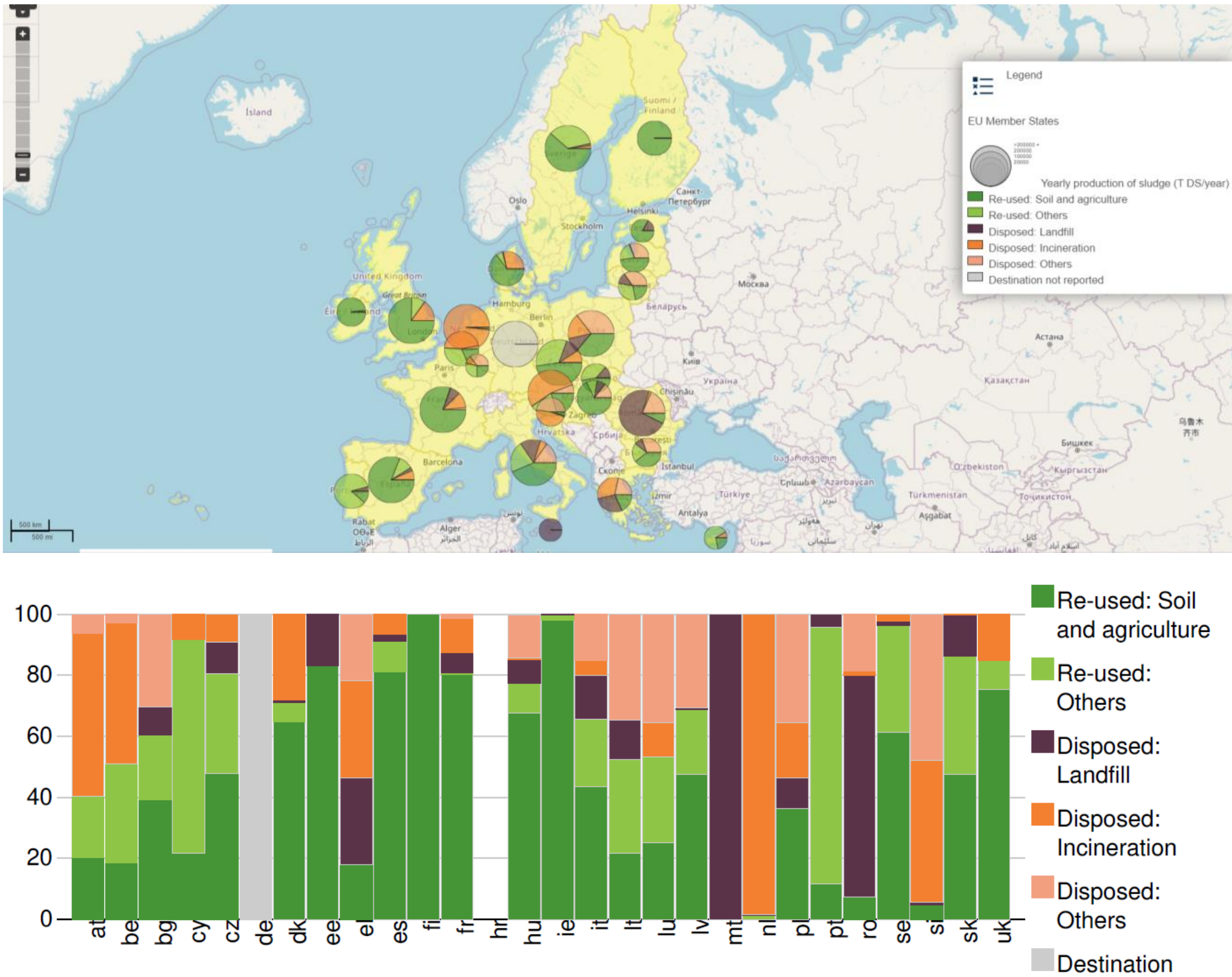

Figure 3-3: Map and accompanying graph of EU-MS sewage sludge production and destination

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Table 3-1: Accompanying data of Figure 3-3 in T DS/year of produced sewage sludge in EU-MS

	at	be	bg	cy	cz	de	dk	ee	el	es
Re-used: Soil and agriculture	48,313	30,254	26,230	1,613	98,506	0	85	15,526	21,528	664,205
Re-used: Others	47,942	53,502	14,228	5,187	67,736	0	8	0	0	82,492
Disposed: Landfill	63	0	6,124	0	21,558	0	1	3,164	34,030	18,693
Disposed: Incineration	127,248	76,270	0	608	18,914	0	37	0	38,366	54,111
Disposed: Others	14,372	4,782	20,339	0	0	0	0	0	25,853	0
Destination not sorted	0	0	0	0	0	1,531,310	0	0	0	0
Destination	fr	hr	hu	lt	lu	lv	mt	nl	pl	
Re-used: Soil and agriculture	754,967	0	108,008	9,702	2,229	11,961	0	0	218,599	
Re-used: Others	4,491	0	15,993	13,629	2,528	5,339	0	4,184	0	
Disposed: Landfill	64,290	0	12,378	5,624	0	145	10,571	1,103	61,990	
Disposed: Incineration	104,527	0	861	0	1,007	0	0	319,846	108,937	
Disposed: Others	13,606	0	22,737	15,466	3,154	7,669	0	0	214,783	
Destination not sorted	0	0	0	0	0	0	0	0	1	
Destination	se	si	sk	uk	ie	it	pt	ro	fi	
Re-used: Soil and agriculture	125,297	1,471	24,53	845,257	55	245,616	13,890	17,569	146,050	
Re-used: Others	71,742	0	20,079	107,094	962	124,573	100,148	0	0	
Disposed: Landfill	3,060	242	6,96	842	102	80,771	5,137	174,448	0	
Disposed: Incineration	4,154	14,479	68	169,085	0	27,720	0	3,900	0	
Disposed: Others	0	14,961	0	0	0	86,087	0	44,500	0	
Destination not sorted	0	0	0	2	0	1	1	0	0	

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In the accompanying data listed in Table 3-1 one can see that utilisation of sewage sludge in agriculture is the first choice for the majority of EU-MS (Bulgaria, Czech Republic, Denmark, Spain, Finland, France, Hungary, Italy, Latvia, Poland, Sweden, Slovakia and the UK). The second most common option for sewage sludge treatment is incineration. Austria, Belgium, Cyprus, Greece, the Netherlands and Slovakia have adopted incineration as the first destination of sewage sludge. The third destination of sewage sludge is landfill disposal with Malta, Romania and Slovenia following this path as the first option for sewage sludge treatment. Other destinations are targeted for the re-use of the majority of produced sewage sludge in Portugal and the Republic of Ireland. On the other hand, Lithuania and Luxembourg follow other paths of sewage sludge disposal. As one can see in Table 3-1, although disposal is the first destination for the sewage sludge produced in Lithuania (15.47 t DS/year) and Luxembourg (3.15 t DS/year), the quantity is very low when compared to the quantity of sewage sludge disposal from Poland (214.78 t DS/year – 2nd sewage sludge destination), Italy (86,087 t DS/year - 3rd sewage sludge destination), Romania (44,5 t DS/year - 2nd sewage sludge destination), Greece (25.85 t DS/year - 3rd sewage sludge destination), Hungary (22,737 t DS/year – 2nd sewage sludge destination) and Bulgaria (20.34 t DS/year – 2nd sewage sludge destination).

Municipal WW stream outputs are certainly not bio-fertilising products. They are however bio-based input streams and from their valorisation via Nutrient Recovery practices, economically prime important nutrient resource-based products can derive to be used as bio-based fertilisers. The latest update on the ‘Urban WW Treatment map’ (European Environment Agency, 2022a) was published on January 12, 2022, and presents the data collected from 2018 in EU-28 countries plus Iceland and Norway. The information on the implementation of the ‘Urban WW Treatment Directive UWWTD)’ was reported by the countries in 2020.

An initiative for the systematic registration of urban WW treatment plants in the EU targets the organisation and the easier access to the reported data to handle the information and export significant conclusions.

By clicking on the blue circle of each country in Figure 3-4, you can have access to the national UWWTD Structured Implementation and Information Framework (SIIF) node of each EU-MS. As an example, by clicking on Greece one is welcomed to the UWWTD website for Greece accompanied by the following description: ‘In 2018, Greece had 464 urban WW agglomerations of more than 2 000 population equivalent (p.e). These agglomerations generated a total load of 11,870,177 p.e.. 91% of this load is connected to a collecting system and 9 % is addressed through Individual and Appropriate Systems (storage or septic tanks, micro-stations). These agglomerations are connected to 6 secondary treatment plants and 226 more stringent treatment plants. All these treatment plants have a total design capacity of 13 982 461 p.e..’

By clicking on each agglomeration point on the map Figure 3-5 you get access to pieces of information regarding the:

- Generated load in p.e.
- Compliance
- Connection compliance
- 2nd treatment compliance
- 3rd treatment compliance

It is important to map the degree of treatment compliance to be able to locate the potential candidates for Nutrient Recovery practices.

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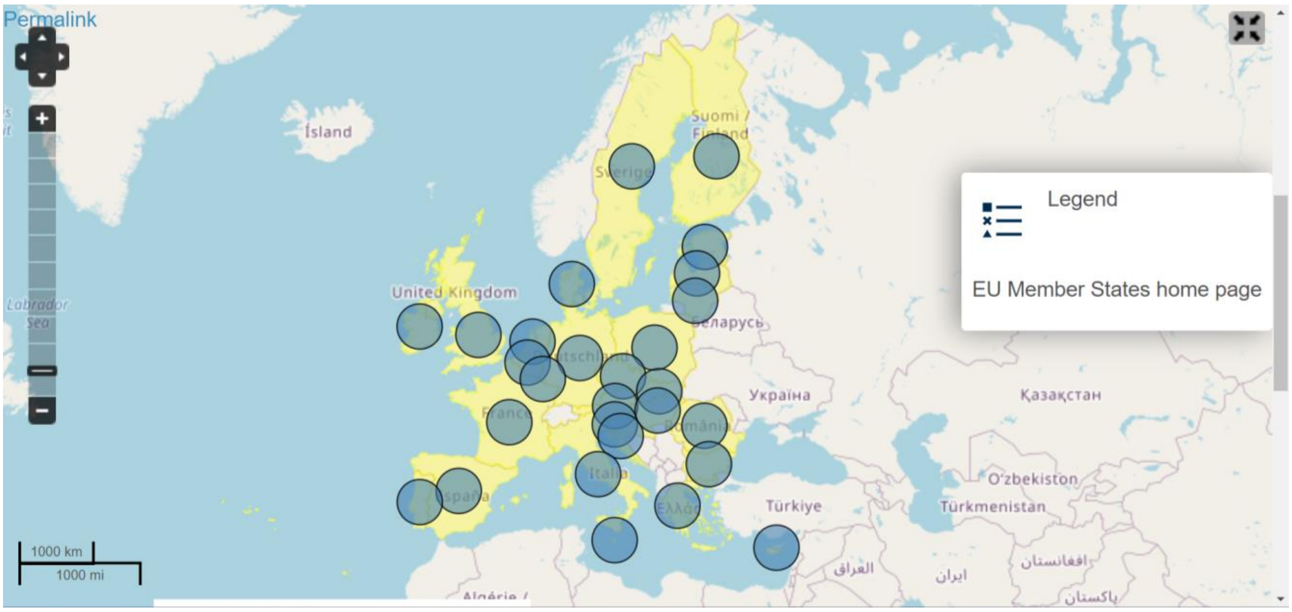

Figure 3-4: Map of EU-MS urban WW home pages (Urban Waste Water Treatment Directive: Dissemination, 2022)

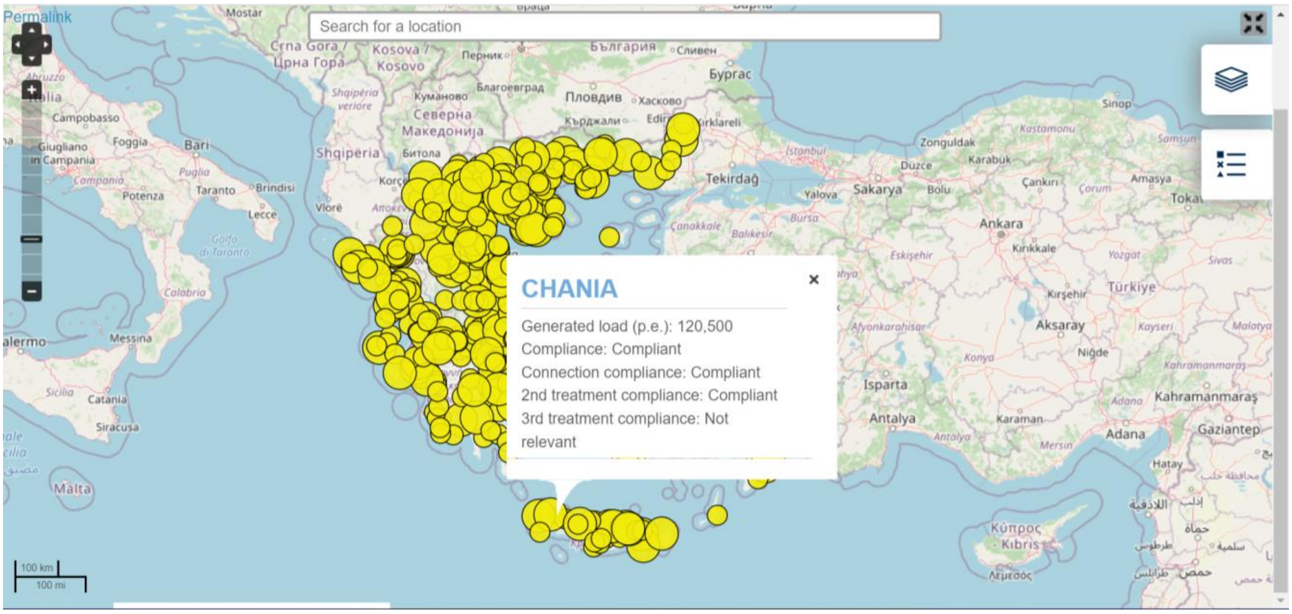

Figure 3-5: Map of urban WW agglomerations in Greece (Urban Waste Water Treatment Directive: Dissemination, 2022)

Regarding compliance, one can access the list of available maps in the UWWTD: dissemination platform to verify the compliance of each region with the directive. The degree of treatment compliance indicates the potential of an EU-MS as a candidate for Nutrient recovery practices. Moreover, the higher valorisation capacity is indicative of a higher potential of the country. The accompanying data of Figure 3-6 are presented in Table 3-2. The EU-MS with the least percentages of compliance (< 50%) are Italy (48 %) > Ireland (42 %) > Slovenia (33 %) > Bulgaria (22 %) > Romania (6 %).

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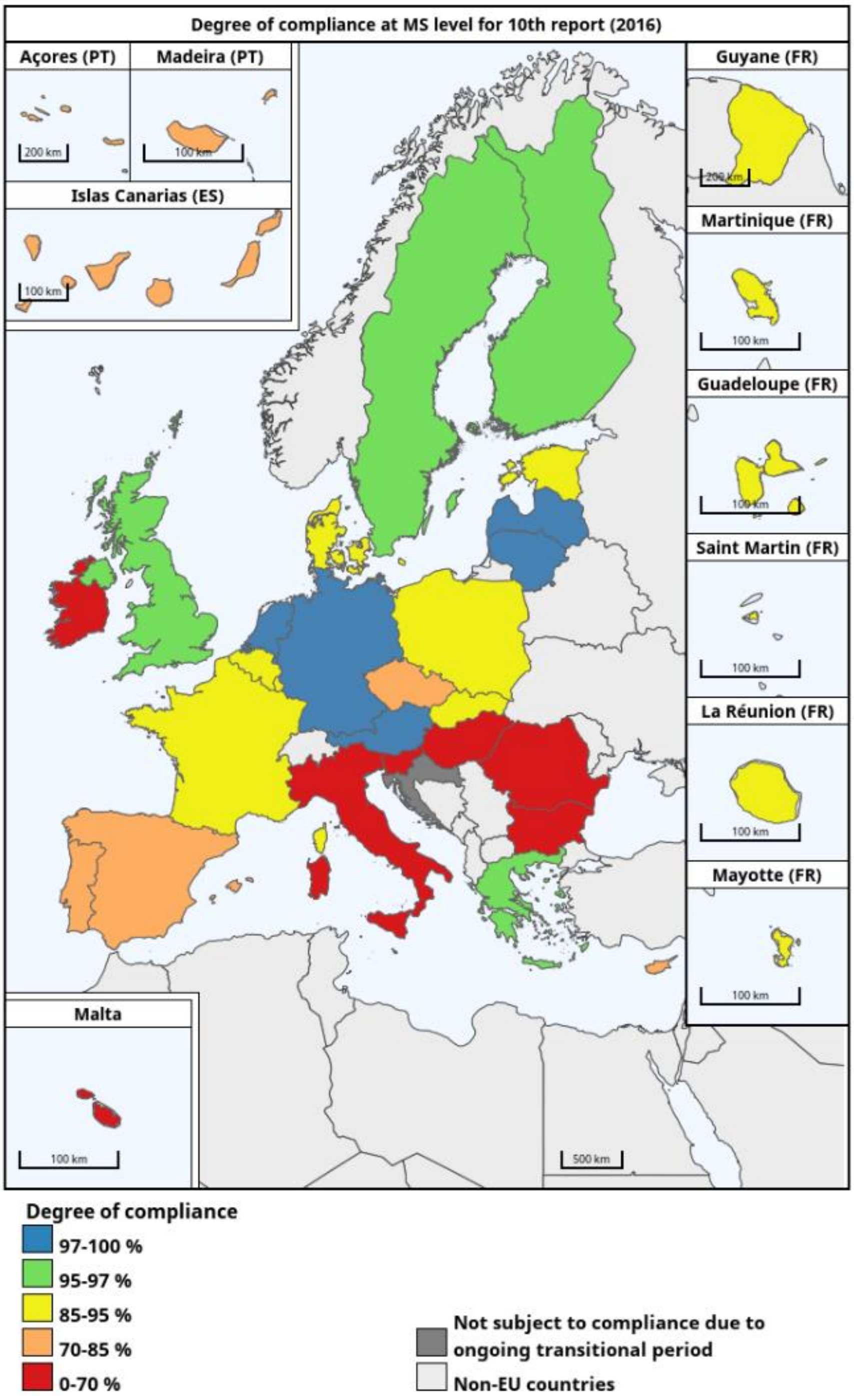

