Phosphorus as a strategic resource

Recommendations for action by the water industry to establish a market for secondary phosphorus

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Discussion paper by
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Management Summary

Phosphorus: strategic resource ...

- Phosphorus is a basic nutrient in our society: as a fertiliser, as animal feed and in a range of industrial applications
- In agriculture, phosphorus cannot be substituted and is therefore essential for security of supply

... and a critical raw material

- This great economic importance is offset by a considerable risk: Germany is 100% dependent on imports
- The EU is also largely dependent on imports
- Germany and the EU mainly source phosphorus from countries with low rule of law standards

There will be a recovery obligation from 2029

- Phosphorus can be recovered from sewage sludge; this is a resource that has not yet been tapped in Germany
- From 2029, sewage sludge producers must recover the highest possible quality of phosphorus from sewage sludge and operators of incineration plants must recover phosphorus from sewage sludge ash

This can be realised in two ways:

- In matrix decoupling with P extraction, the phosphorus is extracted from the ash matrix and separated as a defined (basic) substance, e.g. as calcium phosphate or phosphoric acid. It is also efficiently separated from heavy metals in the process
- In technologies with matrix retention, the phosphorus remains in the ash matrix, which is merely modified and remains part of the product. This results in only partial pollutant removal or dilution of the pollutant concentration

Only matrix decoupling fulfils the ambition of the AbfKlärV

- The Wastewater Treatment Ordinance (AbfKlärV) was amended with the aim of increasing environmental and resource protection and, in particular, further reducing the input of pollutants into the soil
- The input of pollutants can only be sustainably reduced if the pollutants are consistently removed from the cycle
- In the interests of a genuine circular economy, matrix decoupling with P extraction must take place

Therefore, an amendment to the DüMV to promote ash-based fertilisers does not make sense

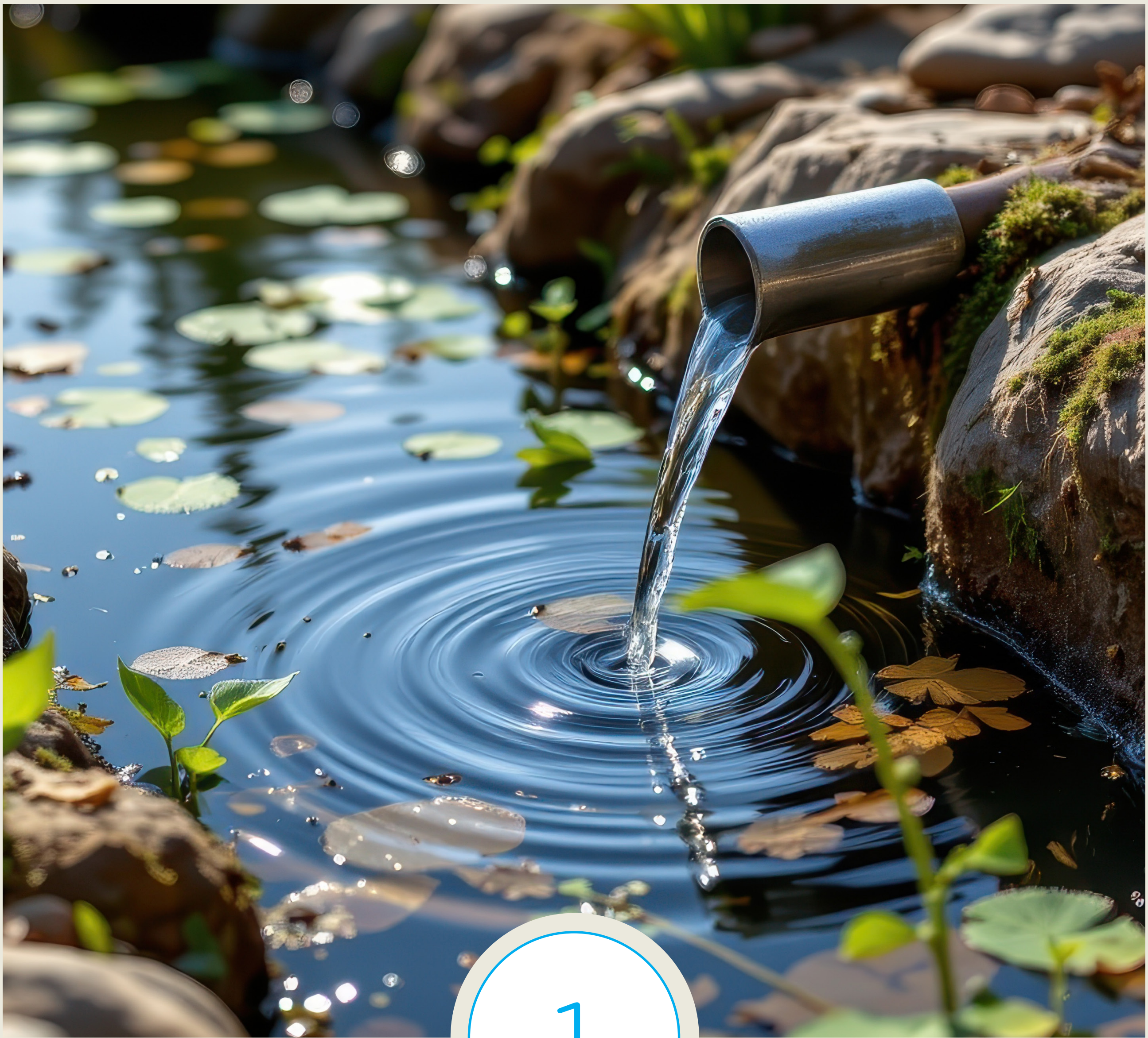
- Ash-based fertilisers can be produced using technologies with matrix retention
- Ash-based fertilisers return the pollutants contained in the ash to the soil and thus to the water cycle
- As sewage sludge ash is subject to landfill, pollutants that were previously extracted from the environment are returned to the environment
- There are calls in some quarters for the DüMV to be further developed in order to promote ash-based fertilisers
- This is not sensible and contradicts the idea of a closed cycle

