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School of Chemical and Bioprocess Engineering - UCD

Nutrient recovery and recycling from wastewater in Ireland, with associated policy gaps and recommendations.

Policy brief

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Summary:

Nutrient recovery from wastewater can play a crucial role in improving the quality of Ireland's waterbodies, while reducing the dependency on fertiliser imports and the energy consumption of the wastewater treatment sector.

Technologies for nutrient recovery are already available, but their adoption can be fostered through dedicated regulations.

1. Legislation to support nutrient recovery and recycling should be uniform and homogeneous across the EU.
2. More ambitious limitations for cadmium and uranium in fertilising products, as well as more flexible discharge regulations can promote the adoption of recovered phosphorous based fertilising products.
3. Continuous monitoring and assessment of the effects of new regulations are crucial to prevent the shift of environmental problems from one sector to another.

Economic instruments are also necessary:

1. Life cycle assessments of the impact of traditional fertilisers can help factor in the indirect costs associated with current approaches.
2. Incentives/penalties can significantly increase the adoption of nutrient recovery.
3. A shift towards "polluter pays principle" could be considered for the current discharge limitations.

Increasing the awareness of the importance of nutrient recovery remains essential:

1. Awareness campaigns targeting both policy makers and the public are necessary.
2. Dedicated training for the wastewater treatment plant operators

1 Introduction.

Nitrogen, phosphorous and potassium, together with carbon, are the nutrients at the basis of life, and thus they are widely used as fertilisers in agriculture and food production. Historically, fertilisers were only obtained from organic sources (e.g. manure), but at the beginning of the 20th century they became extensively available following the development of industrial processes for their large scale production, and the demand for these man-made fertilisers are steadily increasing.

Raw materials for producing industrial fertilisers are not globally available; more than 85% of the global phosphate reserves are located in five countries, and among them Morocco is projected to provide 80% of the world supply by 2100 (Cooper, Lombardi, et al., 2011). European Countries import over 90% of the demand from US and China (*Consultative Communication on the Sustainable Use of Phosphorous*, 2013). Potassium-containing salts (e.g. KCl) and mineral phosphates have become the main source of both potassium and phosphorous fertilisers as result of increasingly efficient processes to mine them and convert them into soluble forms that plants can use.

Phosphate rock was added to the EU critical raw material list in 2014 (*EU*, 2014), as well as white phosphorous in 2017 (*EU*, 2017). As there is no substitute for phosphorous in food production, this might jeopardise food security, especially considering that the world population is expected to reach 9.7 billion over the next 30 years (ONU, 2019) and that the pro-capita meat consumption is also increasing (animal derived food require 7-10 times phosphorus than crops - Metson, Bennett, et al., 2012).

Ireland is the 9th largest fertiliser consumer in the EU (European Environment Agency, 2015). Only one third of Ireland phosphorous requirements comes from indigenous sources (mainly cattle and pig slurry, poultry waste, dairy processing sludge and municipal wastewater sludge), and it is necessary to import 43 000 tonnes of phosphorus alone every year (O'Donnell, Egan, et al., 2021).

The majority of nitrogen-based fertilisers used in agriculture are manufactured using ammonia as raw material. At present, ammonia is mostly produced through the Haber-Bosch process, which is energy intensive and responsible for roughly 2% of the global energy consumption (Desloover, Abate Woldeyohannis, et al., 2012). Industrial fertilisers obtained from Haber-Bosch ammonia are so widespread that they are estimated to have originated roughly 80% of the nitrogen currently found in human tissues (Howarth, 2008). Similarly,

Natural gas is required for ammonia production, which makes the fertilisers industry vulnerable to prices volatility. As an example, in recent months a combination of reduced natural gas export from Russia, increased demand from China and India and reopening after COVID-19 restrictions, has resulted in a very sudden and significant increase in the natural gas price in Europe (Bond, Cornago, et al., 2021). The Ukraine-Russia war further exacerbate the issue, which not only affected electricity prices, but also impact on the cost of fertiliser: according to the Irish Farmer's Association, the price of UAN (Urea/Ammonium/Nitrate) increased 228% compared to 2020, costing as much as 860 €/ton. A report from the Agriculture and Food development Authority suggests that increases in fertiliser prices in the order of 100% can be expected in 2022 (Teagasc, 2021).

Industrial fertilisers can also negatively impact the environment and ecosystems; High levels of nitrogen compounds can be toxic for certain organisms, can lead to soil and water acidification and even contribute to global warming when released into the atmosphere.

Excess nitrogen and phosphorous from both raw/untreated wastewater and agricultural activities is linked to algal blooms in aquatic ecosystems, which pose a threat to the life of plants and animals and reduce the quality of the water they live in. In particular, the decomposition of dead algae can create anoxic zones where the dissolved oxygen concentration is not sufficient to support most organisms (i.e. eutrophication). Moreover, eutrophication can also negatively affect human health, and directly impact on activities such as fishing industry and tourism.