Figure 3-6: Degree of compliance at a MS level for the10th report (2016) (Degree of compliance at MS level for 10th report (2016), 2022)

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Table 3-2: Accompanying data of Figure 3-6 for the degree of compliance at a MS level for the 10th report (2016)

Country	Total generated load (kg)	Targeted load (kg)	Compliant load (kg)	Rate
AT	20,667,206	20,667,206	20,667,206	100%
BE	9,211,400	9,211,400	8,699,100	94%
BG	7,442,699	7,433,306	1,728,506	23%
CY	1,029,000	1,029,000	780,000	76%
CZ	9,355,394	9,355,394	6,706,464	72%
DE	111,906,058	111,906,058	111,807,101	100%
DK	11,598,945	11,598,945	10,350,645	89%
EE	1,589,716	1,589,716	1,429,566	90%
EL	11,803,450	11,794,658	11,314,410	96%
ES	64,819,277	64,819,277	50,651,183	78%
FI	5,057,300	5,057,300	4,861,950	96%
FR	71,732,929	71,732,929	61,112,455	85%
HR	4,999,712	0	0	Pending deadline
HU	13,588,976	13,588,976	9,063,583	67%
IE	5,080,615	5,080,615	2,136,939	42%
IT	76,682,102	76,682,102	36,724,723	48%
LT	2,905,700	2,905,700	2,905,700	100%
LU	637,438	637,438	602,380	95%
LV	1,588,668	1,588,668	1,564,977	99%
MT	789,039	789,039	0	0%
NL	19,440,165	19,440,165	19,440,165	100%
PL	38,542,418	38,542,418	33,084,486	86%
PT	12,237,640	12,237,640	9,839,040	80%
RO	20,142,050	16,831,883	1,046,986	6%
SE	12,509,265	12,509,265	11,942,365	96%
SI	1,462,223	1,462,223	476,610	33%
SK	4,225,468	4,225,468	3,623,403	86%
UK	71,093,713	71,093,713	68,555,940	96%

12 MS in the EU-28 in 2016 achieved a higher than 90% degree of compliance according to the 10th report in 2016. The publicly accessible representative data have not been renewed so far.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 101000752.

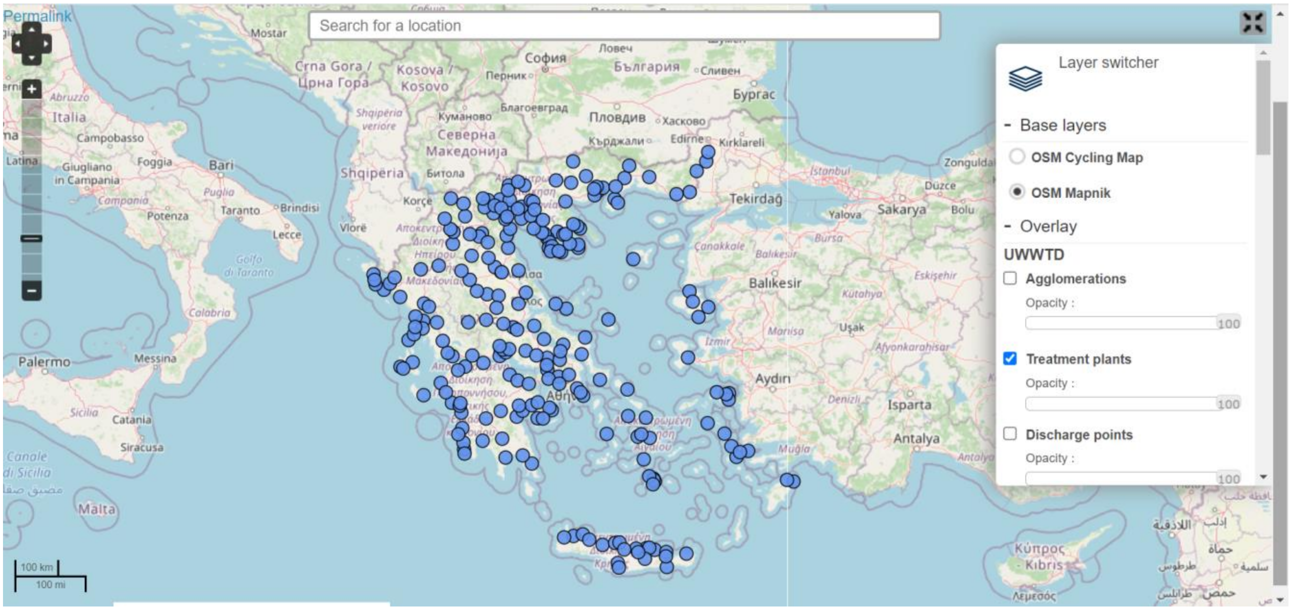

Figure 3-7: Map of urban WW treatment plants in Greece (Urban Waste Water Treatment Directive: Dissemination, 2022)

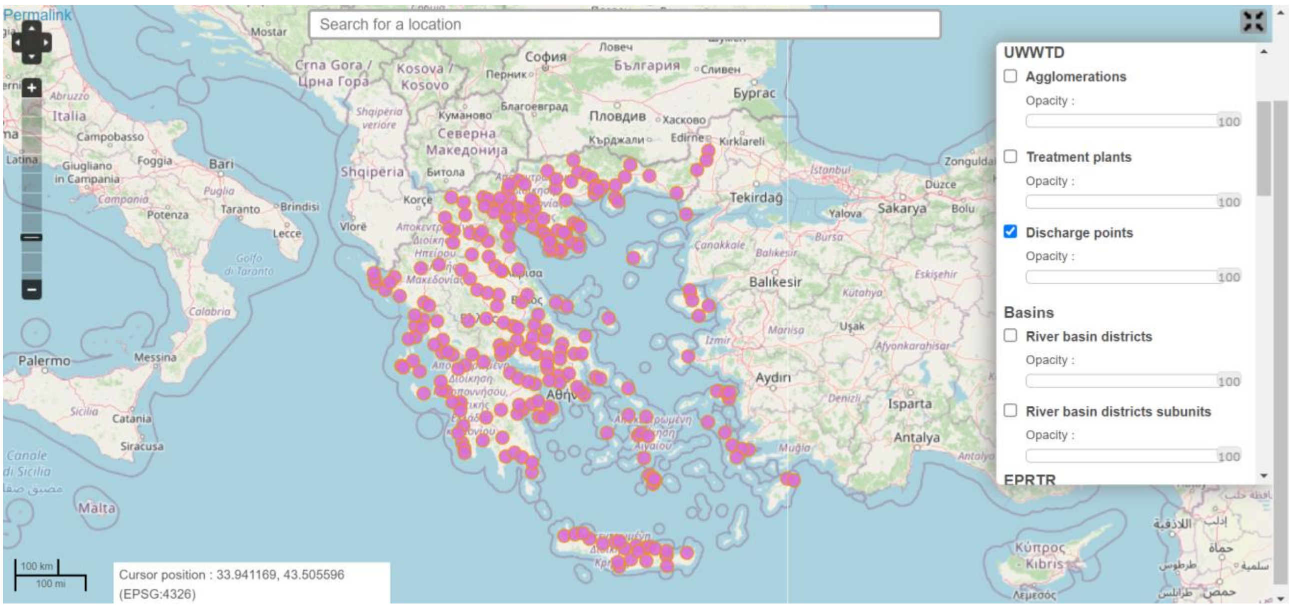

Figure 3-8: Map of discharge points in Greece (Urban Waste Water Treatment Directive: Dissemination, 2022)

3.1 The European Pollutant Release and Transfer Register

As presented in the following figures, one can have access to the European Pollutant Release and Transfer Register (E-PRTR) data regarding total nitrogen (Figure 3-9), total organic carbon (Figure 3-10) or total phosphorus (Figure 3-11).

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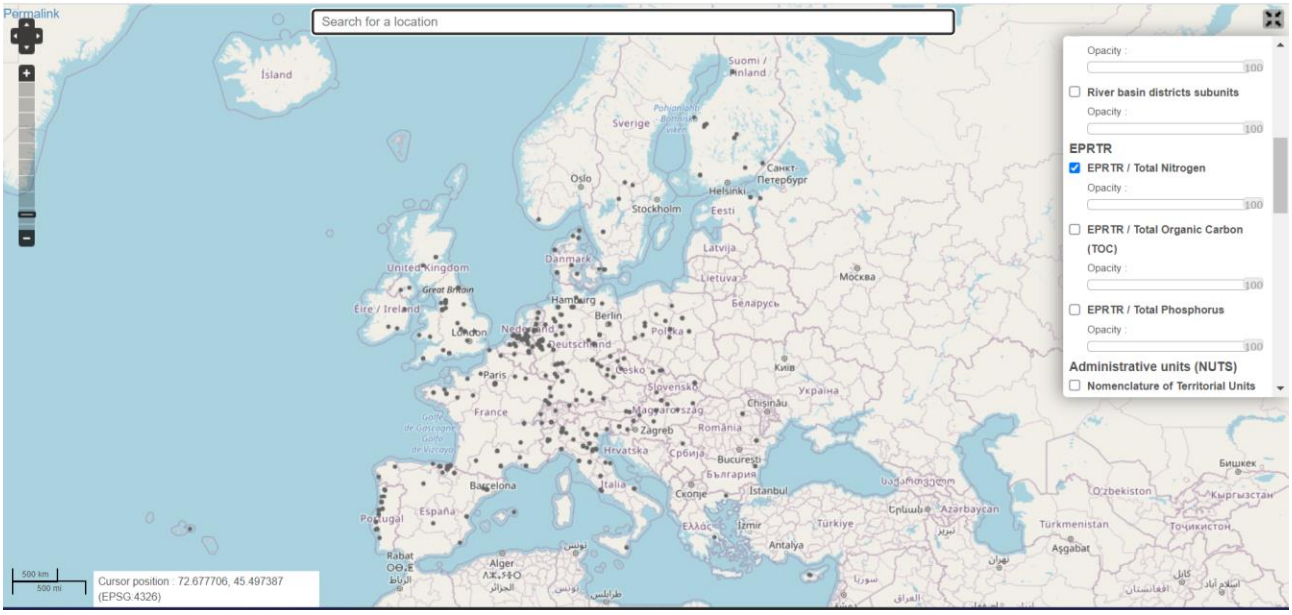

Figure 3-9: EU-MS map of E-PRTR data for Total Nitrogen (Urban Waste Water Treatment Directive (UWWTD) website for Italy, 2022)

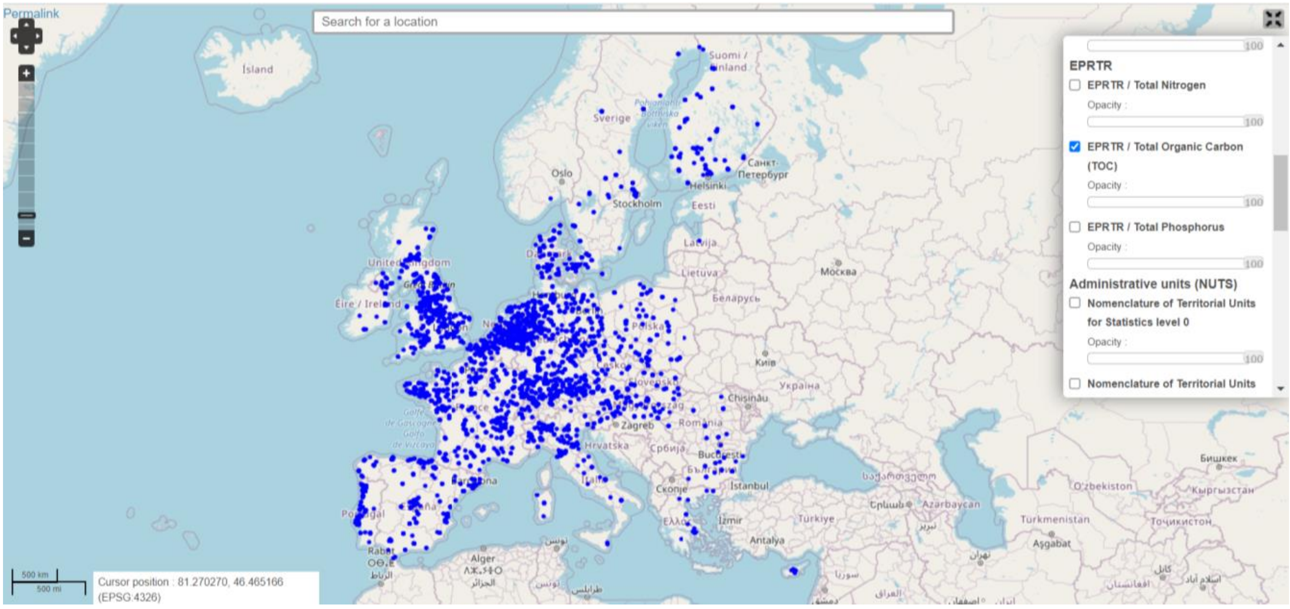

Figure 3-10: EU-MS map of E-PRTR data for Total Organic Carbon (Urban Waste Water Treatment Directive (UWWTD) website for Italy, 2022)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 101000752.

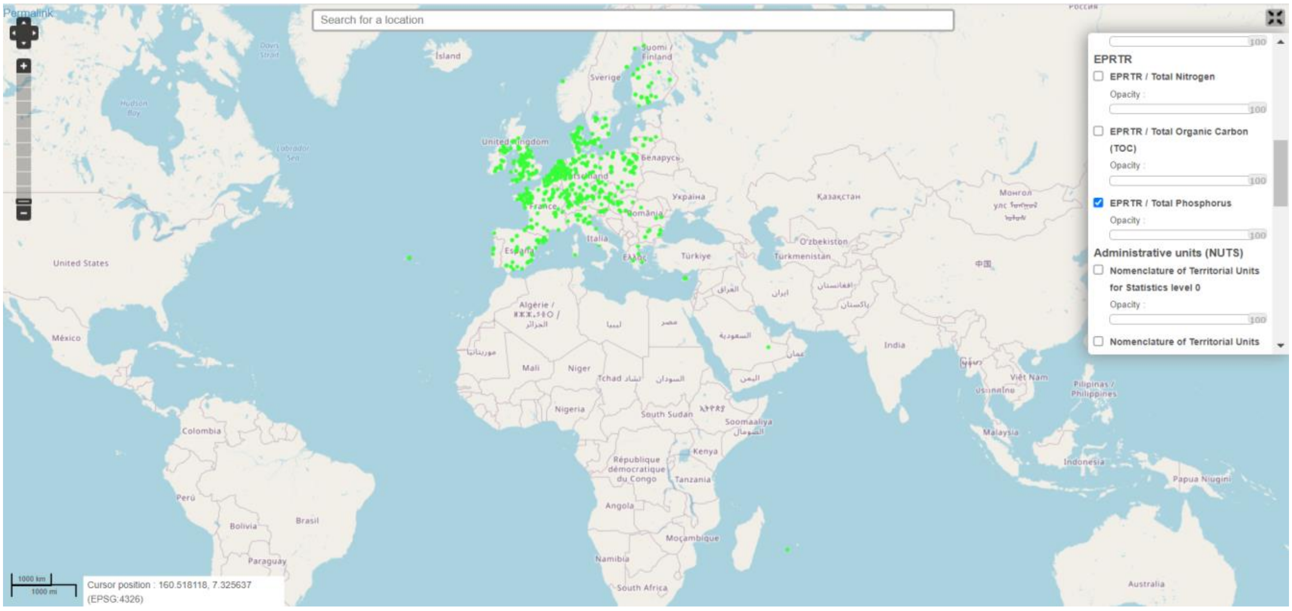

Figure 3-11: EU-MS map of E-PRTR data for Total Phosphorus (Urban Waste Water Treatment Directive (UWWTD) website for Italy, 2022)

The collected data regarding Figure 3-9 to Figure 3-11 derive from the European Pollutant Release and Transfer Register (E-PRTR). 'E-PRTR provides easily accessible key environmental data from industrial facilities in European Union Member States. The E-PRTR also covers Iceland, Liechtenstein, Norway, Switzerland, Serbia and the UK. Subject to reporting thresholds, each industrial facility provides information to their national authority on the quantities of pollutants released to air, water and land. This data covers 91 key pollutants including heavy metals, pesticides, greenhouse gases and dioxins. There is also data on off-site transfers of waste and WW and information on releases from diffuse sources. The E-PRTR is an important contribution to transparency and public participation in environmental decision-making.' (European Commission - Environment, 2022)

3.2 The European Industrial Emissions Portal

As presented in Figure 3-12, the European Industrial Emissions Portal (European Environment Agency, 2022b) has mapped the 'Waste and WW management' facilities in EU-MS. These facilities concern urban WW treatment plants (with the exception of certain cases that can be identified when investigating a certain region with a certain purpose). In the scope of Section 3, the European Industrial Emissions Portal is a tool of assistance in WalNUT's attempt to locate, present and evaluate the valorisation capacity of urban WW -based economically prime important nutrient resource-based products for the manufacturing of bio-based fertilisers. The primary idea is that there is a conflict between the legislation for phosphorus as a resource in fertiliser manufacturing or as a pollutant in WW treatment.