A quota is needed to promote the marketability of secondary phosphorus

- The price of primary phosphorus reflects neither environmental externalities nor social costs
- A quota creates fairer competitive conditions
- The guaranteed purchase creates investment security; the costs for recycling are not only borne by pioneers, but are distributed among all market participants

Proposal for the design

- Scope of application: distributors of P fertilisers in the EU (EU manufacturers and importers)
- Quota model: start with a low quota (e.g. 5%) and gradually increase, also taking into account the (increasing) quantities on the market
- Hybrid model with certificates (physical admixture or purchase of certificates)



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12 recommendations for designing a Market for secondary phosphorus in Germany

For a genuine circular economy, pollutants must be consistently channelled out of the cycle

The Wastewater Treatment Ordinance (AbfKlärV) was amended with the aim of increasing environmental and resource protection and, in particular, further reducing the input of pollutants into the soil.[1] For a long time, it was common practice to return phosphorus to the material cycle through the soil-related utilisation of sewage sludge. In 2022, around 20% of sewage sludge was utilised in agriculture on a soil-related basis. However, this option is sometimes associated with a considerable pollutant load (including pathogens, drug residues, hormones).[2] The AbfKlärV restricts the soil-related utilisation of sewage sludge: From 2029, only sewage sludge from wastewater treatment plants with an expansion size of up to 100,000 population equivalents may be utilised on a soil-related basis, and from 2032 only sewage sludge from plants with an expansion size of up to 50,000 population equivalents.[3]

However, restricting soil-related utilisation is not enough to reduce the input of pollutants. The input of pollutants can only be sustainably reduced if the pollutants are consistently removed from the cycle and kept out.[4] In terms of a genuine circular economy, phosphorus must be extracted from the ash matrix and separated as a defined substance, e.g. as calcium phosphate or phosphoric acid, so that it can also be efficiently separated from heavy metals. In addition to the so-called matrix decoupling with P extraction, however, there are technologies with so-called matrix retention: Here, the phosphorus remains in the ash matrix, this is merely modified and remains part of the product. This results in only partial removal of pollutants. In order to fulfil the ambition of the amendment to the AbfKlärV, technologies should be examined to determine the extent to which they extract pollutants from the cycle. Only technologies with P extraction reduce the input of pollutants into the soil.

For a genuine circular economy, recovery technologies must also be scrutinised for resource conservation

Technologies with matrix retention - the matrix remains part of the product in modified form - must also be viewed critically with regard to the requirement for efficient resource utilisation inherent in the circular economy. In sewage sludge ashes, the phosphate is not chemically bound in a form that is available to plants. In order to dissolve it and make it available to plants, mineral acids are added - either sulphuric acid or phosphoric acid. However, sulphuric acid dilutes the P content and binds the dissolved calcium as gypsum. Phosphoric acid must then be added again to increase the P content. The use of a primary raw material to produce a secondary raw material is not considered sensible for ash-based fertilisers.

In the event of an amendment, the DüMV must be measured against the level of protection provided by the EU Fertiliser Products Regulation

There are some calls to promote the marketability of secondary phosphorus by further developing the German Fertiliser Ordinance (DüMV). This presupposes that the source materials of the fertiliser already comply with the pollutant limits of the DüMV. However, many sewage sludge ashes only fulfil this requirement after the phosphorus recovery process.[5] However, the production of fertilisers that contain phosphorus together with the ash matrix cannot be what the legislator intended. The AbfKlärV was amended with the aim of greater environmental and resource protection and, in particular, a further reduction in the input of pollutants into the soil. The input of pollutants can only be sustainably reduced if the pollutants are consistently removed from the cycle and kept out. In the sense of a genuine circular economy, matrix decoupling with P extraction must take place. Ash-based fertilisers return the pollutants they contain to the soil and thus into the water cycle. Of course, ash-based fertilisers are bound to pollutant limits and do not exceed them. However, the decisive factor is that the pollutants would have been completely removed from the environment without P recovery, as sewage sludge ash is subject to landfill.

In any case, there is no need for national regulations to promote ash-based fertilisers: unlike the DüMV, the EU Fertiliser Products Regulation allows sewage sludge ash to be used as a source material for fertiliser products - even if the ash itself does not meet the pollutant limits. For this purpose, a mass balance approach must be used to prove that the pollutants have been removed or reduced to values that are below the limits for the pollutants. This must not be achieved by dilution or mixing.[6]

Consequently, harmonisation with European law is desirable in the further development of the DüMV. If national fertiliser regulations continue to exist, the process chain should be taken into account, i.e. a distinction should be made between matrix decoupling and matrix retention. Decontamination and definability of the recyclate can only be ensured with matrix decoupling.