According to the 2019 EPA report, in Ireland only 30.4% of the wastewater treatment plants are designed to provide secondary treatment with some form of nutrient removal, leaving more than 50% of the wastewater generated in urban areas treated below European Union standards (EPA, 2019). This presents significant challenges in terms of improving the currently insufficient infrastructure, but also substantial opportunities to reshape the wastewater treatment sector. For instance, nutrient recovery processes could be included in the layout of existing plants during revamping interventions.

Benefits of nutrient recovery from wastewater:

- Reduction in excess nutrients being released to the environment
- Recovered nutrients can be used as a fertiliser, reducing reliance on imported industrial fertilisers
- Reduced energy requirements (and therefore operational costs) at wastewater treatment plants
- Reduced GHGs emissions
- Contributing to water quality objectives of the Water Framework Directive (e.g. reducing pressures related to treated wastewater discharge)
- Contribution to the circular economy and the UN SDGs 6, 11, 12, 14
- Contribution to Foodwise 2030 – Mission 1, Goal 2, 3, 6

There is a growing awareness of the importance of recovering nutrients from wastewater, and the development of new processes and technologies is promoting a paradigm shift in the wastewater treatment sector. The nutrients dissolved in the wastewater are more and more being considered as a resource to be recovered, rather than merely as pollutants to be removed. Wastewater treatment plants are increasingly becoming water resource recovery facilities (WRRFs) capable of producing clean water and nutrients, as well as renewable energy, without abandoning their traditional role (human and ecosystem health) (Regmi, Miller, et al., 2019; Hamiche, Stambouli, et al., 2016).

2 Processes for nutrient recovery: an overview

Different technologies are available for the recovery of nutrients from wastewater. Table 1 gives an overview of the main processes that can be used to this purpose, together with a summary of the key challenges that are associated to their mainstream implementation. In the main report a detailed description of each process is presented.

Table 1 - Overview of nutrient recovery methods and key challenges for mainstream implementation

Process	Key challenges
Struvite and hydroxyapatite formation	• High operating costs (mainly due to Mg/Ca sources), increases the final product costs • Purity of the final product • More effective on concentrated streams
Adsorption/Desorption processes	• Identification of suitable chemicals to minimise impurities in the final product • Economic feasibility depends on the nutrient concentration stream
Membrane systems	• Membrane fouling
Bioelectrochemical Systems	• Further research and development required for full-scale implementation
Stream segregation technologies	• Significant modifications of the existing infrastructure might be required • Behavioural modifications required

3 Case studies

Processes and technologies for nutrient recovery are widely available, relatively mature, and well developed. For instance, the Veas wastewater treatment plant (Oslo, Norway) recovers ammonium through stripping and adsorption, producing ammonium nitrate with an efficiency of 88% (Ye, Ngo, et al., 2018). Another example of full-scale nitrogen recovery is operated in Italy, in two plants treating digested cattle manure (50 m^3/d and 100 m^3/d respectively). Through a series of physical/chemical treatments (N-Free® process), it is possible to produce up to 1.8 m^3 ammonium sulphate from every 100 m^3 of processed digestate (Ledda, Schievano, et al., 2013).

Among the different possible systems, the recovery of nitrogen and phosphorus in the form of struvite has been particularly successful, with a number of full-scale installations in different parts of the world, from North America, to Japan, to Europe (e.g. the Netherlands, Spain). In Japan, 16 full-scale plants are operated, producing both struvite and calcium phosphate through Gifu or PHOSNIX processes, and there is a strong collaboration between the steel, agriculture and chemical industries (Shaddel, Bakhtiary-Davijany, et al., 2019; Nättorp, Kabbe, et al., 2019). The Pearl process developed by Ostara is particularly relevant for nutrient recovery in Ireland. This technology recovers phosphorous and ammonia from nutrient-rich streams, and converts them to struvite. It is currently operational at 22 WWTPs (Table 2), both in North America and Europe (Siciliano, Limonti, et al., 2020), with the earliest implementation commissioned in 2009 in Portland, USA and the largest facility capable of producing 30 tonnes of struvite per day (Gysin, Lycke, et al., 2018). Up to 22% of the total phosphorous can be recovered from urban sidestream wastewater, and up to 95% and 15% of P and NH_3-N, respectively, from digestion supernatants.

Table 2 - Examples of full scale implementations of Pearl® process (Gysin, Lycke, et al., 2018).