When exploring the data in the European Industrial Emissions Portal by pollutant, one can select the EU-MS of interest, the medium (air or water: water in the case of WalNUT project), the pollutant (Table 3-3) and the sector. Regarding the pollutants, apart from carbon dioxide (CO_2) and monoxide (CO) and methane (CH_4) the tracing of the rest of the pollutants can be beneficial in the scope of Nutrient Recovery from Urban and Industrial WW for they can either be used in bio-based fertiliser manufacturing as primary/secondary macro-components or micro-components or their presence will need to be monitored and their concentration maintained within the imposed limits by Reg. (EU) 2019/1009 in the attempt of the facility to recover the nutrients from the WW before disposal (Figure 3-8) or valorise the WW (influent or effluent) for the manufacturing of bio-based fertilisers.

Table 3-3: List of pollutants mentioned in the European Industrial Emissions Portal that are of interest in the manufacturing of Bio-based fertilisers.

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Pollutants in the European Industrial Emissions Portal
Ammonia (NH_3),
Arsenic and compounds (as As)
Cadmium and compounds (as Cd)
Chromium and compounds (as Cr)
Copper and compounds (as Cu)
Lead and compounds (as Pb)
Mercury and compounds (as Hg)
Nickel and compounds (as Ni)
Nitrogen oxides (NOX)
Nitrous oxide (N_2O)
Non-methane volatile organic compounds (NMVOC)
Nonylphenol and Nonylphenol ethoxylates
Particulate matter (PM10)
PCDD + PCDF (dioxins + furans) (as Teg)
Polycyclic aromatic hydrocarbons (PAHs)
Sulphur oxides (SOX)
Total nitrogen
Total organic carbon (as total C or COD/3) (TOC)
Total phosphorus
Zinc and compounds (as Zn)

The European Industrial Emissions Portal (European Environment Agency, 2022b) covers over 60,000 industrial sites from 65 economic activities across Europe in Table 3-4. Among these are the urban WW treatment plants covered in Section 3.2. The mapping of 'Intensive livestock production and aquaculture' is out of the scope of WalNUT.

In the European Industrial Emissions Portal (European Industrial Emissions Portal, 2022) one can have access to waste and WW management sector in Table 3-4 in the EU. The latest presented data are regarding 2020.

Table 3-4: The sectors of the activities mapped in the Industrial Emissions Portal

Sectors
Energy
Production and processing of metals
Mineral industry
Chemical industry
Waste and WW management
Paper and wood production and processing
Intensive livestock production and aquaculture
Animal and vegetable products from the food and beverage sector
Other activities

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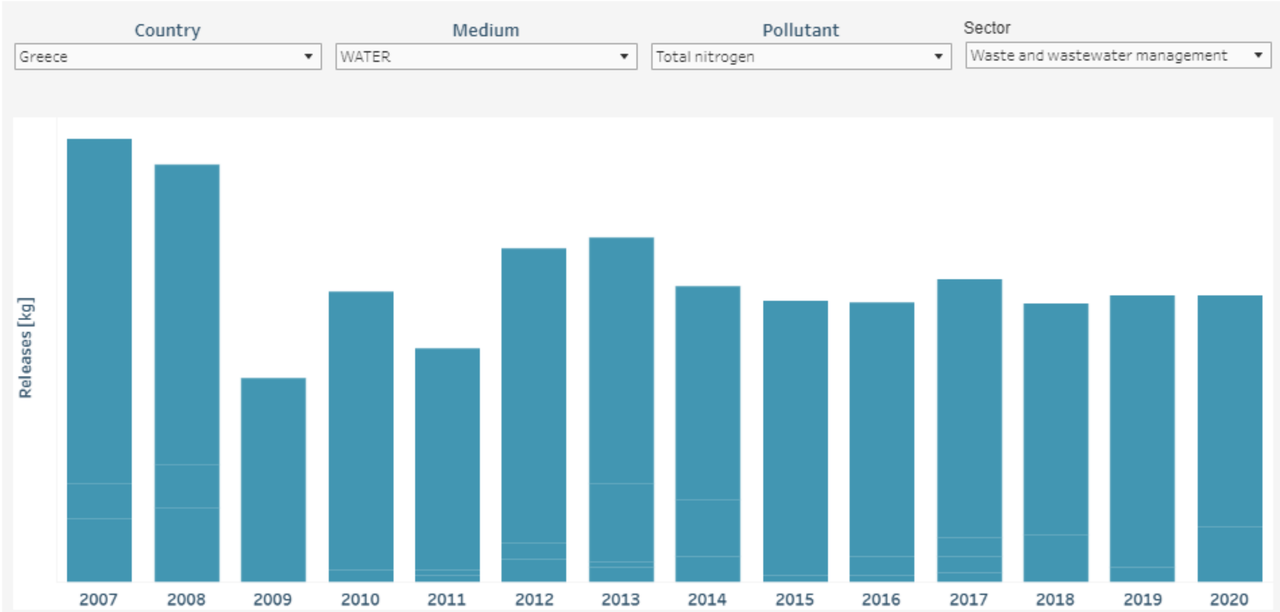
This section provides a close-up view at country level on the most common released pollutants and the total releases at the facility level. By hovering over the bars one can find out the contribution of each facility to the emissions of the selected pollutant in the country of their selection. When clicking on the emissions values in the table below the chart (Figure 3-12), they will find a link to the website where the facility is located (clicking this link opens a new window).



		2012	2013	2014	2015	2016	2017	2018	2019	2020
EYDAP S.A. - PSYTTALIA WASTEWATER TREATMENT PL..	PSYTTALIA	2,670	2,790	2,420	2,290	2,210	2,440	2,620	2,660	2,610
EYATH S.A. – SINDOS WASTEWATER TREATMENT PL..	SINDOS	0,525	0,531	0,637	0,465	0,460	0,473	0,345	0,406	0,419
EYDAP S.A. - METAMORFOSI WASTEWATER TREATMENT PL..	ATHENS	0,130	0,220	0,107	0,185	0,203	0,217	0,185	0,172	0,153
GREATER VOLOS AREA WASTEWATER TREATMENT PL..	VOLOS	0,120	0,132	0,125	0,172	0,211	0,190			
WASTEWATER TREATMENT PLANT OF CHANIA	CHANIA	0,072	0,064	0,065	0,069	0,083	0,102			0,062
HERAKLION WASTE WATER TREATMENT PLANT	HERAKLION									
PATRAS WASTE WATER TREATMENT PLANT	PATRA	0,166	0,166							
	PATRA									
	PATRAS									
SANITARY LANDFILL VOLOS	VOLOS	0,093								
ARGOS – NAYPLIO – NEA KIOS WASTEWATER TREATMENT PL..	NEA KIOS									

Figure 3-12: Close-up view of Greece on the release of the registered WW treatment plants on nitrogen (European Industrial Emissions Portal, 2022)

In the case of large-scale urban WWTP (Figure 3-12) the ability to sell recovered P is a secondary economic driver for Nutrient Recovery. The main incentive is P removal to avoid valves and pipes damage by struvite precipitation and reduce the OPEX. Typically, the expenses associated with struvite precipitation issues inside a medium-sized WWTP (25 MGD = 25 106 gallon per day multiplied by 4.54 litres per gallon is 113,500,000 litres per day) surpass US $100,000 or 83,366.68 € per year. Depending on the size of the treatment plant, the overall savings could range from 1,470 € to 7,350 € per 4,540 m^3 when accounting for the reduction in operational and maintenance costs brought on by struvite scaling, including chemical addition for chemical struvite precipitation, manpower, and maintenance costs (Achilleos, Roberts, & Williams, 2022). The cost savings is calculated to be 0.97 €/m^3 of waste water if a mean price is considered.

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In the portal, it is stated that the threshold for total nitrogen release in the water is 50,000 kg/year. Accordingly, industries do not have to report total phosphorus emissions as long as they release under 5,000 kg N/year. In order to calculate the dimension of the P-leakage, it is enough to mention that for a 150 bushel per ha soybean crop, there is a 53.8 kg P/ha demand for P_2O_5 fertiliser to maintain P levels. Introducing the soybean cultivator to an approximate P- recovering industry would guarantee the autonomy of ~100 ha for a year.

According to the European Industrial Emissions Portal, in 2020, in France, the leakage of total nitrogen and phosphorus in the water bodies from industrial emissions (Table 3-5) surpassed 41,777 t and 228 t, respectively. The number of industries is also mentioned in the right column of Table 3-5 for a more explicit interpretation of the data of N and P emissions. Table 3-5 reports on both urban and industrial waste water-based N and P emissions in order to pinpoint that 38,924 t of N and 2,961 t of P were emitted during urban waste and WW treatment practices in the status of France in 2020. Such data can be accessed (European Industrial Emissions Portal, 2022) to better interpret the necessity for the inclusion in 'other practices' of valorisation of WW – based products as fertilisers as a way to avoid and thus limit N and P emissions to such an extent in all EU-MS, as an outcome of the implementation of WalNUT's delivered pilot plants.

Table 3-5: Industrial N and P emissions in France in 2020 (European Industrial Emissions Portal, 2022).

Nutrient/Pollutant	Industrial sector	Emission (kg)	No of industries
Total N	Urban Waste and Waste water Treatment	38,924,400	21
Total P	Urban Waste and Waste water Treatment	2,961,240	66
Total N	Chemical Industry	2,147,800	13
Total P	Chemical Industry	32,400	2
Total N	Energy Sector	414,500	4
Total P	Energy Sector	38,140	4
Total N	Paper and Wood production and processing	867,000	4
Total P	Paper and Wood production and processing	99,900	5
Total N	Production and Processing of Metals	186,300	2
Total P	Production and Processing of Metals	–	–

Moreover, the so-called pollutants reported in the (European Industrial Emissions Portal, 2022) (Table 3-3) are actually not-valorised nutrients with the potential to be used as bio-fertilising products. The EU's need to be independent of fertilising products' imports was highlighted in Section 2.1. In matters of supply and demand, as demand increases, uncritical disposal of economically prime important nutrient resource-based products will no longer be a sustainable option. And this effort cannot be differentiated between the public (urban WW) and private (industrial WW) sectors. One could assume that enforcement of stricter effluent disposal criteria to implement N and P release reporting even from small-scale industries by the public administration would facilitate the transition to gradual obligation to their recovery thus the implementation of Nutrient Recovery options in WWTP and the synthesis of WW-based bio-fertilisers (in addition to the re-use of not-valorised nutrients) and definitely avoid their disposal. Such legal obligations for the recovery of nutrients from WW streams, along with others that will be further discussed in D1.4 'Barriers on BBF development' would guarantee the valorization of economically prime important nutrient resource-based products as bio-based fertilisers.

Phosphate rock is the raw material used to make most commercial phosphate fertilisers on the market. Phosphate rock cannot be used as a fertiliser because it is insoluble, but the phosphorous compounds it contains can be used to make fertilisers. In the past, ground phosphate rock itself was used as a phosphorus source in acidic soils. Black phosphorus is the most stable form. Atoms are bonded like graphite in wavy layers. Red phosphorus is more thermally stable than white phosphorus. White phosphorus is a white waxy solid. It is soft and can be cut with a knife. It is also called yellow phosphorus because it turns yellow when exposed to light. Phosphate fertilisers are made by adding acid to crushed or powdered rock phosphate. Using simple or ordinary sulfuric acid, phosphate (SSP) with a phosphorus content of 16-21% is formed as phosphorus pentoxide (P_2O_5). There are many commercially available phosphorous fertilisers such as phosphate rock, phosphoric acid, calcium orthophosphate, ammonium phosphate, ammonium polyphosphate and phosphate nitrate.

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'In 2020, the top exporters of phosphorus were Vietnam ($251M), Kazakhstan ($213M), United States ($39.8M), Poland ($25.8M), and the Russian Federation ($21.1M). In 2020, the top importers of phosphorus were India ($115M), Germany ($95.2M), Poland ($72.9M), Japan ($62.9M), and Czech Republic ($38.3M)' (Kanbrik.com, 2022).

'In 2019, top importers of phosphorus from Kazakhstan were the European Union ($152,213.64K, 59,520,600 Kg), Germany ($58,334.15K, 21,690,900 Kg), Czech Republic ($47,156.45K, 19,305,600 Kg), Poland ($47,131.88K, 18,576,100 Kg), United States ($18,474.06K, 6,427,430 Kg)' (World Integrated Trade Solution, 2022).

In 2019, 'European Union imports of phosphorus were $220,277.73K. The European Union imported phosphorus from Kazakhstan ($152,213.64K, 59,520,600 kg), Vietnam ($57,309.52K, 17,996,700 kg), China ($7,042.31K, 1,537,360 kg), Japan ($1,426.72K, 404,762 kg), India ($1,210.46K, 237,727 kg), the United States ($862.78K, 227,052 kg), the Russian Federation ($12.67K, 2,459 kg) Australia ($3.45K, 1,278 kg)' (World Integrated Trade Solution b, 2022).

In Europe, phosphorus (71% of EU supply from Kazakhstan), phosphate rock (24% of EU supply from Morocco) and magnesium (93 % of EU supply from China) are listed as 'Critical Raw Materials' given their economic importance and risk of supply shortage (Publications Office of the European Union, 2022). Increase in nutrients' demand due to the global population increase, the finite area of arable land and the decreased supply due to the already reported physical depletion of non-renewable mineral resources will lead to a nutrient market price increase that will ultimately render the recovery of nutrients inevitable. This scenario could evolve in the close future (e.g. in Canada in 2008, there was an eightfold price increase from CAD 50 per ton P to CAD 400 per ton P, due to an expansion of mortgage credit that resulted in the subprime crisis (2007-2010)). Simultaneously, the current status of NR practices is very limited since the price of nutrients recovered from WW streams does not make NR practices feasible/sustainable/profitable/competitive and WW producers/WWTP cannot be motivated to invest.

Regarding phosphorus recovery however, one has to keep in mind that elemental phosphorus refers to the specific forms of the element phosphorus (P) in which it is produced as an isolated element (P 4) in dedicated electrothermal reducing furnaces (in different forms: white/yellow or red phosphorus). White/yellow and red phosphorus are not used for the production of fertilisers. Phosphate rock is a raw material for fertiliser production. 84% is exported from non-EU countries (20% from the Russian Federation and 5% from Syria which is also controlled by Assad government, the Russian Federation and Iran). The low cadmium (20-25 mg/kg and low uranium) the Russian Federation magmatic phosphate rock is imported from Kola (Russia) (20 %) and another 5 % is imported from Syria. The high cadmium (60-200 mg/kg) and high uranium (10-210 mg/kg) Morocco sedimentary phosphate rock is imported at the level of 24% and it will most likely not be possible to use after July 16th, 2022 as of EU (Reg) 2019/1009. Cadmium removal of this material is extremely costly and technically challenging, as well as demanding in high amount of process sweet water, that is not available in the Sub-Sahara.

3.3 Industrial Reporting Database

The European Environment Agency (EEA) in collaboration with the European Environmental Information and Observation Network gather and assess data on a wide range of topics regarding the environment. The target is 'to provide sound, independent information on the environment for those involved in developing, adopting, implementing and evaluating environmental policy, and also the general public'.

The Industrial Reporting Database is the result of this fully functioning cooperation. The accessible files represent the status of the EEA Industrial Reporting database as of 22 March 2022. The publicly accessible Industrial Reporting Database (European Environmental Agency, 2022c) makes the mapping of bio-based (nutrient rich) input streams possible since the registered companies (Table 3-6 to Table 3-8) are potential candidates for the implementation of P and/or N – recovery. The reporting of the data includes ages 2007 to 2020.

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An extensive evaluation of bio-based input streams has been performed by numerous sources. Another option of EU-MS is the incineration or even co-incineration of products that derive after the treatment of urban and industrial WW, Sewage sludge and Food (in the scope of the WalNUT project). Incineration ash and sewage sludge ash are rich in phosphorus and more than 90 % of it can be valorised towards the production of an adequate phosphate fertiliser. Attention must be paid to the purification stage due to the accumulative effect of heavy metals (Cu, Ni, Cd) on soil contamination in case a dewatered phosphate sludge (after for example the precipitation of phosphates with lime water) is used as a bio-based fertiliser (Franz, 2007). The industrial Reporting Database provides access to the waste incineration (WI) and waste co-incineration (co-WI) plants in EU-MS. In Table 3-9, Denmark will be used as an example of the presentation of WI plants registered in 2020.