A centralised phosphorus recovery via the ash route, decoupled from the wastewater treatment plants, is recommended

The production and sale of secondary phosphorus and the associated assumption of product responsibility require resources and expertise that are not part of the core business of wastewater disposal companies. In addition, the market demands minimum purchase quantities that significantly exceed the production capacities of most disposal companies. Pooling volumes also offers advantages: On the one hand, the homogenisation of the recyclate is made easier against the background of the strongly fluctuating composition of sewage sludge or sewage sludge ash, and on the other hand, the product is less susceptible to operational disruptions specific to sewage treatment plants. For logistical reasons, it also makes more sense to transport the sewage sludge ash to centralised plants.

Specialisation along the secondary phosphorus value chain therefore makes sense: Sewage sludge producers send the sewage sludge for thermal utilisation (mono-incineration). The operators of mono-incineration plants process the sewage sludge into sewage sludge ash. Process suppliers accept sewage sludge ash from various sources, extract phosphorus from it and place it on the market.

Wastewater disposal companies often point out the difficulty of forming cooperations. In view of the market structure - hundreds of sewage sludge producers of different sizes spread throughout Germany - cooperations are particularly suitable. More in-depth research is needed into how cooperation between wastewater disposal companies can be promoted.

Transparency and commitment are prerequisites for building up the necessary capacities in good time by 2029

The operators of wastewater treatment plants are faced with the task of implementing a process by the beginning of 2029 for which there is still no proven solution. There is a mutual dependency between sewage sludge producers and process providers: process providers invest in capacities if sewage sludge producers commit to them in the long term; sewage sludge producers are reluctant to commit to process providers in the long term because this could result in financial disadvantages. To make matters worse, the technology and business model of process providers are often perceived by sewage sludge producers as a „black box“. A closer exchange between water companies and process providers is recommended here, as observed by phosphorus stakeholders in the UK or the Netherlands, for example. The exchange between process providers should also be promoted in a way that is compatible with competition.

Investment security requires binding deadlines and compliance with them should not lead to disadvantages

Planning and investment security also includes adherence to the deadlines set out in the AbfKlärV. In addition to adhering to the deadlines, it is important that sewage sludge producers who have endeavoured to implement the phosphorus recycling obligation on time are not disadvantaged. This could be implemented, for example, by levying a levy on sewage sludge producers who do not fulfil the obligation on time.

Long-term storage of sewage sludge ash is not a solution

The AbfKlärV permits the storage of sewage sludge incineration ash in a longterm storage facility[7] , provided that no mixing takes place and the possibility of later phosphorus recovery is guaranteed. The storage of ash is often seen as an obstacle to investment in recovery capacities. At the 101st Conference of Environment Ministers, it was noted that decisions were not made due to the possibility of longterm storage, among other things.[8] The German Phosphorus Platform (DPP) and the Association of Municipal Enterprises (VKU) advise against the longterm storage of ashes.[9,10] The additional expense for storage, retrieval and subsequent phosphorus recovery causes high costs compared to direct phosphorus recovery, which are avoidable. In addition, the problem is postponed to future generations.

Feed legislation must be adapted to enable the sale of secondary phosphorus

The current European feed regulation makes it impossible to sell secondary phosphorus as an additive in animal feed because no waste obtained from the treatment of waste water may be used. Opening up feed legislation to defined, quality-assured secondary phosphorus products would create new sales markets..

A recyclate quota creates market security, forces manufacturers to utilise it and promotes the development of a circular economy

The marketability of secondary phosphorus requires a level playing field between primary and secondary phosphorus. As the price of primary phosphorus does not reflect environmental externalities or social costs, secondary phosphorus is less attractive on the market, at least in terms of price.

Recyclate utilisation quotas can create fairer competitive conditions and thus increase the use of recyclates. Recent examples of recyclate use quotas include the EU Battery Regulation (2023), which provides for recyclate use quotas for certain metals, and the EU Packaging Regulation (2022), which provides for recyclate use quotas for plastic packaging.[11]

The guaranteed purchase through the quota creates investment security. The costs of recycling are not only borne by pioneers, but are spread across all market participants.

A quota for secondary phosphorus could be designed in such a way that it makes distributors of P fertilisers in the EU (i.e. EU manufacturers and importers) liable. It would be conceivable to start with a low quota (e.g. 5%) and a gradual increase, also taking into account the (increasing) quantities on the market. It would need to be clarified whether a physical addition of secondary phosphorus is mandatory or whether the obligation can also be met by purchasing certificates; this would then be a hybrid model with certificates. This would take into account, for example, the fact that many P fertiliser production sites are located outside the EU.

Calculation example:

- Domestic sales in tonnes of P/year for fertilisers: approx. 90,000
- A quota of 5% would mean a guaranteed purchase volume of 4,500 tonnes of recycled phosphorus per year
- According to a UBA study, the maximum potential for secondary phosphorus is 50,000 tonnes of P/year.
- The blending rate of 5% would mean that 9% of the available secondary phosphorus would be used

The public sector must strengthen the market and set an example by procuring products containing secondary phosphorus

Demand from the federal, state and local governments can create market potential and contribute to the circular economy: Public procurement has both market power and a role model function.[12] Municipalities also purchase fertilisers, for example for parks and cemeteries. According to Section 45 of the German Waste Management Act (KrWG), the public sector must favour products that have been produced by recycling waste, among other things. Nevertheless, in practice, procurers face concerns and hurdles that make it difficult to implement this preference. The conditions must be created to ensure that fertilisers containing secondary phosphorus can be given priority in public procurement, for example with separate quotas, the definition of evaluation criteria in procurement or guidelines for the evaluation of secondary phosphorus.