Plant location	Plant PE	Start of operation
Slough - UK	250 000	2012
Amersfoort - NL	500 000	2016
Madrid - ES	1 200 000	2016
Chicago - USA	2 300 000	2016
Portland - USA	500 000	2009

This process was selected as part of the larger upgrade plan for the Ringsend wastewater treatment plant in Dublin, which is responsible for the treatment of over 40% of Ireland wastewater. Ringsend plant was designed for 1.64 million PE, but is currently overloaded, receiving wastewater for approximately 1.98 million PE (with even larger peak flows). As part of the retrofitting plan, a reactor for struvite crystallisation is scheduled to be installed in the plant layout. This crystalliser is designed for the production of 14 tonnes of struvite per day (Ostara Inc., 2021).

There is also a radically different approach which requires to move past the conventional combined sewers, in favour of a system that not only allows for dividing wastewater and meteoric water, but also for separate collection and individual treatment of different wastewater fractions. In the context of municipal wastewater, to separate the different streams (e.g. urine, faecal matters…) at the source would have clear benefits on the nutrient recovery. Human urine contributes for less than 1% of the total wastewater volumetric flowrate, but it contains more than 80% of the total nitrogen, and more than half of the total phosphorous and potassium (Larsen, Lienert, et al., 2004; Vinnerås and

Jönsson, 2002). Dedicated toilets (urine diverting toilets – UDTs) are already available in various models and at competitive prices. Pilot projects were also implemented in industrialised countries such as Denmark (Magid, Eilersen, et al., 2006), Germany (Winker, Vinnerås, et al., 2008), as well as India (Langergraber and Muellegger, 2005) and China (Zhou, Liu, et al., 2010). In Ireland, one example of stream segregation can be found in the Ballymum Rediscovery Centre (Co. Dublin), where composting toilets were introduced in the 2016 refurbishments, together with the urinal wastewater collection and use for plant nutrition within the internal comfrey wall. To retrofit existing infrastructure at residential scale is not economically feasible, but it might be possible to concentrate the efforts on public buildings such as cinemas, malls, stadiums or universities (in these settings, urinals are already commonly installed in the men's restrooms, which makes it easier to implement source segregation).

Nutrient recovery technologies alone are however not sufficient. In some cases, it is necessary to ensure that they are accepted by the public. For instance, approaches such as stream segregation do not only require retrofitting of the infrastructure, but also behavioural modifications. In this regard, information provided to the people is critical to promote a wide acceptance, as highlighted by surveys presented in the research report. Once the benefits of novel approaches were explained, the acceptance of new technologies or processes for nutrient recovery from wastewater and alternative products can increase.

4 Policy challenges and considerations

Regulations that favour the implementation of nutrient recovery technologies are also crucial, and can help promote their diffusion in many different ways.

- It is essential that the legislation is uniformed and homogeneous across the EU, for instance by ensuring that recovered nutrients are granted the status of products, which removes some obstacles to their trade across national borders.
- Cadmium and uranium often contaminate mineral phosphorous fertilisers, and the updated European fertilising product regulation failed to impose lower limits. More ambitious limitations for cadmium and uranium in fertilising products can help promoting the adoption of recovered phosphorous based products, while enhancing environmental protection (Garske and Ekardt, 2021).
- Continuous monitoring and assessment of the effects of the implementation of new regulations and policies remain crucial, as they have the potential to trigger the shift of environmental problems from one sector to another. For instance, an increase in crops cultivation for bioenergy purposes might result into a more extensive application of industrial fertilisers, and it is also possible that without homogeneous legislation the burden for the ecosystems are merely passed on to countries with less restrictive environmental protection laws (Garske, Stubenrauch, et al., 2020).
- Review of the current building regulations to allow for the inclusion of nutrient recovery approaches in new buildings, for example stream segregation opportunities in new public buildings.

A more sustainable nutrient management in Europe requires not only regulations, but also economic instruments.

- It is important to find ways to factor in the indirect costs associated with the current approaches, for instance fostering the research in terms of good and reliable life cycle assessments of the impact of traditional fertilisers in comparison to wastewater derived ones.
- To offer incentives for the production or purchase of fertilisers obtained from recovered sources, or to impose penalties on the ones produced from conventional sources can significantly increase the adoption of nutrient recovery.
- It could also be possible to envision a scheme analogue to the EU emission trading system, where the amount of extra nutrients that are allowed in a given area is limited, and recover and recycle are encouraged (Garske, Stubenrauch, et al., 2020).
- Modifications in the way the discharge limitations are designed can also be considered. For instance, the transition from the current approach, which is based on thresholds that should not be exceeded, to a system where the "polluter pays principle" is applied might prove beneficial in incentivising nutrient recovery from waste streams.

Finally, to raise awareness on the topic of nutrient recovery remains essential.

- Awareness campaign for policy makers to increase understanding around the benefits of nutrient recovery from both wastewater treatment facilities and through stream segregation approaches in public buildings.
- Awareness campaign for the public to increase understanding of the needs and benefits of nutrient recovery to increase public acceptance to the recovery of nutrients from wastewater.

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