'This database contains identification and administrative information reported to the EU Registry on Industrial Sites. It includes facilities involved in activities listed in Annex I of the European Pollutant Release and Transfer Register (E-PRTR) Regulation and installations involved in activities listed in Annex I of the Industrial Emissions Directive (IED), with additional granularity on installations subject to Chapters III and IV of the IED (large combustion plants (LCPs), waste incinerators (WIs) and co-waste incinerators (co-WIs). The database creates a (geographical) relationship between entities covered by the E-PRTR Regulation and the IED. The database brings together thematic data formerly reported separately under Article 7 of the E-PRTR Regulation and IED Article 72. It includes annual facility releases to air, water and land of pollutants listed in Annex II of the E-PRTR Regulation (above Annex II release thresholds only) as well as off-site transfers in waste-water. Off-site transfers of waste are also included (above Article 5 thresholds only). The database also includes plant-by-plant data on LCPs including rated thermal input, annual energy input and emissions of SO_2, NOX and dust. This dataset contains the location and administrative data for the largest industrial complexes in Europe, releases and transfers of regulated substances to all media, waste transfers as well as more detailed data on energy input and emissions for large combustion plants. These data are reported to EEA under Industrial Emissions Directive (IED) 2010/75/EU Commission Implementing Decision 2018/1135 and the European Pollutant Release and Transfer Register (E-PRTR) Regulation (EC) No 166/2006 Commission Implementing Decision 2019/1741. The dataset brings together data formerly reported separately under E-PRTR Regulation Art.7 and under IED Art.72. Additional reporting requirements under the IED are also included. It contains by EU Member States, Iceland, Liechtenstein, Norway, Serbia, Switzerland and the United Kingdom. The provided files represent the status of the EEA Industrial Reporting database as of 22 March 2022.' (European Environmental Agency, 2022c).

Regarding 2020, the latest accessible version uploaded on April 25th 2022 ((European Environmental Agency, 2022c) of the accessible data is organised as follows:

- Total releases at national level into water
- Total release at E-PRTR Sector (check Table 3-4) into Water
- Total release at E-PRTR Annex I Activity into Water
- Detailed releases at facility level with E-PRTR Sector and Annex I Activity detail into Water
- Total pollutant transfer
- Detailed pollutant transfer at facility level with E-PRTR Sector and Annex I Activity detail
- Total waste transfer
- Detailed waste transfer at facility level with E-PRTR Sector and Annex I Activity detail
- Detailed information on WI and co-WI

The mapping also includes the 'Total information on Installations' file

The accessible data will be presented for Belgium, Portugal and Hungary. In Table 3-6, Table 3-7 and Table 3-8 one can find the addresses of all the registered Urban WW Treatment Plants in the Waste and WW management sector. Regarding the non-hazardous waste and the selection of recovery as a path of treatment, the registrations and the quantities are as follows:

Table 3-6: Place of Origin and quantity (kg) of the non-hazardous WW that is managed in materials and resources recovery facilities in Belgium (European Environmental Agency, 2022c)

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Place of Origin in Belgium	2016	2017	2018	2019	2020
Forest	28,900	30,400	29,000	25,000	24,000
Oupeye	20,900	19,400	19,300	21,100	22,500
Bruxelles	23,500	20,200	23,900	21,400	18,100
Mouscron		13,406	1,3202	14,670	13,250
Liege		9,190	8,750	9,660	9,300
Pepinster	7500	8,150	7,960	7,180	8,530
Montignies-sur-Sambre		7,222	6,775	7,086	7,170
Aiseau-Presles		2,941	4,501	4,040	6,246
Rosières		4,300	4,050	4,057	4,592
Wavre		2,861	2,411	1,811	3,532
Wasmuel		1,760	1,490	10,600	3,280

Table 3-7: Place of Origin and quantity (kg) of the non-hazardous WW that is managed in materials and resources recovery facilities in Portugal (European Environmental Agency, 2022c)

Place of Origin in Portugal	2016	2017	2018	2019	2020
Lisboa		55,100	55,900	54,200	46,500
Cascais			23,900	25,400	26,500
Porto		20,300	20,900	17,500	22,200
Serzedelo GMR		19,300	18,900	17,800	18,500
Coimbrão		7,230	7,980	12,100	17,900
Fradelos VNF		18,600	17,300	18,800	17,500
Frielas		13,800	13,700	14,500	13,500
Corroios			8,800	10,300	11,000
Cacia		9,230	9,270	10,600	10,200
Lisboa		5,940	11,300	9,360	9,790
Lisboa		10,900	11,500	11,000	9,550
Santo Tirso		8,260	10,800	10,100	8,680
Alverca do Ribatejo		5,860	5,140	7,080	7,470
Gafanha da Encarnação		4,930	4,270	6,070	6,960
Lordelo GMR		8,140	7,150	7,080	6,810
Paramos		3,830	2,690	6,260	6,320
Braga	4,620	6,970	8,010	7,470	6,050
Matosinhos			4,700	6,860	5,760
Vila Nova de Gaia		18,800	5,850	12,200	5,640
São João da Talha		5,060	4,220	4,620	5,490
Setúbal		4,190	5,170	6,690	5,470
V Frescainha (S Pedro)		11,900	12,100	9,890	5,330
Faro					4,730
Coimbra		3,550	6,320	8,500	4,110
Porto		5,390	5,640	5,150	4,060
Almada		4,880	8,800	3,900	3,960
Albufeira	5,120	6,560	7,140	6,880	3,890
Guia ABF	4,030	4,750	5,250	4,860	3,410
Portimão			1,860	5,570	3,210
Quarteira	4,340	4,190	4,500	4,290	2,920
Tougues		2,790	2,370	3,090	2,860
Vila Real Santo António		2,730	3,270	3,580	2,610

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Quinta do Conde		2,350			2,510
Lavradio		5,490	8,510	3,870	2,330

Table 3-8: Place of Origin and quantity (kg) of the non-hazardous WW that is managed in materials and resources recovery facilities in Hungary (European Environmental Agency, 2022c)

Place of Origin in Hungary	2016	2017	2018	2019	2020
Miskolc	371,000	446,000	373,000	325,000	317,000
Budapest 21. ker.	60,100	55,100	59,500	62,200	57,900
Budapest 04. ker.			49,900	50,300	50,300
Győr	58,100	50,900	10,900	11,100	11,800
Székesfehérvár	10,500	14,800	12,200	9,450	10,700
Nyíregyháza	10,600	11,400	11,700	12,200	10,200
Kaposvár		16,200	20,200	15,300	7,620
Pápa	6,230	7,500	7,850	7,250	7,000
Szolnok	6,210	6,330	6,570	6,660	6,840
Szentes					4,180
Zalaegerszeg					3,020
Vác	2,700			2,490	2,460

In Table 3-9, Denmark is used as an example of the presentation of WI plants registered in 2020. Nutrient recovery can be applied on the incineration ash in WI plants with nutrients and nutrient content depending on the origin of the waste or waste water (Krüger & Adam, 2015).

Table 3-9: Place of Origin of WI facility and Permitted capacity (t) of non-hazardous waste in Denmark (European Environmental Agency, 2022c)

Place of Origin of WI facility in Denmark	Permitted capacity (t) of non-hazardous waste
Slagelse	6
Næstved	4.5
Næstved	9.2
Aarhus N	8
Aarhus N	19
Roskilde	20
Roskilde	25
Hjørring	3.8
Hjørring	7.2
København K	5.9
Hvidovre	6
Rønne	2.75
Esbjerg Ø	24
Kolding	9
Kolding	10.5
Odense C	8.1
Odense C	14.4
Horsens	5.7
Frederikshavn	5
Grenaa	2.5
Hammel	2.3
Hammel	4.1
København S	35

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Hørsholm	11
Hørsholm	10
Aars	3.5
Aars	5
Thisted	6.3
Holstebro	10
Nykøbing F	4.6
Nykøbing F	10.2
Aalborg Øst	11
Aalborg Øst	22
Skanderborg	4.5
Skanderborg	5.5
Svendborg	7.2
Sønderborg	8
Glostrup	32
Glostrup	37.2

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Key results

- Section 3 is a detailed description of the available databases and a guide to navigate them efficiently to map the Urban WW as a bio-based input stream in the EU27-matrix.

- There are ppublicly accessible databases with formal data published by the European Commission that The European Pollutant Release and Transfer Register has assembled under the 'Urban WW Treatment map' (European Environment Agency, 2022a) which is accompanied by the registration of pollutants (not valorised nutrients) emissions in the European Industrial Emissions Portal (Industrial Reporting Database, 2022). Last but not least, the Industrial Reporting Database also comes in handy in the mapping of bio-based input with details about the location and the waste and waste water quantity and mode of management (Table 3-5 to Table 3-9).

- In the European Industrial Emissions Portal (Table 3-5) it was identified for a representative example of EU-Member State that in 2020 the N and P emissions from Waste and WW treatment (38,924,400 and 2,961,240 kg, respectively) were many orders of magnitude higher than the highest in emissions industry (the chemical industry) N and P emissions: 2,147,800 and 32,400 kg, respectively.

- Practicing N and P Recovery in the registered WW input streams can allow alternative N and P sources to be used for fertiliser manufacturing. The latter do not need to be put through purification procedures that are as intensive as those necessary for the high concentration cadmium-uranium phosphate rock (due to rapid consumption), which is currently the main source for P in manufactured fertilisers.

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4 EU27 matrix for bio-based input streams (Industrial WW)

4.1 The European Industrial Emissions Portal

In the scope of Section 3, the European Industrial Emissions Portal is a tool of assistance in WalNUT's attempt to locate, present and evaluate the valorisation capacity of urban WW -based economically prime important nutrient resource-based products for the manufacturing of bio-based fertilisers.

The selection of 'total phosphorus' allows for the recognition of emission in the water bodies of phosphorus regardless the form.

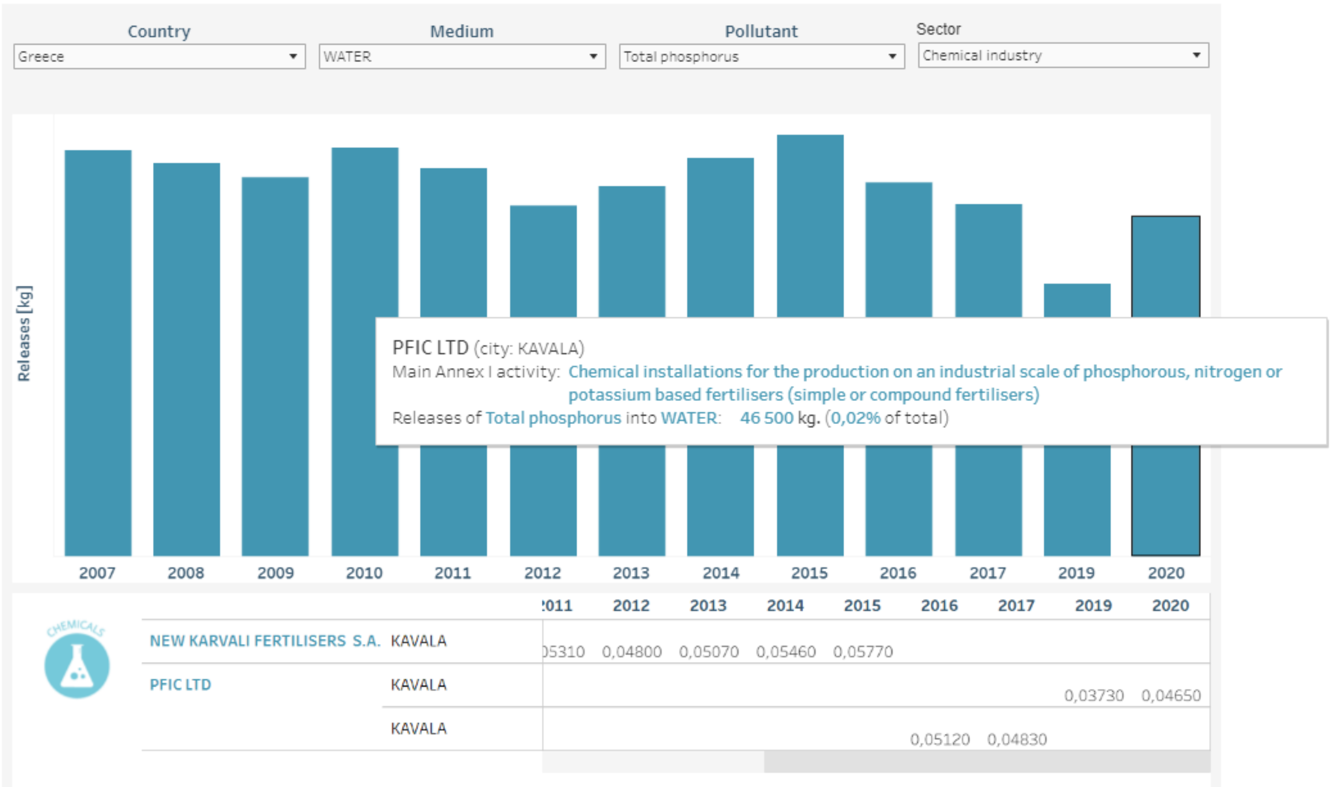

Figure 4-13: Close-up view of Greece on the release of the registered chemical industries on Total phosphorus (European Industrial Emissions Portal, 2022)

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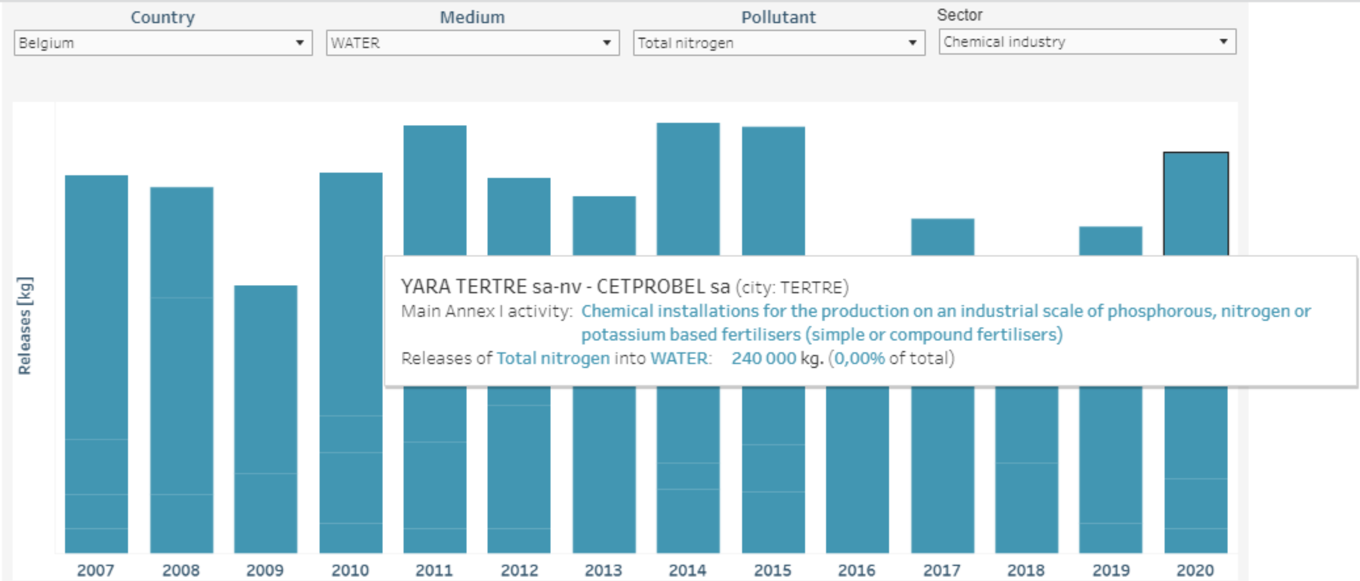

		'012	2013	2014	2015	2016	2017	2018	2019	2020
YARA TERTRE sa-nv - CETPROBEL sa	TERTRE	4650	0,3290	0,2990	0,2190	0,1980	0,1980	0,2410	0,2340	0,2400
BASF ANTWERPEN	Antwerpen	0965	0,1450	0,0969	0,1090	0,1210	0,1360	0,1260	0,0562	0,1810
5N PLUS BELGIUM SA	TILLY	0861	0,1140	0,2010	0,3250	0,1510	0,2310		0,3180	0,2470
PRINCE ERACHEM sprl	SAINT-GHISLAIN	0722	0,0817	0,1010	0,0962	0,0654	0,0524			
BP CHEMBEL	Geel	0509	0,0643	0,0540	0,0622	0,0689	0,0707	0,0588	0,0616	
PB LEINER VILVOORDE	Vilvoorde			0,1310	0,0657					
COVESTRO	Antwerpen									
PRINCE Minerals sprl	SAINT-GHISLAIN									0,1020
TESSENDERLO GROUP HAM	Ham									
TIMAC AGRO BeLux SA	Marchienne au Pont									0,0518
BAYER ANTWERPEN (LINKER OEVER)	Kallo (Kieldrecht)									

Figure 4-14: Close-up view of Belgium on the release of the registered chemical industries on Total nitrogen (European Industrial Emissions Portal, 2022)