Fertilising with secondary phosphorus should be anchored in the Common Agricultural Policy

Fertilisers with secondary phosphorus should be anchored in the basic requirements for farm management and good agricultural and environmental conditions (GAEC standards).[13] In addition, there should be closer dovetailing between the Common Agricultural Policy, the EU Circular Economy Strategy and the EU Fertiliser Products Regulation.

The externalities of primary phosphorus must be priced in

The price of primary phosphorus does not adequately reflect the associated externalities (environmental damage, human rights violations, etc.). If these are priced in, primary phosphorus becomes more expensive and secondary phosphorus more attractive. Models for pricing in the externalities of primary phosphorus should be urgently developed and analysed. One proposal from the European Sustainable Phosphorus Platform (ESPP) is the expansion of the Carbon Border Adjustment Mechanism (CBAM).[14] The CBAM taxes emission-intensive goods when they are imported into the EU. This is implemented through the obligation to purchase CBAM certificates. The price of CBAM certificates is closely linked to European emissions trading. From January 2026, EU companies will have to purchase CBAM certificates for the emissions contained in imported fertilisers.[15] The ESPP proposes introducing a „Phosphorus Border Adjustment Mechanism“ (PBAM) for products containing phosphorus (fertilisers, animal feed, food).[16]

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Background: Phosphorus and the potential for recycling

Phosphorus is a raw material that is indispensable for global security of supply as a fertiliser and animal feed. It is also widely used in industry. This great importance is offset by a considerable supply risk: Germany has no natural phosphate deposits and is 100% dependent on imports. The majority of phosphorus is imported from countries with low rule of law standards. The phosphorus that accumulates in sewage sludge as a result of human excrement is a resource that has not yet been tapped in Germany. From 2029, it will be mandatory in Germany to recover phosphorus from sewage sludge and sewage sludge ash . This could unlock a potential of around 50,000 tonnes of phosphorus per year. This would cover a large part of the phosphorus demand in Germany. Recycling phosphorus not only contributes to Germany‘s independence, but also reduces the environmental and social impact associated with the production of primary phosphorus.

Phosphorus is an indispensable nutrient and basic material for our society

Phosphorus is a raw material that is indispensable as a nutrient for all life on earth. In humans, animals and plants alike, it is an indispensable building block of cells and genetic material and plays a central role in energy supply.[17] It cannot be produced from other substances, nor can it be replaced by other substances. As early as the last century, the author Isaac Asimov therefore described it as the *„bottleneck of life“*[18] .

Plants absorb phosphorus through the soil, humans and animals through their food.[19] Without human intervention, phosphorus is naturally cycled: Plants die and rot, the phosphorus is returned to the soil and is available for new growth.[20] This cycle is broken with the harvest. The soil is depleted and must be artificially supplied with nutrients[21]. Alongside potassium and nitrogen, phosphorus is one of the most important nutrients in agriculture. The majority of mined phosphorus is used in fertiliser production: Estimates range from around 80 to 95%.[22] Phosphate fertilisers are used extensively in both industrial and small-scale agriculture and are of fundamental importance for maintaining soil fertility and thus for global supply security.[23] The second most important application of phosphorus is also in agriculture, as animal feed.[24]

Phosphates that are not used in the fertiliser industry are referred to as technical phosphates.[25] Industrial phosphates are the basic material for a wide range of industrial applications, particularly in the food and beverage industry and in the cleaning agent industry.[26]

Excessive input of phosphorus pollutes the environment

Human intervention in the form of fertilisation can unbalance the natural phosphorus cycle.[27] For example, excessive phosphorus concentrations are measured at more than half of all monitoring sites on German rivers. The over-fertilisation of water bodies (eutrophication) triggers excessive growth of algae and aquatic plants and can lead to fish kills in extreme situations.[28] Technical phosphates exacerbate the problem of eutrophication, for example by allowing phosphorus-containing cleaning agents to enter water bodies via wastewater.[29] A decisive countermeasure is the production and use of fertilisers whose nutrient content is tailored to the needs of the soil. Other counter-measures include reducing the amount of phosphorus in products and improving the purification performance of wastewater treatment plants.[30]