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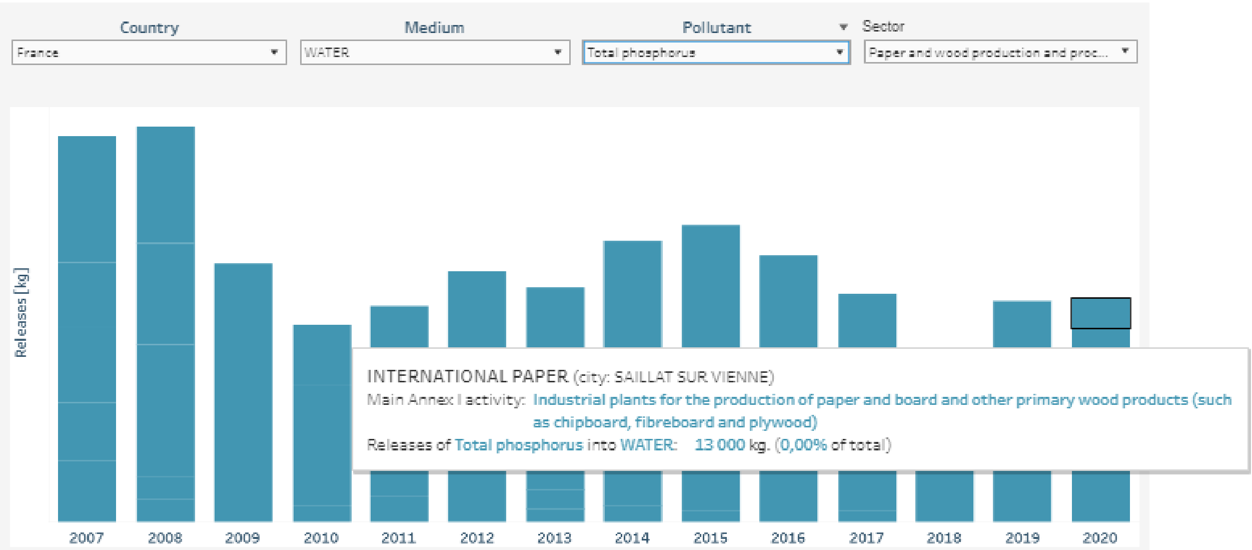

		'012	2013	2014	2015	2016	2017	2018	2019	2020
RAYONIER A.M. TARTAS SAS	TARTAS	)5230	0,03940	0,04980	0,05400	0,05340	0,05230	0,03370	0,02580	
INTERNATIONAL PAPER	SAILLAT SUR VIENNE								0,01250	0,01300
	SAILLAT-SUR-VIEN..	)2330	0,02130	0,02450	0,02140	0,01270	0,01260	0,01220		
SMURFIT KAPPA CELLULOSE DU PIN	BIGANOS	)1100	0,01740	0,02090	0,02480	0,02090	0,01070	0,01260	0,01210	0,01310
SMURFIT KAPPA PAPETERIE DE SAILLAT	SAINT-JUNIEN	)1490	0,01220	0,01570	0,01250					
NORSKE SKOG GOLBEY	GOLBEY	)1100	0,00869	0,00788	0,00555	0,00755	0,00725		0,00549	
DA ALIZAY	ALIZAY									
FIBRE EXCELLENCE SAINT-GAUDENS	SAINT-GAUDENS					0,01230	0,01420	0,01390		
	ST GAUDENS								0,01690	0,01220
FIBRE- EXCELLENCE	TARASCON								0,02600	0,02940
RAYONIER A.M. TARTAS	TARTAS									0,03220
EMIN LEYDIER CHAMPBLAIN	SAINT-VALLIER				0,00984	0,01280	0,00506			
SAICA PAPER FRANCE	VENIZEL									
STORA ENSO CORBEHEM	CORBEHEM									
RDM LA ROCHETTE SAS	ROCHETTE			0,00718	0,00507					
PAPETERIES DE LANCEY	VILLARD-BONNOT									
EUROPAC PAPETERIE DE ROUEN	SAINT-ETIENNE-DU..		0,00588							
SAICA PAPER CHAMPBLAIN	SAINT-VALLIER							0,00548		
GEMDOUBS	NOVILLARS									

Figure 4-15: Close-up view of France on the release of the registered paper and wood production and processing industries on Total phosphorus (European Industrial Emissions Portal, 2022)

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4.2 Industrial Reporting Database

According to the 'Detailed waste transfer at facility level with E-PRTR Sector and Annex I Activity detail' described in Section 3.3 one can locate for the sector of their interest (according to Table 3-4) the non-hazardous industrial waste and WW that are transferred in materials recovery centers and are not disposed of. This tool will be of great assistance in the mapping of nutrient recovery facilities.

Some random examples will be presented:

In Portugal, there are in total 20 registrations between 2016 and 2020 as Chemical installations for the production on an industrial scale of basic inorganic chemicals: salts, such as ammonium chloride, potassium chlorate, potassium carbonate, sodium carbonate, perborate, silver nitrate in the 'Chemical industry' sector. In Table 4-10 one can see the ones (eight) that produce non-hazardous waste and waste water. The repetition of some companies (e.g., Specialty Minerals Portugal) refers to different installations of the same company. The location details of each installation are available in (European Environmental Agency, 2022c). Between 2016 and 2020 some installations have applied recovery practices (noted are 'R' in Table 4-10) while the rest dispose of their waste and waste water (noted as 'D' in Table 4-10). In 2020 only two of them recovered materials from their waste and WW. The recovery practices (the technologies, the recovered nutrients or products) are not specified. In addition to publishing the data for the current status (2022) of waste management of the registered companies it is to be expected that in the future, the published information will include the not valorized nutrient recovery practices as well.

Table 4-10: Chemical Industry registration, Place of Origin and quantity of the non-hazardous WW that is managed in materials and resources recovery facilities (R) or that is disposed of (D) in Portugal (European Environmental Agency, 2022c)

Chemical Industry	Place of Origin in Portugal	Non hazardous	2016	2017	2018	2019	2020
Omya, SA	Setúbal	R				3,680	4,240
Specialty Minerals Portugal	Figueira da Foz	R				2,910	3,510
Omya, SA	Setúbal	D				1.08	0
Specialty Minerals Portugal, Especialidades Minerais, S.A.	Figueira da Foz	R	4,520				
Specialty Minerals Portugal, Especialidades Minerais, S.A.	Figueira da Foz	R		3,790	3,490		
Omya, SA	Soure	D		34.5	15.7		
Omya, SA	Soure	R		4,200	5,010		
Omya, SA	Soure	R	5,640				

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In the WalNUT scope, the mapping of the bio-based input streams as nutrient-rich candidates for nutrient recovery include agri-food waste water. In the Industrial Reporting Database (European Environmental Agency, 2022c) in the animal and vegetable products from the food and beverage sector, one can locate such streams. As a representative example, in France (Table 4-11), in the animal and vegetable products from the food and beverage sector, the attempt for the registration of recovery practices in the treatment and processing of milk was very intensive in 2020 as compared to the noticeably fewer registrations in 2019. Hopefully, in the following attempts, all types of industries will be represented in the database apart from the registration of treatment and processing of milk.

Table 4-11: Treatment and processing of milk registrations, Place of origin and quantity (kg) of the non-hazardous WW that is managed in materials and resources recovery facilities in France (European Environmental Agency, 2022c)

Treatment and processing of milk	Place of Origin in France	2019 (kg)	2020 (kg)
Euroserum	St Martin Belle Roche	3,190	14,432
Eurial Ultra Frais	Gruchet Le Valasse		13,903
Groupe Sodiaal B	Carhaix Plouguer		12,487
Novandie (Sas)-(Ex Générale Uitra Frais)	Vieil Moutier		9,025
Laiterie Du Val D'ancenis	Ancenis	8,450	8,756
Armor Proteines	St Brice en Cogles	9,939	7,674
Milleret Fromagerie	Charcenne		6,918
Compagnie Des Fromages & Richesmonts Sca	Ducey		6,856
Ingredia	St Pol Sur Ternoise	5,035	6,622
Bongrain Gerard (Usine)	Illoud		6,487
Lacto Serum France	Verdun		6,011
Danone Produits Frais France	Bailleul		5,856
Triballat Noyal	Noyal Sur Vilaine	4,973	5,505
Fromagerie de Clerval	Clerval	4,301	5,366
Yoplait Production France - Nobleval	Moneteau		4,915
Compagnie des Fromages Et Richesmonts	Benestroff		4,887
Ysco France	Argentan	1,911	4,820
Entremont Sodiaal	Peigney		4,749
Candia	Awoingt		4,596
Les Fromageries Occitanes	St Mamet La Salvetat		4,150
Lactalis Nestle Ultra-Frais Marques SA	Vallet		4,092
Les Fromageries Occitanes	St Flour	4,320	3,980
Societe Laitiere de Retiers	Retiers		3,820
Candia/Yoplait	Vienne		3,564
Nestle France SAS	Boue		3,534
Eurial Food Service Et Industry	Lucon		3,527
Haagen Dazs	Tilloy Les Mofflaines	3,522	3,434
Fromageries Perreault	Chateau Gontier	2,801	3,414
Societe Laitiere de Vitre	Vitre		3,385
Froneri France SAS (Ex. Rolland SAS)	Plouedern		3,343
Union Laitiere Vitteloise	Bulgneville		2,802
Nestle France SAS	Challerange		2,749
Bongrain Gerard	Le Tholy		2,744
Bledina	Steenvoorde		2,632
Fromagerie Henri Hutin	Dieue Sur Meuse		2,616

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Danone	Ferrieres en Bray		2,572
Schreiber France	Clery Le Petit		2,537
Maitres Laitiers du Cotentin	Sottevast	2,024	2,463
Faurecia Inspiring Mobility	Marckolsheim		2,427
Danone	Villecomtal Sur Arros		2,410
Lnuf Marques - Cuincy	Cuincy		2,340
Yoplait Production France	Le Mans		2,119
Cooperative Isigny Sainte Mere	Isigny Sur Mer		2,019
Elvir S.A.S.	Conde Sur Vire		1,905
Herbignac Cheese Ingredients	Herbignac	1,987	1,876
Societe Laitiere De L'hermitage	L Hermitage		1,732
Novacarb	Laneuveville Devant Nancy		974
Societe Laitiere De Montauban	Montauban		140
Even Lait Industrie	Ploudaniel		45
Uclab Industrie	Pencran		21

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Table 4-12: Industry name, Sector, Main activity, Place of Origin and quantity (kg) of the non-hazardous WW that is managed in materials and resources recovery facilities in Greece (European Environmental Agency, 2022c)

Industry name	Sector	Main activity	Place of Origin in Greece	2019 (kg)	2020 (kg)
SOVEL HELLENIC STEEL PROCESSING COMPANY S.A.	Production and processing of metals	Installations for the production of pig iron or steel (primary or secondary melting) including continuous casting	ALMYROS	165,000	159,000
MYTILINEOS S.A. / METALLURGY BUSINESS UNIT PLAN-ALOUMINIUM OF GREECE	Production and processing of metals	Installations for the production and/or smelting of non-ferrous metals. Note to reporters, use Level 3 activity e.g. 2(e)(i), in preference to 2(e). Level 2 activity class (i.e. 2(e)) only to be used where Level 3 is not available.	VIOTIA		123,000
HELLENIC HALYVOURGIA S.A.-VELESTINO PLANT	Production and processing of metals	Installations for the production of pig iron or steel (primary or secondary melting) including continuous casting	MAGNESIA	95,409	82,300
ELVALHALCOR S.A. - ALUMINIUM ROLLING DIVISION	Production and processing of metals	Installation for the smelting, including the alloying, of non-ferrous metals, including recovered products (refining, foundry casting, etc.)	VIOTIA		74,700
TOSOH HELLAS A.I.C.	Chemical industry	Chemical installations for the production on an industrial scale of basic inorganic chemicals: Non-metals, metal oxides or other inorganic compounds such as calcium carbide, silicon, silicon carbide	THESSALONIKI		68,100
SIDENOR STEEL INDUSTRY S.A.	Production and processing of metals	Installations for the production of pig iron or steel (primary or secondary melting) including continuous casting	THESSALONIKI		63,900
EYDAP S.A. - PSYTTALIA WASTEWATER TREATMENT PLANT	Waste and waste water management	Urban waste-water treatment plants	PSYTTALIA	42,200	36,100
HELLENIC HALYVOYRGIA S.A.-VOLOS PLANT	Production and processing of metals	Installations for the processing of ferrous metals, Hot-rolling mills	MAGNESIA	18,082	21,900
HALYVOURGIKI INC.	Production and processing of metals	Installations for the production of pig iron or steel (primary or secondary melting) including continuous casting	ELEFSIS		21,000

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ELVALHALCOR - COPPER TUBES PLANT	Other activities	Installations for the surface treatment of substances, objects or products using organic solvents, in particular for dressing, printing, coating, degreasing, waterproofing, sizing, painting, cleaning or impregnating	OINOFYTA	22,500	20,100
FAGE DAIRY INDUSTRY S.A. METAMORFOSI	Animal and vegetable products from the food and beverage sector	Treatment and processing of milk	METAMORFOSI		15,500
EYATH S.A. – SINDOS WASTEWATER TREATMENT PLANT	Waste and waste water management	Urban waste-water treatment plants	SINDOS	7,650	6,700
FITCO S.A METAL WORKS	Production and processing of metals	Installations for surface treatment of metals and plastic materials using an electrolytic or chemical process	VIOTIA		6,100
HELLENIC PETROLEUM S.A. - INDUSTRIAL DIVISION OF ASPROPYRGOS	Energy sector	Mineral oil and gas refineries	ASPROPYRGOS	4,420	4,590
MORNOS S.A.	Other activities	Installations for the surface treatment of substances, objects or products using organic solvents, in particular for dressing, printing, coating, degreasing, waterproofing, sizing, painting, cleaning or impregnating	THIVA		3,750
FULGOR CABLES PLANT	Production and processing of metals	Installation for the smelting, including the alloying, of non-ferrous metals, including recovered products (refining, foundry casting, etc.)	KORINTHOS		3,530
EYDAP S.A. - METAMORFOSI WASTEWATER TREATMENT PLANT	Waste and waste water management	Urban waste-water treatment plants	ATHENS	4,390	3,400
MOTOR OIL (HELLAS) - CORINTHOS REFINERIES S.A.	Energy sector	Mineral oil and gas refineries	SOUSSAKI, AG. THEODORI	2,680	3,170
SYMETAL - ALUMINIUM FOIL INDUSTRY S.A.	Other activities	Installations for the surface treatment of substances, objects or products using organic solvents, in particular for dressing, printing, coating, degreasing, waterproofing, sizing, painting, cleaning or impregnating	MANDRA	3,220	3,000

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POLYECO S.A. - Aspropyrgos plant	Waste and wastewater management	Installations for the recovery or disposal of hazardous waste	ASPROPYRG OS		2,560
EPALME SA	Production and processing of metals	Installation for the smelting, including the alloying, of non-ferrous metals, including recovered products (refining, foundry casting, etc.)	VIOTIA	2,460	2,540
EYDAP S.A. - THRIASIO WASTEWATER TREATMENT PLANT	Waste and waste water management	Urban waste-water treatment plants	ATHENS	2,520	2,520
UPFIELD HELLAS S.A.	Animal and vegetable products from the food and beverage sector	Treatment and processing intended for the production of food and beverage products from vegetable raw materials	MAROUSI	2,170	2,420
ELVALHALCOR S.A. - FOUNDRY PLANT	Production and processing of metals	Installation for the smelting, including the alloying, of non-ferrous metals, including recovered products (refining, foundry casting, etc.)	VIOTIA		2,360
VEPAL S.A.	Production and processing of metals	Installations for surface treatment of metals and plastic materials using an electrolytic or chemical process	VIOTIA		2,200
ANOXAL S.A.	Production and processing of metals	Installation for the smelting, including the alloying, of non-ferrous metals, including recovered products (refining, foundry casting, etc.)	VIOTIA		2,190
EXALCO SA - NIKAIA PLANT	Production and processing of metals	Installations for surface treatment of metals and plastic materials using an electrolytic or chemical process	LARISA		2,180
FLEXOPACK S.A.	Other activities	Installations for the surface treatment of substances, objects or products using organic solvents, in particular for dressing, printing, coating, degreasing, waterproofing, sizing, painting, cleaning or impregnating	KOROPI		2,040
SUNLIGHT SYSTEMS S.A.	Production and processing of metals	Installation for the smelting, including the alloying, of non-ferrous metals, including recovered products (refining, foundry casting, etc.)	XANTHI	11,300	1,750
HELLENIC QUALITY FOODS S.A. KAKIA LASPI	Animal and vegetable products from the food and beverage sector	Slaughterhouses	KAKIA LASPI		1,620
POLYECO S.A.- Sindos plant	Waste and waste water management	Installations for the recovery or disposal of hazardous waste	THESSALONI KI		1,070

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SUNLIGHT SYSTEMS S.A.	Production and processing of metals	Installation for the smelting, including the alloying, of non-ferrous metals, including recovered products (refining, foundry casting, etc.)	KOMOTINI		959
I.M. MAILIS S.A.	Production and processing of metals	Installations for surface treatment of metals and plastic materials using an electrolytic or chemical process	OINOFYTA		149
HELLENIC PETROLEUM S.A. - THESSALONIKI INDUSTRIAL COMPLEX	Energy sector	Mineral oil and gas refineries	ECHEDOROS	966	119
ELPEDISON S.A.- THISVI POWER PLANT	Energy sector	Thermal power stations and other combustion installations	THISVI		0.32

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4.3 Industrial WW guide

The predecessor of the attempt to better systemise the bio-based input streams, is the industrial WW guide of the Better Efficiency for Industrial Sewage Treatment (BEST) project, funded by the Interreg Baltic Sea Region Programme 2014-2020 (Finnish Industrial Wastewater guide, 2022). This industrial WW guide describes the collaboration model between municipalities, water utilities and industrial enterprises. This guide also reports the legislation applied to industrial WW. The regulatory framework and the WW disposal limits are part of the questions the Industrial WW producers are subjected to as part of their interview in the WalNUT project. As part of this guide, the characteristics of industrial WW (i.e. bio-based input streams) are presented regarding:

Food industry

- Dairy industry
- Slaughterhouses and meat processing plants
- Breweries and the soft drink industry
- Potato and root vegetable processing plants
- Bakeries
- Fish processing plants

Metal industry

- Surface finishing plants
- Steel pickling plants
- Phosphating process plants
- Anodising plants
- Shipyards

Chemical industry

- Paint and coatings industry
- Rubber industry
- Explosives factory and blasting sites
- Pharmaceutical production plants
- Enzyme production plants
- Sulphuric acid production plants
- Printing ink factories

Printing industry

- Offset printing plants
- Silk-screen printing plants

Forest industry

- Pulp and paper industry

Textile and leather industry

Textile printing
- Tanneries
- Laundries

Manufacturing of mineral products

- Glassworks and fibreglass plants

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- Concrete plants

Transport

- Ports
- Waste water from airports
- Energy production

Waste management

- Waste treatment plants and landfills
- Composting plants and facilities
- Biogas plants
- Sludges from septic tanks and cesspits

Services

- Hospitals
- Dental clinics
- Service stations and garages
- Restaurants
- Waste grinders
- Water of public indoor swimming pools

Construction

- Construction sites
- Remediation of contaminated soils

Other

- Laboratories
- Art workshops and hobby clubs
- Waste water from animal shelters
- Stormwater
- Sludge generated by other water utilities

This also acts as an exhaustive list for the better systemisation of bio-based input streams and their characteristics that render them potential candidates for nutrient recovery practices can be accessed in the (Finnish Industrial Wastewater guide, 2022).