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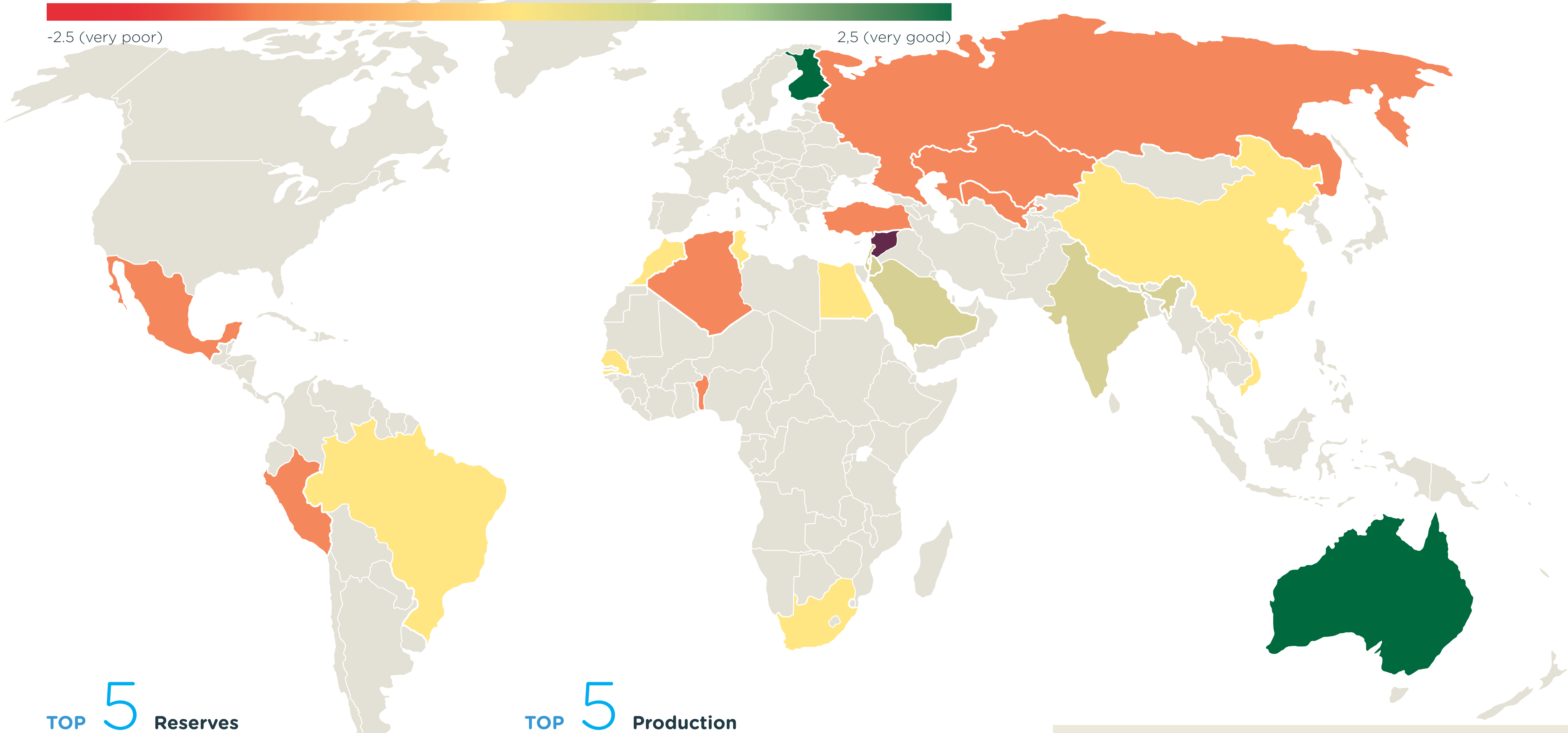
Phosphorus:

Phosphorus (symbol „P“, atomic number 15) is an essential element for all living organisms, as it is a main component of DNA and RNA and plays a role in energy transfer in cells. In nature, phosphorus does not occur as a free element, but mainly in bound form as phosphate (P_2O_5) , mostly in minerals in the earth‘s crust. In terms of quantity, phosphorus is one of the most common elements on earth. In the relevant literature, phosphorus is very often referred to as phosphorus, although it is actually phosphate.[55, 56, 57]

Phosphate is mainly found in countries with a low level of rule of law; by importing phosphate products, Germany and the EU are making themselves dependent on geopolitically difficult partners

Fig. 1: Countries that have phosphate reserves incl. labelling of the rule of law score 2023

Rule of law indicator of the World Bank 2023



TOP 5 **Reserves**

1. Morocco - 50 billion tonnes
2. China - 3.8 billion tonnes
3. Egypt - 2.8 billion tonnes
4. Tunisia - 2.5 billion tonnes
5. Russia - 2.1 billion tonnes

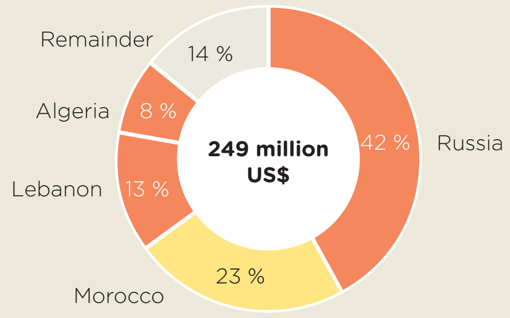
TOP 5 **Production**

1. China - 90 million tonnes
2. Morocco - 35 million tonnes
3. USA - 20 million tonnes
4. Russia - 14 million tonnes
5. Jordan - 12 million tonnes

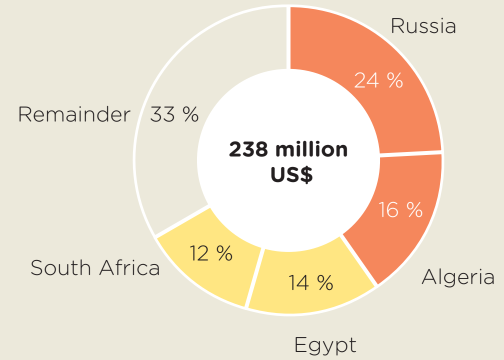
Source: U.S. Geological Survey 2025, World Bank 2025

Fig. 2: Imports of selected phosphorus trade products into the EU in 2023 by country of origin

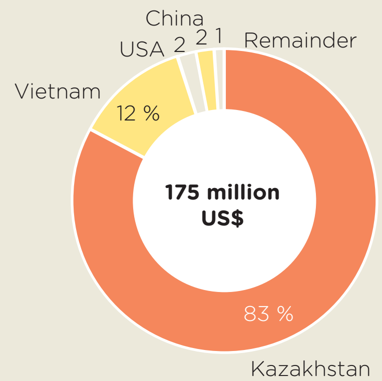
Natural calcium phosphates, natural aluminium calcium phosphates and phosphate rocks (not ground) (2510.10.00*)