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Key results

- Section 4 is a detailed description of the available databases and a guide to navigate them efficiently to map the industrial WW as a bio-based input stream in the EU27-matrix.

- As part of the contribution to Task 1.2 and targeting novelty instead of the predictable citation of bio-based input streams' sources, it was attempted to contact key stakeholders from each country, as part of an interview, to map the current status of the Nutrient Recovery Circle in the EU27 matrix. Due to personal data handling concerns and the publication of information regarding industries in the private sector, in the following sections all publicly accessible official data sources were presented and their content was evaluated and the private information is being used in D1.4 for the interpretation of the responses of the interviewees.

- The continuously evolutionary attempts of the EU matrix towards mapping industrial (and urban as presented in Section 3) bio-based input streams are verified by the publication of updated information in the databases in the previous 50 days. Nevertheless, it is necessary to be further updated, to cover the 2021 gap of data otherwise, the extraction of safe conclusions for the current status of the EU matrix can be in vain.

- Simultaneously, such attempts need to be accompanied by the intensive mapping of the constantly evolving status of the Nutrient Recovery practices on waste and WW and of the recovered nutrients in both the Urban (Section 3) and industrial WW sectors that also need to be represented in these databases.

- Towards this end, it is of high importance to register in the European Pollutant Release and Transfer Register, the European Industrial Emissions Portal and the Industrial Reporting Database other nutrients as well (Table 3 3) even if their disposal limit is not reached that can be valorised and are present in the registered waste and WW.

- The list mentioned in the Industrial WW guide complements the sectors of the activities mapped in the Industrial Emissions Portal (Table 3-4) whose registration should also be enforced in the aforementioned databases.

- Addressing of the obstacles (previous five key results regarding the data gaps on the publicly accessible databases and the protection of private information) that were faced during the mapping of EU's current status of bio-based input streams, highlights the urgent need for the launch of the interactive platform (D1.5 and D1.6 (WP1)) to track and trace bio-based input streams and match the economically prime important nutrient resource - based products and recovered nutrients that derive from the application of Nutrient Recovery practices on them with Bio-based fertiliser applications.

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5 Current status in the EU-matrix of the Nutrient Recovery technologies from bio-based input streams

5.1 Support in the attempt to address Nutrient Recovery practices

As it was discussed in Sections 3.3 and 4.2 access to the public to the Industrial Reporting Database was granted in 22 March 2022. An attempt to report the current status of Nutrient Recovery technologies, could be facilitated by tracking the industries that practice material and resources recovery from their waste and WW at a national and regional level (representative examples from Table 3-6 to Table 3-8 and from Table 4-10 to Table 4-12). The currently presented data concern 2020 but are a solid base for the mapping of the nutrient recovery practices at an industrial level in the future. The registered industries are potential candidates for Nutrient Recovery practices and their participation in the WalNUT interviews is key parameter for the allocation of Nutrient Recovery Technologies in the EU -27 matrix.

Earlier registrations (up until 29.01.2021) of mature N and P recovery technologies can be found in the Research and Innovation page of the European Commission Participant Portal (European Commision, 2021).

There are numerous publicly accessible Nutrient Recovery platforms and the EU COM has an open dialogue with anyone who wishes to address their opinion.

Another source for the current status of Nutrient Recovery technologies is the publicly accessible inventory of the P-recovery routes and processes published on the European Sustainable Phosphorus Platform (ESPP), (latest version accessible to the public 26/4/2022) (Phosphorus Platform, 2022). This catalogue is published with the assistance of the German Phosphorus platform (DPP) (Deutsche Phosphor Plattform, 2022) and the Netherlands Nutrient Platform (NPP) (Nutrient Platform NL, 2022).

This document summarises a number of phosphorus recovery technologies, particularly targeting operational information on processes to this day operating full-scale for P-recovery from sewage (Table 5-13), but also including a number of processes which concern nitrogen recovery (full scale) (Table 5-14) or R&D scale P-recovery from sewage (Table 5-15). Due to personal data handling concerns and the publication of information regarding industries in the private sector, in this section, all publicly accessible official data sources are presented and their content is evaluated. Therefore, the catalogue aims to specify input materials for each process, output products, the fate of iron/aluminium and of heavy metals or other contaminants, a summary of the process steps, current operating status (full-scale or pilot operation at how many sites, capacity and duration of operation).

The previous version of the ESPP, DPP and NNP P-recovery technology catalogue (14/9/21) (Phosphorus Platform, 2021) included:

- ✓ Sewage P-recovery (full scale plants operating or under permitting/construction
- ✓ Sewage P-recovery(TRL 6^{+})
- ✓ Other Nutrient Recovery (TRL 6^{+})
- ✓ Nutrient Recovery technologies at R&D scale and
- ✓ Nutrient Recovery technologies no longer under development.

The latest version (26/4/2022) (Phosphorus Platform, 2022) includes:

- ✓ Sewage P-recovery (full scale plants operating or under permitting/construction
- ✓ Sewage P-recovery(TRL 6^{+})
- ✓ Other Nutrient Recovery (TRL 6^{+})
- ✓ Nutrient Recovery technologies at R&D scale and

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- ✓ Nutrient Recovery technologies currently no longer under development (to our knowledge)-or integrated into other processes (Extraphos-RecoPhos thermal-BioEcoSim (Suez)-ePhos (Fraunhofer IGB were removed from the previous version)
- ✓ Nutrient Recovery technologies whose update has not been completed by 2022 or is underway.

In the 'Recovered products' column in Table 5-13, Table 5-14 and Table 5-15 one can locate all possible candidates for economically prime important nutrient resource-based products derived from Nutrient Recovery Practices in Bio-based input streams and how they can be associated with fertilisation practices.

For the better interpretation of the information presented in Table 5-13, Table 5-14 and Table 5-15, some key points are summarised as follows:

- Combining biological, chemical, and physical methods with thermal treatment appears to be the most effective way for the treatment of waste water sludge in terms of phosphorus recovery.
- Accessibility and efficiency of the osmotic membrane bioreactors (OMBR) and the bioelectrochemical systems (BES)-based hybrid systems for Nutrient Recovery can increase by the reduction in their operational costs along with the improvement of their technical feasibility.
- Attention must be paid on the evaluation of the feasibility and the performance (sludge properties, membrane fouling, permeate flux) of OMBR with different WW solutions as feed and the necessity of pre-treatment.
- Integration of membrane technology into current and conventional technologies increases the quantity and the quality of recovered nutrients due to low fouling potential and low energy consumption.
- Further research on the anaerobic OMBR –based hybrid systems should be considered regarding nutrient recovery, given the lower energy consumption when compared to the aerobic ones.
- Microbial Fuel Cells (MFC) have great potential in Nutrient Recovery due to the electricity generation and the high pH zone for chemical precipitation. The combination of MFC with forward osmosis, membrane distillation or electro dialysis favours nutrient enrichment from diluted WW, as well as the quality and the quantity of recovered nutrients.
- Hydrothermal, thermochemical, and adsorption on thermally treated adsorbents are characterised by a high phosphorus recovery rate (over 95%).
- Due to its large volume and relatively low phosphorus content, WW is a resource that requires additional treatment to recover the highest possible amount of phosphorus.
- Pretreatment of WW with combined methods seems to be a possible way to improve phosphorus recovery.
- Regarding N-recovery, mainly struvite precipitation and acid absorption followed by separation by gas stripping or gas permeable membranes can be applied. Electrodialysis, bioelectrochemical processes and Ion Exchange/adsorption can be applied for the concentration of N.
- The combination of enhanced biological phosphorus removal with (electro)chemical struvite precipitation and chemical precipitation alone can be applied for P-recovery in centralised WW treatment plants. The preference towards struvite precipitation is pointed out.
- Regarding low requirements in maintenance and chemicals, ability to adapt on-site and to implement on pre-manufactured WWTP, electrochemical and chemical precipitation as well as ion exchange processes are mostly preferred.

Nutrient Recovery in algal biomass may be particularly useful for the production of bio-based fertilisers and biostimulants. Further investigation is required for the direct microbiological recovery as a protein source in food

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Table 5-13: 2022 additions of nutrient – recovery technologies in the EU, in the catalogue of phosphorus recovery technologies updated on 26/4/2022.

	Bio-based Input streams	Recovered Products	Nutrient Recovery Technology	Current operating status
Renewable Nutrients (Quick Wash ©)	Solid or liquid waste streams: - sewage sludge digestates, - food processing wastes.	The final product is a stackable solid, typically c. 20% dry matter (can be dried to c. 90% dry matter), consisting of a mixture of amorphous calcium phosphate with organics (10 - 40 % dry matter organic carbon), and containing also organic nitrogen and minerals such as calcium, sulphur, magnesium. P-content of the final product: c. 0.25 – 0.55 % dry matter P for recovery from manures, digestates, wastewater or e.g. >6% for recovery from P-rich industrial stream. The amorphous calcium phosphate has high P fertiliser effectiveness* **. Data on NAC solubility (required for labelling as a "Mineral" fertiliser under the EU Regulation 2019/1009) are not provided. Contaminants will depend on the input stream treated. Typical levels of copper and zinc are 100 – 300 mg/kg dry matter.	The QuickWash process consists of: 1) Solubilisation of phosphorus using acid at pH 3-5 (e.g. citric acid or hydrochloric acid). 2) Solid is then separated from the acid liquid by settling. 3) Precipitation of calcium phosphate from the acid solution by increasing to pH 8-10 by lime dosing. 4) Recovery by settling. Anionic polyacrylamide polymer (at c. 7 mg/l) is dosed to enhance settling and recovery of the precipitated calcium phosphate. Recovery of P from input material is generally > 95%. This process enables recovery of a relatively pure amorphous calcium phosphate, but in operations today this is recovered along with organics, in order to provide organic carbon and other nutrients to farmers.	Over 20 pilot installations have been constructed and tested at sites including municipal wastewater treatment works, farms and industrial sites, treating up to c. 0.5 million litres/day (c. 1 500 t/y output product). 1.5 million litres/day installations are under planning in the UK and USA.
TetraPhos (Remondis)	- sewage sludge incineration ash, from sewage works using biological and/or chemical P-removal	- phosphoric acid - gypsum - iron and aluminium salts - mineral ash residues	- Ash leaching - Heavy metals precipitation - Solid-liquid separation - Gypsum precipitation - ion-exchange and optionally nano-filtration	Full scale plant: Hamburg, Germany (commissioning underway 2022) Throughput: 20,000 t/y ash. Further full scale plants are in project phase in Kiel, (Germany), Lünen (Germany) and Moerdijk (The Netherlands).

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RAVITA (Helsinki HSY) TRL 6+	- P-rich sludge from chemical post-precipitation (P-recovery) - sewage sludge dewatering liquor (N-recovery)	- Phosphoric acid - Iron/aluminium chemicals for use as coagulants in WWTP P-removal. - Ammonium phosphate	- tertiary post precipitation - Sludge dissolution -solvent-solvent extraction - Ammonia stripping from secondary sludge dewatering liquors	Post-precipitation: 1 000 p.e. pilot for tertiary P-removal operating since 2017 (achieving 0.4 mgP/l WWTP discharge). P-recovery: 1 000 p.e. pilot under testing, started in 2020.
Struvite enhanced Phosphogreen (Suez). Phosforce (Veolia) Parforce	Only applicable to WWTP operating biological P removal, usually with sludge digestion (AD).	Struvite, useable directly as a fertiliser. Has added value as a slow-release, low leaching, non root-burning fertiliser. Over 50 studies show that struvite is plant available an effective fertiliser. EU Fertilising Products Regulation criteria for recovered struvite proposed are under finalisation (see the final STRUBIAS report Sept. 2019). Recovered struvite already has End-of-Waste status and EU 2003/2003 fertiliser validation in a number of countries. In bio-P WWTP, struvite precipitation.	Sludge return streams or side streams in the biological treatment process are adapted to optimise soluble orthophosphorus release and to increase P available for struvite precipitation, enabling recovery of 20 – 35 % of sewage works inflow P as struvite. This rate can be further increased to 45 – 50 % by processes which hydrolyse sewage sludge to render the phosphorus soluble (see “Sludge lysis” below)	Ostara WAASTRIP (Crystal Green) is operating at 12 WWTP worldwide, recovering 45 – 50% of WWTP inflow P. Phosphogreen at Aarhus Åby, 70 000 p.e. since 2013: 45-50% recovery of WWTP inflow P is achieved so long as ferric dosing is not required in WWTP operation. NuReSys (Apeldoorn Hybrid Unit): 30% recovery of WWTP inflow P. Veolia Phosphogreen: pilot scale trials at 3 sites, demonstration scale planned Parforce: under construction (early 2022) at Wolfsburg, Germany, 150,000 p.e. up to 60 – 70% recovery of WWTP inflow P by struvite precipitation from hydrolysed sludge

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ViViMag™ (WETSUS - Kemira)	- sewage sludge digestate, before dewatering, from WWTP using iron salts for chemical P removal	- vivianite (iron(II) phosphate). Can be used as an iron fertiliser. Or possibility to process to PK fertiliser and iron coagulants for use in WWTP)	- Anaerobic digestion for magnetic separation of iron phosphate precipitation by iron (III) reduction to iron (II).	Manual 1 m^3/h pilot for magnetic separation of vivianite tested at Nieuwveer WWTP, NL. Automatic 1 m^3/h pilot currently under construction, with continuous trials planned in Germany, Denmark and the Netherlands starting from summer 2022.
AshDec (Metso Outotec) TRL 6+	- All ashes with P content >7%	- Modified Rhenania Phosphate (Calcium-Sodium-Phosphate) P_{nac} solubility >80%; granular material with P_2O_5 content of 15-25% (depending on the input-ash); no organic matter; product is blendable with all other fertilising products.*	- Ash is mixed with a sodium carrier (Na_2CO_3 or $NaHCO_3$) and heated to about 850-900°C in a rotary kiln to modify the P-compounds to neutral ammonium-citrate soluble $CaNaPO_4$ (Rhenania Phosphate).	Pilot plant (300 kg/h) operational for several years, Leoben, Austria. Continuous operating campaigns produced several hundred tons of product. A full scale plant (30 000 t/y ash input) is planned in Altenstadt (Bavaria), with Enter GmbH and sePura GmbH, in the R-Rhenalia RePhoR project.
CarboREM TRL 6+	- Digested dewatered sewage sludge (10- 15% DS).	- Precipitated phosphate salts.	- hydrothermal carbonisation - solid-liquid separation of hydrochar - dissolution in acid (citric acid or HCl) - addition of alkali (NaOH) for phosphate salt precipitation**	Industrial-scale continuous HTC plant installed in 2019 and located in the wastewater treatment plant of Mezzocorona, Italy. Capacity: 1.4 t/h of wet digested sewage sludge

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Table 5-14: 2022 additions of nutrient – recovery technologies in the EU, in the catalogue of other recovery technologies updated on 26/4/2022.