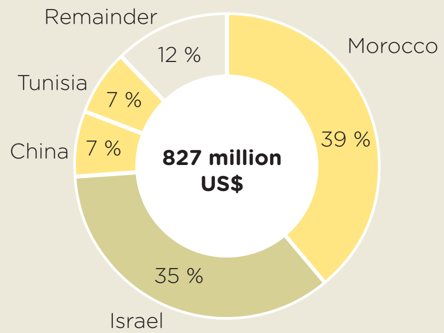
Natural calcium phosphates, natural aluminium calcium phosphates and phosphate chalks (ground) (2510.20.00*)



Phosphorus (2804.70*)



Phosphoric acid and polyphosphoric acids (2809.20.00*)



* Nomenclature used: H0 - HS 1988/1992

Source: World Integrated Trade Solution 2025

Germany is 100% dependent on imports for its phosphorus supply

The great economic importance of phosphorus is offset by a considerable supply risk: Germany has no natural phosphate deposits and is 100% dependent on imports.[31]

Phosphorus deposits worth mining are very unevenly distributed globally.[32] The U.S. Geological Survey (USGS) estimates that there are 74 billion tonnes of rock phosphate reserves worldwide. On the world map in Figure 1, the countries with known reserves are coloured in. According to the USGS estimate, Morocco has by far the largest reserves with 50 billion tonnes, followed by China with 4 billion tonnes.[33] An acute shortage of raw materials is not expected.[34,35] In addition, it is highly likely that new resources can be tapped.[36]

In 2023, the largest producer of rock phosphate was China with 90 million tonnes, followed by Morocco (35 million tonnes), the USA (20 million tonnes) and Jordan (12 million tonnes).[37]

Figure 2 shows EU imports of selected phosphate trade products. In 2023, the EU imported phosphate in the form of rock worth US$ 487 million. Unground phosphate came mainly from Russia and Morocco, ground phosphate mainly from Russia and Algeria. The largest import value was recorded for the trade product „phosphoric acid and polyphosphoric acids“ at US$ 827 million. The EU imported US$ 175 million worth of phosphorus, mainly from Kazakhstan.[38]

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The EU categorises phosphorus as a „critical raw material“.[39] According to the EU definition, these are raw materials that are *„considered critical due to their high economic importance and high supply risk, often caused by a high concentration of supply from a few third countries“.*[40]

The supply of phosphorus is subject to price and supply risks

The German Mineral Resources Agency regularly determines price and supply risks for various raw materials based on the country concentration (Herfindahl-Hirschman Index, HHI) and the weighted country risk (GLR). With regard to phosphate, five trade products are examined in the categories of stones, chemical products and fertilisers. As can be seen in Figure 3, all of these products were at risk in the last assessment in 2020, four of which were even at high risk[41].

Looking at the countries from which Germany sources these products, there has been a more critical risk since the 2020 risk assessment. In a press release from June 2022, the German Chemical Industry Association (VCI) warned of the strategic risk in the phosphorus sector because logistics from Kazakhstan take place via Russia and Belarus.[42]

The fertiliser industry is highly vertically integrated

The phosphate fertiliser industry is highly vertically integrated, meaning that most phosphate fertiliser manufacturers are active in mining themselves. Only 30% of phosphate fertiliser manufacturers rely on the purchase of rock phosphate or phosphoric acid.[43] Of the 5 members of the German Agricultural Industry Association (iva) that sell phosphate fertilisers in Germany, 4 have their own phosphate mines: ICL in Israel and China, Yara in Finland, EuroChem in Kazakhstan, Brazil and Russia and Compo‘s parent company, Grupa Azoty, in Senegal.

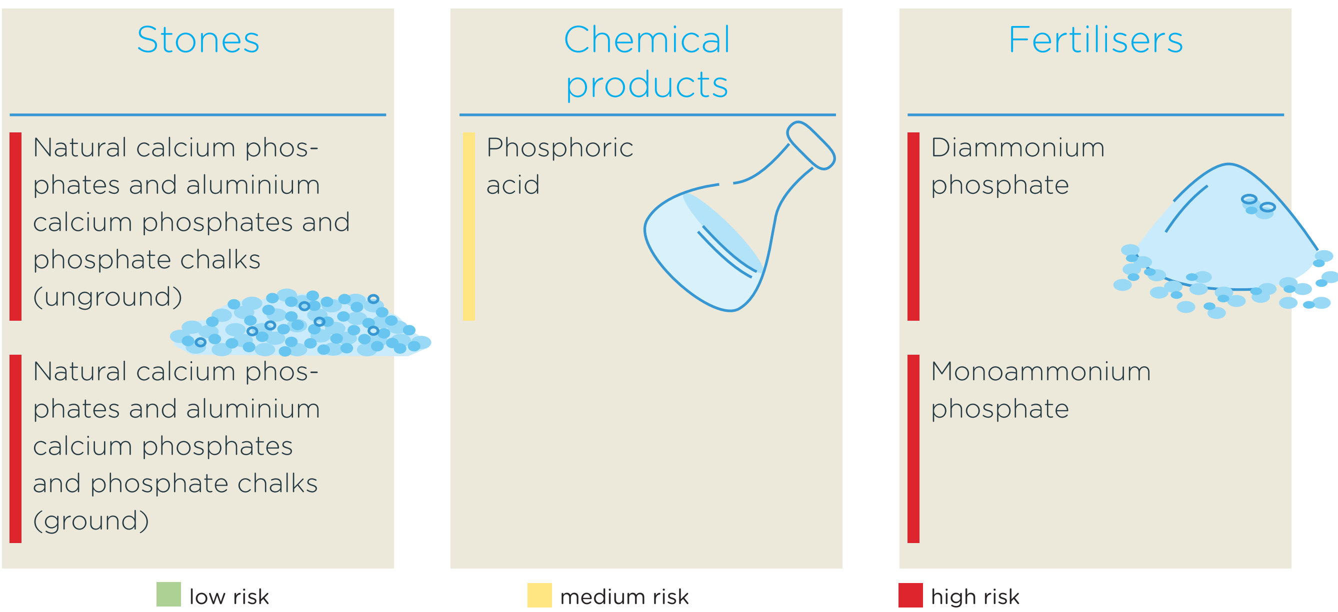
The trend towards vertical integration is continuing. The countries with the largest phosphorus deposits are increasingly taking over the value chains.[44] 80% of the raw phosphate mined worldwide is processed locally.[45] This not only has an impact on value creation potential in Germany, but also poses an additional supply risk because fertilisers are particularly affected by trade barriers.[46]

The embedding of the phosphorus value chain in larger political and economic contexts has an impact on the prices of fertilisers and food.[47] In its analysis of the fertiliser year 2024, the Industrieverband Agrar e.V. (IVA) lists numerous factors that have had an impact on the fertiliser market. In particular, disruptions in global supply chains caused by the coronavirus pandemic are still having an impact and are leading to higher transport costs and delays.[48]

Imports into the EU of phosphorus fertilisers from Russia and Belarus are not affected by the sanctions resulting from the Russian war of aggression against Ukraine due to existing dependencies and the relevance for security of supply. Intermediate products are also not affected. In 2023, Russia was the main importer of natural calcium phosphates to the EU (see Figure 2).[49]

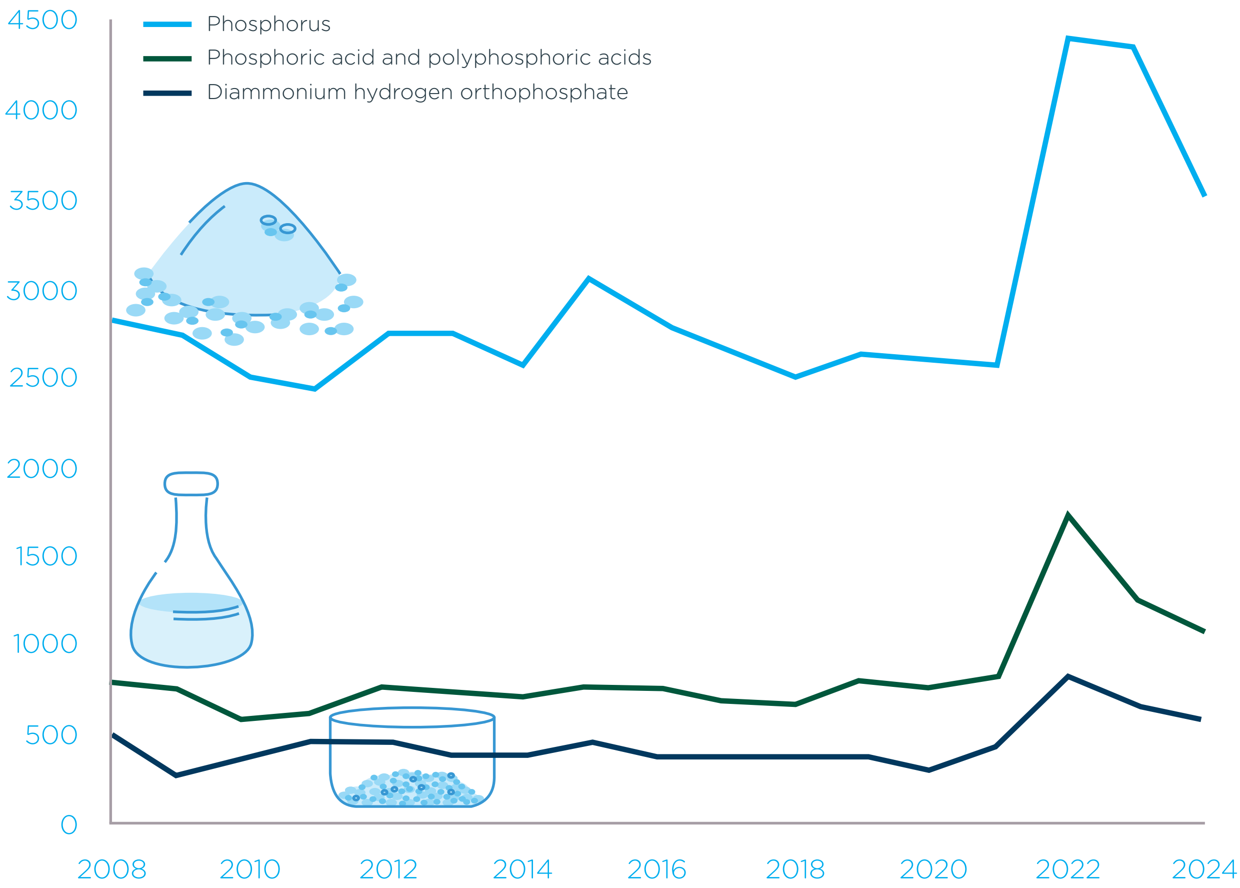
In 2024, the fertiliser DAP and the intermediate products phosphoric acid and phosphorus led the foreign trade statistics in terms of value among products containing phosphorus. In 2022, there is a sharp increase for all products; prices have not yet returned to pre-2022 levels (Figure 4).[50]