	Bio-based Input streams	Recovered Products	Nutrient RecoveryTechnology	Current operating status
Ash2Salt (EasyMining)	- Fly ash from municipal solid waste incineration (not bottom ash)	- Potassium chloride - Sodium chloride - calcium chloride The salts are of high quality and suitable for industrial use and fertilisers. -Ammonium sulphate (40% solution)	- Ca, S, K dissolution - Sulphates precipitation - Vacuum filtration - The treated brine is upconcentrated by recirculation, then undergoes ammonia removal and recovery (as ammonium sulphate). After removal of ammonia, the brine is evaporated and three different salts are recovered: potassium chloride (solid), sodium chloride (solid) and calcium chloride (solution). The salt separation is based on differences in the solubilities of the salts involved. The clean condensate water can be recycled in the process or be used for other purposes.	A first full scale plant is being built at Ragn-Sells waste management plant, Högbytorp, near Stockholm, Sweden. Planned start-up: late 2022. This plant will have a capacity of 130 000 ton fly ash per year, producing approx 3 500 t/y (dry) potassium chloride, 7 000 t/y (dry) sodium chloride and 32 000 t/y calcium chloride (36% solution).
Project Nitrogen (EasyMining)	- Liquors with a high ammonium concentration, e.g. WWT sludge dewatering liquors.	- Ammonium sulphate ($(NH_4)_2SO_4$). (10-25% solution) Contaminations in the ammonium sulphate are well below fertilizer requirements.	In the first step, the ammonium nitrogen is precipitated with a specific chemical. In the second step, the precipitant is regenerated and sent back to the first step, and acid is used to convert the nitrogen to a form usable either directly in fertilisers or in fertiliser production.	The processes are currently (early 2022) being demonstrated in a continuous demonstration plant of capacity 4 m^3/h inflow. This installation was tested December 2021-March 2022 at RagnSells' waste management plant Högbytorp in Bro, Sweden, and in AprilSeptember 2022 at BIOFOS' municipal wastewater treatment plant

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				Lynetten in Copenhagen, Denmark.
CCm CCm Technologies Carbon Capture and Utilisation TRL 6+	-Digestates of sewage sludge, - food waste - In some cases, also other secondary materials e.g. wood chips, organic fibres, biomass ash - Offgas CO_2	Pelletised organo-mineral fertiliser, containing stabilised N and P. Field tests of the fertiliser product show compatibility of the pellets with existing farm fertiliser equipment: rotating discs up to 36m wide spreading radius), crop performance comparable to commercial mineral fertilisers and positive impacts on soil bioflora, water retention, soil carbon and reduced nutrient runoff	Ammonia captured from digestate is used to capture (as carbonate) CO_2 from digester biogas (mixed off-gas or separated CO_2 stream from biomethane). This is then combined with organics in digestate cakes, further stabilising the nitrogen and carbon. The product is then dried and pelletised, to produce a stable organo-mineral fertiliser (OMF). Additionally, CCm are operating a pilot unit Pilot (4 m_3/day) at Yorkshire Water Caldervale site, UK, to remove and recover phosphorus as struvite from Prich sludge dewatering streams, using magnesium and ammonia. The output integrates the phosphorus into the stable organo-mineral fertiliser pellets. Aim: 75% P reduction from liquors. Startup planned Q2 2022.	Industrial demonstrator at Kew Technology Sustainable Energy Centre, UK, to produce OMF fertiliser. Output: 500 t/yr. Inputs: biochar, digestate, recovered CO_2 from enhanced thermal conversion technology. Operational in Q1, 2022. Industrial demonstrator is located at Severn Trent Water Minworth site, UK. Output 10 000 t/yr OMF fertiliser pellets. Input capability: sewage sludge, biomass ash, recovered CO_2, recovered ammonia. Operational from 2021. Full scale plant at Walkers potato processing plant (Pepsico, Leicester, UK). Outputs: 12 000 t/yr OMF fertiliser pellets. Inputs: food waste digestate, recovered CO_2. Operation start Q2, 2022.
Parforce	- Sewage sludge incineration ash, - other ashes, - phosphate rock or - other secondary materials	- Phosphoric acid - By-products or waste streams depending on process design and input material.	1) Acid digestion using HCl or HNO3, to generate raw phosphoric acid 2) solid-liquid separation (filtration) 3) if the input material is	Batch pilot, capacity 150 - 250 kg ash per batch and semi-continuous acid purification, tested for several different materials

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	- Struvite can be used as raw material after calcining (prior to step 1) to remove organic contaminants, with ammonia recovery	- % of P in input material recovered in phosphoric acid: > 80% for sewage sludge incineration ash, higher for other input materials. - Approx. 5 – 35% of iron and 40 – 55% of aluminium in ash are leached by acid in step (1). Iron must then be removed in step (3) to protect the electrodialysis of step (4). - >99% removal of leached heavy metals, copper, zinc can be achieved in the phosphoric acid purification, step (4).	sewage sludge ashes, then iron and aluminium are extracted (prior to electrodialysis) by either ion exchange or solvent extraction 4) membrane electrodialysis to separate metal cations (especially Ca, Mg and heavy metals) to a concentrated solution. 5) concentration of the remaining phosphoric acid 6) the metal Ca, Mg, heavy metals etc solution (separated from the phosphoric acid in step 4) is treated with lime. This precipitates the metals to a waste stream leaving a salt solution which can possibly processed to road salt. In pilot trials, some of the phosphorus passed the electrodialysis membranes. so that a return stream was required. This is resolved in larger scale trials where continuous electrodialysis offers better selectivity.	in since 2018 at Freiberg University of Mining and Technology, Germany. An automated demonstration plant is now planned (2022) for Bottrop, Germany, capacity 1 000 t/y ash. Continuous campaigns will test different ash inputs.

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Table 5-15: 2022 additions of nutrient – recovery technologies in the EU, in the catalogue of recovery technologies under R & D updated on 26/4/2022.

	Bio-based Input streams	Recovered Products	Nutrient RecoveryTechnology	Current operating status
P-roc	Sewage sludge dewatering liquor.	Highly disordered and microcrystalline phosphate salts (hydroxyapatite, struvite, Kstruvite).	Crystallization by means of CalciumSilicate-Hydrate	Mobile pilot plant: 300 litres/hour.
Susphos	Tested to date: - sewage sludge - incineration ash, - struvite. Planned: - other phosphate-rich materials with low levels of organics, e.g. vivianite.	Phosphoric acid, or mono- or diammonium phosphate (fertilizer or flame retardant quality). Iron / aluminium salts as aqueous solution: can be recycled to sewage works for P-removal. Solid magnesium sulphate salts (if struvite is input), recycled by sewage works for struvite precipitation. Inert mineral material stream (containing sand, gypsum, iron oxides) can be used in the construction industry.	The input materials are attacked with concentrated sulphuric acid. The resulting phosphoric acid is purified using a proprietary organic solvent extraction process, without requiring ion-exchange or membrane filters. The acid has low levels of impurities and concentration >50% P_2O_5 (from ash), because the only water input is in the sulphuric acid. Iron and aluminium are c. 99% removed from the phosphoric acid, and partly recovered for recycling, partly fixed in the insoluble minerals stream. Mono- or diammonium phosphate can be precipitated from the phosphoric acid by reaction with ammonia gas. Heavy metals are largely removed and rendered inert in insoluble calcium minerals: e.g. >95% of Cd, Hg, Cu, Zn.	25 kg/day pilot operated in Leeuwarden (NL) for 8 months for struvite and tests with sewage sludge incineration ash are underway since May 2021. Full scale plant of 50 000 t/y is planned in The Netherlands, with objective of operation in 2023-2024.
Spodofos (ThermusP)	- Ashes from sewage sludge incineration and bone meal, precipitated phosphate salts (struvite, calcium phosphate).	P4 (white phosphorus). High aluminium-content slag (may find specific uses). Ferrophosphorus (low value by-product). Volatiles (lead, zinc, other heavy metals) to recycling or disposal.	Secondary aluminium (post-consumer, low quality) is heated to 600 °C with the ash (or other input materials), resulting in a solid-solid, exothermic thermite reaction, raising the temperature to > 1800°C. Unlike in conventional P4 reducing furnaces (using coke and electricity), pre-sintering of the input materials is not necessary, carbon-monoxide is not generated. External heat energy is only needed for preheating the	Laboratory experiments at 100g scale to date (end 2021) and thermodynamic modelling. Pilot development now underway

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			input materials, because of the intrinsic energy content of the secondary aluminium.	
SIMPhosprocess (Cirkel)	-Dewatering liquor from sewage sludge digestate, containing soluble phosphate, optionally after re-dissolution of phosphates. 90 – 95 % of soluble phosphate (orthophosphate) is removed and recovered in the final product	Granular calcium phosphate. The final product contains up to 13% P DM. Water content of the final product is around 50 – 60% after standing to dry (dries easily due to pore structure). Organic carbon content of the final product not yet available and depends on the input stream. Plant availability of P has been demonstrated in pot trials but P-solubility in NAC as specified in EU Fertilising Products Regulation is not yet available.	Crystallisation of calcium phosphate from dewatering liquor by means of SIMPur, a specific calcium silicate hydrate (CSH), which releases SiO_2 / silicon compounds and takes up phosphorus, with 7:1 ratio of input consumed SIMPur CSH:P in the final product. SIMPur is produced by processing the natural CSH mineral tobermorite to tailored granulometry. Contaminant levels in SIMPur are low. Contaminant levels in the final product depend on the input stream, with the following results from tests to date: - Cu, Hg, Cd : not detectable - Zn: 10 mg/kg DM - Fe: 2 mg/g DM - Al: 1 mg/kg DM	Operational test in 2016: mobile unit, inflow 0.5 m^3/h, operated continuously for c. 3 months using real sewage sludge digestate. Planned operation in 2022 with capacity 7.5 m^3/h treating part of the sludge digestate centrate at the WWTP Neuburg an der Donau, Germany (67,000 p.e).

* Removal of heavy metals (% from input ash in the final phosphate product): Cd: ~ 50 % removal, Pb: ~10 %, As: ~ 50 %. Cu, Zn and Ni are not removed from the ash with the standard process. Removal of Cu and Zn can be enhanced by use of chlorine additives.

** Metal removal from digestate after HTC and acid leaching of hydrochar: - Cd~80% - Pb~70-80% - Zn~90% - Cu~70% - Cr VI~90%.

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Key results

Earlier than 29.01.2021 registrations of mature N and P recovery technologies can be found in the Research and Innovation page of the European Commission Participant Portal (European Commision, 2021).

- Tracking the industries that practice material and resources recovery from their waste and WW at a national and regional level registered to the Industrial Reporting Database as potential candidates for the application of Nutrient Recovery technologies can lead to mapping of the current status in the EU matrix.

- Full scale Nutrient recovery plants operating or under permitting/construction, Nutrient Recovery technologies at TRL 6+ or at R&D scale were presented according to the latest version (accessible to the public 26/4/2022) of the European Sustainable Phosphorus Platform (ESPP) (Phosphorus Platform, 2022) report on Nutrient Recovery technologies with the assistance of the German Phosphorus platform (DPP) (Deutsche Phosphor Plattform, 2022) and the Netherlands Nutrient Platform (NPP) (Nutrient Platform NL, 2022).

- In 2019, Nutrient Recovery processes focused on recovery of P or N separately (Perera, Englehardt, & Dvorak, 2019). Currently, Nutrient Recovery technologies involve the recovery of both P and N and there are cases in which micronutrients are also recovered from the input streams.

- SuSPhos 'has built and validated a kilogram-scale prototype reactor and is now ready for the realisation of the industrial pilot in order to validate the market and the technology' (SusPhos, 2022).

- The 'Recovered products' column in, Table 5-13, Table 5-14 and Table 5-15, mentions all currently available candidates as economically prime important nutrient resource-based products derived from Nutrient Recovery Practices in Bio-based input streams and how they can be associated with fertilisation practices.

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6 Presentation of economically prime important nutrient resource-based products

As mentioned in the previous section, in the 'Recovered products' column in, Table 5-13, Table 5-14 and Table 5-15, one can locate all possible candidates for economically prime important nutrient resource-based products derived from Nutrient Recovery Practices in Bio-based input streams and how they can be associated with fertilisation practices. The road towards the utilisation of these products as Bio-based fertilisers, as it will be discussed in the following Sections is paved by the European fertilisers regulation FPR (Regulation (EU) 2019/1009, 2022) to be implemented July 16th, 2022.

6.1 Nutrient resource-based products in the Component Material Categories of FPR

EU fertilising products may consist solely of materials complying with the requirements for one or more of the component material categories listed in the Annex II – Component Material Category (CMC) of FPR.

There are 11 component material categories:

1. Virgin material substances and mixtures
2. Plants, plant parts or plant extracts
3. Compost
4. Fresh crop digestate
5. Digestate other than fresh crop digestate
6. Food industry by-products
7. Micro-organisms
8. Nutrient polymers
9. Polymers other than nutrient polymers
10. Derived products within the meaning of the Animal By-products Regulations (ABPR).
11. By-products within the meaning of the Water Framework Directive (WFD).
12. Precipitated salts and derivatives (EU) 2021/2086
13. Thermal oxidation materials and derivates
14. Pyrolysis and gasification materials.

The FPR lays down different rules for each component material category regarding, for instance, the input materials or the processing methods.

The manufacturer has to draw up the technical documentation in support of the conformity assessment of their fertilising product. The technical documentation, among others, has to contain a list of every component material used in the final product, with reference to its corresponding CMC and information on its origin or its manufacturing process. This list has to contain all the component materials and consequently no other ingredient deliberately incorporated into the fertilising product is expected to be found in the final composition of this fertilising product. This does not concern contaminants as they are not intentionally added.

There is no obligation for the manufacturer to declare the actual percentage of each component material as part of the final product. In case a component material could comply with the requirements for more than one Component Material Categories (CMCs), the manufacturer is free to choose the CMC that suits best his or her material and production. The manufacturer has to make sure that their material complies with all the requirements as set for the respective CMC. There are situations where two CMCs are mutually exclusive. A material that falls under the scope of CMC 11 (by-product within the meaning of WFD) is by definition

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excluded from the scope of CMC 1 (virgin substance) (see Annex II, part II, CMC 1, point 1(d)). If a by-product is chemically reacted with another substance, then the resulting material can be eligible for CMC 1, as this CMC does not exclude materials derived from by-products. However, a food industry by-product that complies with requirements of the CMC 6 (food industry by-products) could also comply with the requirements set in the CMC 11.

With regards to the WalNUT project, Bio-Based Fertilisers (BBFs) are fertilisers that contain macro- (NPK) and/or micro - nutrients that derive from Nutrient Recovery practices on Bio-based input streams (Urban WW, agri-food WW, Industrial WW and brine) in order to replace them in the composition of fossil – based nutrients or they are the aforementioned economically prime important nutrient resource-based products that derive from the valorisation of the aforementioned Bio-based input streams.

6.2 Component materials out of recovered waste

Module D1 (quality assurance of the production process) implies setting up a quality system for the production process to ensure the compliance of the EU fertilising products with the FPR.

In Annex IV, there are detailed requirements concerning the objective of the quality system and the organisational structure which has to be put in place. The quality system has to be assessed by a notified body. The notified body is also surveying the functioning of approved quality systems, in order to make sure that the manufacturers comply with their obligations.

Annex IV contains special requirements for products containing some CMCs where various waste streams may be used as input materials.

Module D1 is a conformity assessment procedure which implies, among others, that the manufacturer:

- operates an approved quality system for production, the final product inspection and testing of the EU fertilising products concerned and
- is subject to surveillance by a notified body.

Manufacturers buying (part of the) component materials for the production of an EU fertilising product are bound by the same obligations. Therefore, they have to make sure that in their contractual relationship with the supplier they will include the relevant stipulations which will allow them to fulfil these obligations.

Two options can be envisaged:

1. either the compost producer has the quality management system audited by a notified body (has a direct contract) or

2. the manufacturer of the final EU fertilising product needs to agree with the compost producer that the notified body who is taking care of the conformity assessment for the EU fertilising product will also audit the quality assurance system of the compost producer as part of the conformity assessment process.

If the manufacturer produces various types of EU fertilising products containing the same component material out of recovered waste but in combination with other materials, in various concentrations, they have the possibility to cover with the same quality assurance system the production of all the relevant products. Nevertheless, some steps in the conformity assessment are specific to each product (such as drafting the technical documentation). Therefore, the manufacturer will have to draft separate technical documentations and make them all available to the notified body.

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6.3 Clarifications on economically prime important nutrient resource-based products

6.3.1 Compliance of the reaction product (in CMC 1) not of the chemical substances (‘precursors’) with the requirements of the FPR

In some cases during the manufacturing process of a CMC 1, different precursors are expected to react with each other following a series of chemical conversions. At the end of the manufacturing chain, a final substance or mixture will be produced. This final substance or mixture will be part of the composition of the EU fertilising product, so only this one needs to comply with the provisions of CMC 1 and the requirements of the corresponding PFC.

For example: Spent sulphuric acid may be a by-product from industry. If it meets all requirements for constituting a by-product according to the WFD (Article 5(1)), it can be directly used as a reactant for the production of a material belonging to CMC 1. In the latter production process, the sulphuric acid chemically reacts with rock phosphate, dried and granulated to single super phosphate. The sulphuric acid is not directly used as a fertilising product component, so it cannot be considered as a CMC 11 material. It is used as a precursor to react with another substance (phosphate rock) to produce the single super phosphate which will be part of the final composition of the EU fertilising product. For this reason the single super phosphate, in the example case explained above, is eligible to be considered as a material covered by CMC 1.

Following the same logic, whenever an ‘additive’ reacts with a substance, the additive has to be considered, together with the said substance, as a precursor; in any event, by virtue of the REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) Regulation itself, it needs to be registered under REACH unless exempted or considered a constituent part of the reacted substance.

Similarly, it is the product in its final composition that need to respect all thresholds in relation to macro- or micro- nutrients content or contaminants content relevant to the claimed product function category.

For example, in the case of the production of an inorganic micronutrient fertiliser, iron sulphate, zinc sulphate and boric acid are added to the chemical process. The reaction products, at the end of the manufacturing process, will be part of the EU fertilising product’s composition. So, when the manufacturer will assess the compliance of this micronutrient fer the FPR rules related to the minimum micronutrients content (specified in PFC 1(C)(II)), he/she will need to analyse the product in its final composition. If these limits are not reached therein, the product does not fulfil the requirements for the respective PFC, even if the precursors’ content in micronutrients complied with the same limits.

6.3.2 Placement of EU fertilising products containing compost or digestate even if the compost or digestate therein do not meet the national end-of waste criteria on the market in an EU country

The FPR is legally binding in all EU countries. Once it is applicable, EU fertilising products containing compost or digestate complying with the requirements of the CMCs 3, 4 or 5 may be placed on the market in any EU country.

The end-of-waste criteria in CMCs 3, 4 and 5, like any harmonisation rules, may be more restrictive than the national legislation in some EU countries or more permissive in others. However, this does not have an impact on placing CE marked products on the market. In the same way, the end-of-waste criteria in the FPR have no influence on placing on national market of compost or digestate complying with the national rules.

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6.4 Exemptions to economically prime important nutrient resource-based products

6.4.1 Exemption of 'sewage sludge', 'industrial sludge' and 'dredging sludge' in the FPR

CMCs 3 (compost) and 5 (digestate other than fresh crop digestate) allow as input materials living or dead organisms except 'sewage sludge', 'industrial sludge' and 'dredging sludge'. CMC12: waste waters and sludge from processing of foods, beverages, pet foods, animal feeds, or dairy products, other than animal by-products or derived products within the scope of Regulation (EC) No 1069/2009, unless processing steps involved contact with biocidal products within the meaning of Article 3(1), point (a), of Regulation (EU) No 528/2012 of the European Parliament and of the Council (*1) other than those defined as product-type 4 of main group 1 of Annex V to that Regulation.

The notion of 'sludge' is defined in the Sewage Sludge Directive (Council Directive 86/278/EEC) as follows:

'sludge' means:

(i) residual sludge from sewage plants treating domestic or urban WWs and from other sewage plants treating WWs of a composition similar to domestic and urban WWs;

(ii) residual sludge from septic tanks and other similar installations for the treatment of sewage;

(iii) residual sludge from sewage plants other than those referred to in (i) and (ii).'

The notions 'industrial sludge' and 'dredging sludge' used in the FPR are not defined as such in the Sewage Sludge Directive and therefore they should be understood in the usual meaning of the terms.

'Industrial sludge' covers the residual sludge from plants treating industrial WW, including from agro-food industry. During the negotiations for the adoption of the Fertilising Products Regulation, the European Parliament proposed to allow as input 'non-consumable food residues, fodder and plantations linked to agrofuels'. The European Commission explained to the co-legislators that the risks from agro-fuel industry sludge have not been assessed (in particular if plant protection products or biocides are present) and this may negatively affect the composting/digestion process. This amendment has not been included by the European Parliament and the Council in the Regulation. The fact that certain types of sludge are allowed in the context of the ECOLABEL Decision for certain types of fertilising products does not mean that they may also be used as input materials under the FPR.

In the FPR it is stated that 'Promising technical progress is being made in the field of recycling of waste, such as phosphorus recycling from sewage sludge, and fertilising product production from animal by-products, such as biochar. It should be possible for products containing or consisting of such materials to access the internal market without unnecessary delay when the manufacturing processes have been scientifically analysed and process requirements have been established at Union level. For that purpose, the power to adopt acts in accordance with Article 290 TFEU should be delegated to the Commission in respect of defining and introducing additional component materials eligible for use in the production of EU fertilising products and corresponding contaminant limit values in such products. That empowerment should only apply to the extent justified by technical progress established after the adoption of this Regulation, and not for the purpose of amending any elements of this Regulation in the absence of new evidence of such progress. In order to base the introduction of new contaminant limit values in EU fertilising products on full consideration of the direct and indirect impact on food and feed safety and on the environment, scientific opinions of the European Food Safety Authority, the European Chemicals Agency or the Commission's Joint Research Centre, as relevant, should be taken into account prior to the adoption of new contaminant limit values. For derived products within the meaning of the Regulation (EC) No 1069/2009, component material categories should be expanded or added only to the extent that an end point in the manufacturing chain has been determined in accordance with

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the procedures laid down in that Regulation, since derived products for which no such end point has been determined are in any event excluded from the scope of this Regulation.’.

6.4.2 Ammonium sulphate as a by-product from caprolactam or coke oven production

The ammonium sulphate from caprolactam or coke oven production cannot be classified as a component material belonging to CMC 1 (Virgin material substances and mixtures), since it is a by-product. The appropriate category to cover this ingredient seems to be CMC 11, since it covers by-products that are part of the final composition of an EU fertilising product, under the condition that they fulfil all requirements of that category.

6.4.3 Detectable traces of unreacted ingredients or processing agents in a substance or mixture belonging to CMC 1

Having in mind the common industrial practices, it is evident that the substances and mixtures belonging to CMC 1 present in the final composition of an EU fertilising product cannot be 100% pure. Thus, irrespectively of the actual industrial process followed, component materials belonging to CMC 1 in a fertilising product are expected to contain detectable traces of impurities.

The FPR refers to the REACH definition of ‘a substance’. A substance is defined under Article 3(1) of REACH as “a chemical element and its compounds in the natural state or obtained by any manufacturing process, including any additive necessary to preserve its stability and any impurity deriving from the process used, but excluding any solvent which may be separated without affecting the stability of the substance or changing its composition”.

Following the substance definition, impurities are part of the substance composition. The Guidance for identification and naming of substances under REACH and CLP defines an impurity as “An unintended constituent present in a substance as manufactured. It may originate from the starting materials or be the result of secondary or incomplete reactions during the manufacture process. While it is present in the final substance it was not intentionally added.” Impurities should not be considered as substances on their own, but should be dealt within the context of the relevant substance they are part of in the REACH registration.

6.5 Background for the identification of the preconditions that drive or hamper the deployment of NR options in WWT facilities

6.5.1 Impurities in CMCs 2, 3, 4, 5, 7, 8 and 9 (where no REACH registration is required)

There are no pure materials and it is to be expected to find impurities in component materials (unintended constituents present in the material). In some CMCs, there are specific provisions regarding some impurities (such as maximum limit values for macroscopic impurities in compost). In such cases, those limit values have to be respected. In addition, the safety criteria in Annex I are also to be taken into account. There are also CMCs where some materials are excluded expressly. For instance, CMC 2 excludes blue-green algae (cyanobacteria) and, therefore, such materials cannot be present in any detectable quantity as impurities either. Finally, there are CMCs where there are no references to impurities at all. In such cases, the level of any impurities in the component materials has to be assessed taking into account the need for the product to remain safe and agronomically efficient. By Article 4(2) FPR, for any aspects not covered by Annex I or II, EU fertilising products have to not present a risk to human, animal or plant health, safety or the environment.

If the presence of impurities in detectable quantities must have been known to the manufacturer (such as a significant level of plastics in CMC 2), he or she is not using the material as described in the CMC, and the product is not compliant. Furthermore, if an unknown impurity poses a risk to, for instance, the environment, the product may be compliant, but both the EU countries and the Commission can react and take the appropriate

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measures in accordance with Articles 38-41 FPR. In addition, if needed, the Annexes to the FPR could also be amended to adopt generally applicable measures to deal with such risks.
In addition, the FPR applies without prejudice to Regulation (EU) 2019/1021 on persistent organic pollutants.

6.5.2 Evolvement of substances over time (compliance with the REACH registration obligations)

Some substances may evolve over time, especially when in contact with soil. In most of cases, the transformation is an expected and desired outcome.
REACH Regulation exempts from the registration substances which result from a chemical reaction that occurs incidentally to exposure of another substance to environmental factors.

For instance, some additives degrade to a metabolite due to exposure to environmental factors or storing conditions or in connection with the end use of the EU fertilising product. The metabolite as such would not be covered by the extended REACH registration requirement imposed by the FPR.

Key results

- Definition of Bio-based fertilisers

- Association of economically prime important nutrient recovery products with Bio-based fertilisers

- Exemption of ‘sewage sludge’, ‘industrial sludge’ and ‘dredging sludge’ in the FPR.

- Identification of the presence of contaminants in bio-based input streams and their potential accumulating effect on soil contamination as a precondition that hampers the deployment of Nutrient Recovery options in WW Treatment facilities

- Fertilising product production from animal by-products, such as ABC Animal Bone Char is defined in the CMC 14 (EU) 2021/2088 pyrolysis and gasification materials as a component material category in EU fertilising products.- EU Fertilising Products Regulation criteria for recovered struvite proposed are under finalisation (see the final STRUBIAS report Sept. 2019). Recovered struvite already has End-of-Waste status.

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7 Evaluation of economically prime important nutrient resource-based products

7.1 REACH registration of economically prime important nutrient resource-based products

REACH (EC 1907/2006) aims to improve the protection of human health and the environment through the better and earlier identification of the intrinsic properties of chemical substances. All REACH relevant and chemically modified substances above 1 t/y capacity for manufacturing, import or placing on the market are mandatory to REACH apply, with capacity classes 1-10 t/y, 10-100 t/y, 100-1000 t/y, above 1000 t/y. Requirements for generation of information on substances should be tiered according to the volumes of manufacture or importation of a substance, because these provide an indication of the potential for exposure of man and the environment to the substances, and should be described in detail. Waste, as defined in the EU's waste legislation 'Waste Directive', is exempt from REACH, but a product recovered from waste is not. REACH applies for any substance, mixture or article one recovers from waste that meets the end of waste criteria that ceases to be a waste and becomes a product. The steps towards this process involve Product Information Collection and Analysis > Registration of Substances > European Chemicals Agency (ECHA) Registration Evaluation > Ruling on Substances by the ECHA > REACH Certification.

7.1.1 Utilisation of recovered substances by manufacturers of EU fertilising products

Under certain conditions, manufactures of EU fertilising products can rely on the REACH registration by other operators for a recovered substance. The requirement for REACH registration in the FPR is considered fulfilled if operators are recovering a substance from a waste stream and have not themselves submitted a REACH dossier to ECHA because they are relying on the registration done by another operator. The registration previously done by the other operator has to fulfil the conditions specified in the relevant provision in the FPR, meaning to cover the use of the substance or mixture as a fertilising product.

7.1.2 Exemptions from the REACH registration obligations

Article 2(7)(d) REACH lays down the situations when a substance, on its own, in mixtures or in articles, recovered from waste in the territory of the Union, is exempted from the registration obligations.
According to this Article, operators 'recovering' such a substance do not have to submit their own REACH registration dossier if certain conditions are met:
(1) the substance has already been registered by another operator;
(2) the recovery operator can demonstrate that the recovered substance is the same as the one already registered; and
(3) the information to be communicated through the supply chain in accordance with Articles 31 or 32 REACH is available to the establishment undertaking the recovery of the substance.

7.2 Economic analysis of recovered nutrients

The commercialisation of recovered nutrients is limited, therefore, there are currently limited data for the accurate market values. Some economic data for struvite and calcium phosphate precipitates are presented in Table 7-16 (Enyemadze, Momade, Oduro-Kwarteng, & Essandoh, 2021), (Daneshgar, Buttafava, Callegari, & Capodaglio, 2019), (BioPhosphate 100 % Natural, 2022). For their more accurate interpretation, the efficiency of the incorporated form of P should be considered as it is a common notion that the commercial fertilisers are

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more economically viable options for end-users (farmers, agricultural associations) given the already evaluated efficiency of P in them (Roberts & Johnston, 2015). Plant-available phosphorus has been extensively tested in routine soil analysis and can be distinguished between immediately available or readily available and extractable in soil solution. Other forms include less readily and much less readily available and extractable. Recovered nutrients and economically prime important nutrient resource-based products still cannot compete with these options. in this evaluation, it should be kept in mind that struvite production in the recovery systems consumes less energy than production of other P-containing fertilisers (e.g. triple superphosphate).

Table 7-16: The estimated market values of struvite and calcium phosphate precipitates

Material	Market values	
Raw Phosphate rock	830-1120 €/t	0.6-1.2 €/kg P
Struvite	310 €/t	2.6 €/ kg P
Struvite	220 €/t (Japan)	
Struvite	300-500AUS $/t (Australia)	
Phosphate-based fertilisers		1.9-3.3 €/kg P
Triple superphosphate	498 €/t	
ABC Animal Bone Char BioPhosphate	500 €/t (BIO-NPK-C formulated compound 750 €/t)	1.2 €/kg P

Economic incentives for nutrient recovery are scarce for it is still economical to utilise phosphate rock and industrial ammonium for fertiliser manufacturing rather than struvite or calcium phosphate precipitates as supplementary fertiliser in agriculture or as the raw materials, respectively.
In the Nutrient Recovery processes, the adaptable to the nutrient concentration operation costs depend on the respective yield and risk the system economic feasibility. The market price of the recovered materials as enabled by the process, along with the economic benefits from the Nutrient Recovery processes should be enough to cover the operational costs.
The viability of the recovered nutrients as commercially sold products is currently limited. Moreover, in the case of the estimated struvite price, it depends not on Nutrient Recovery technology and the concentration on the bio-based input stream but also on the Mg source (magnesite, magnesium sulphate/chloride/oxide), the Mg content, the Mg/P ratio. This factor does not only depend on market demand and product quality but also on governmental policies.

Key results

- The first step towards the valorisation of bio-based input streams needs to be completed by the compliance of economically prime important nutrient resource - based products that derive from the implementation of Nutrient Recovery practices on bio-based input streams with End-of-Waste criteria and Registration Evaluation Authorisation and restrictions for Chemicals.

- Currently, commercially available fossil-based fertilisers outcompete the utilisation of economically prime important nutrient resource (food and waste water) - based products as Bio-based fertilisers.

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8 Conclusions

- This report is submitted (end of June 2022) during a global attempt to redistribute natural resources due to the realisation of their depletion and a period of raking up in the EU-27 regarding the valorisation of bio-based input streams for the manufacturing of Bio-based fertilisers.
- The continuously evolutionary attempts of EU-27 towards this end are verified by the publication of updated databases in the last 60 days.
- The mapping attempts of bio-based input streams, Nutrient Recovery technologies and economically prime important nutrient resource-based products in Europe are without doubt intensive. However, published data pertain to the EU matrix status of 2020. Although some conclusions can be drawn for that period of time, covering the evolutions in this two year gap is of immense importance.
- The final application of Reg. (EU) 2019/1009, which entered into force on July 15th, 2019, on July 16th, 2022 is highly indicative that the EU matrix has come one step closer to handling economically prime important nutrient resource-based products from waste and waste water management as bio-based fertilisers.
- The valorisation of bio-based input streams (Urban WW, sewage sludge, food, Industrial WW and brine) into marketable fertilising products or components is urgent and is guided and directed by accurate legislation for such products to enter the EU market.
- Mapping of the bio-based input streams predicts/controls/avoids the presence of potentially toxic elements, poly aromatic hydrocarbons, pharmaceutical residuals, microbiological pathogens etc. whose accumulation is hazardous in their valorisation as bio-based fertilisers.
- The assembling of the 'Urban WW Treatment map' (European Environment Agency, 2022a) is accompanied by the registration of pollutants (not valorised nutrients) emissions in the European Industrial Emissions Portal (Industrial Reporting Database, 2022) . Both these attempts need to be accompanied by the intensive mapping of the constantly evolving status of the Nutrient Recovery practices and of the recovered nutrients in both the Urban and industrial WW sectors.
- The EU attempts to develop tools and strategies for the efficient implementation of Nutrient Recovery. Follow-up support and monitoring is accompanied by the increasing number of knowledge partners involved in Nutrient Recovery/WW treatment projects. Tools and strategies need to be developed for the recognition of nutrient-rich WW streams that are disposed of without their components valorisation and the stimulation of Nutrient Recovery technology implementation.
- Phosphorus (P) is a non-renewable resource, production of nitrogen (N) fertiliser is energy intensive, and discharge of NPK nutrients in treated waste water causes environmental eutrophication. Hence, recovery of nutrients from municipal waste water has attracted attention. Urban WW and sewage sludge, industrial WW, food waste and brine are progressively investigated as bio-based input streams for Nutrient Recovery.
- Bio-based fertilisers with a little to none post-processing required can be produced by struvite and electrochemical P precipitation. Regarding struvite precipitation, Mg salts, pH adjustment and drying would be required. Regarding electrochemical precipitation, filtration and drying are required.
- EU Fertilising Products Regulation criteria for recovered struvite proposed are under finalisation (see the final STRUBIAS report Sept. 2019). Recovered struvite already has End-of-Waste status.

Nutrient Recovery sustainability remains to be evaluated in the outlines of conventional systems for the manufacturing of fertilisers currently outcompeting the valorisation of WW and food waste –based input and recovered nutrients as bio-based fertilising products.

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