Fig. 3: Price and supply risks of 5 phosphorus trading products 2020



Source: DERA 2023

Fig. 4: Price development of three selected phosphorus-containing products in euros/tonne



Source: Destatis 2025

Rock phosphates of sedimentary origin have high heavy metal contents

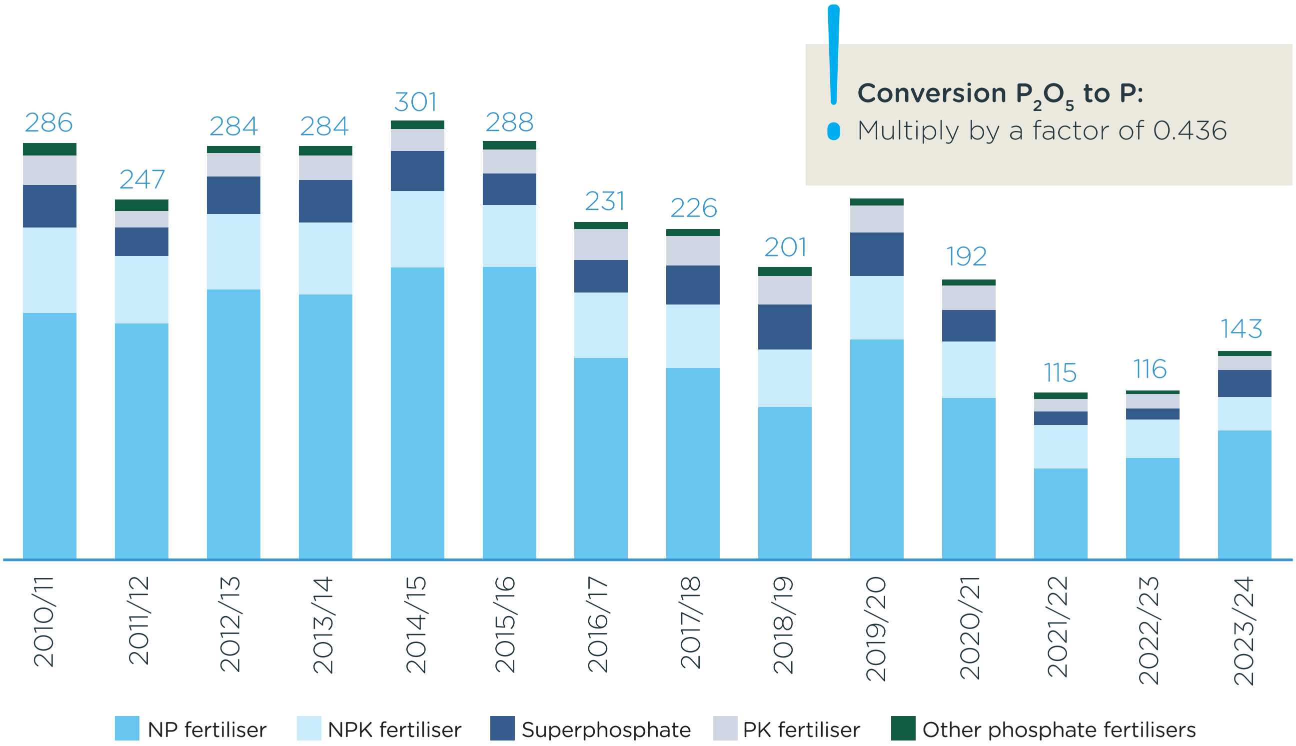
Another critical development for supply is the increasing pollution of primary phosphorus.[51] The rock phosphates mined from sedimentary sources are increasingly contaminated with toxic heavy metals (especially cadmium and radionuclides).[52] The rock phosphate imported to Germany from Russia in 2019 was of magmatic origin and had no relevant heavy metal content; the rock phosphate from Israel, Senegal and Morocco, on the other hand, was of sedimentary origin and had a high heavy metal content[53].

Phosphorus from sewage sludge could cover large part of the demand in Germany

Germany has no natural reserves of phosphorus, which is why the raw material is currently sourced exclusively from imports. According to fertiliser statistics, domestic sales* of phosphate fertilisers (in tonnes $P_2 O_5$ fluctuated between 115,000 and 301,000 tonnes per year in the period from 2010 to 2024, which corresponds to a range of 50,000 to 131,000 tonnes of P per year.[54]

* Deliveries by producers and importers to sales organisations or end consumers in Germany; sales and actual consumption may differ, e.g. due to stockpiling.

Fig. 5: Domestic sales of phosphate fertilisers in Germany by fertiliser type in thousand tonnes P_2O_5



Source: Destatis 2025

The phosphorus absorbed by humans and animals as well as the phosphorus used in industry is retained and is merely found elsewhere in the system. A significant proportion of the phosphorus is accumulated in the sewage sludge produced during wastewater treatment.

In 2022, 1.7 million tonnes of dry matter sewage sludge was disposed of from biological wastewater treatment, with the majority (80%) being disposed of thermally. 20% was utilised in agriculture in relation to soil.[58] The portion of municipal sewage sludge that was used as fertiliser on agricultural land had an average phosphorus content of 26 grams per kilogram of dry matter in 2016.[59]

There are various estimates of the phosphorus recycling potential in Germany. In an article from 2019, Christian Kabbe estimates the theoretical market volume from phosphorus recovery from sewage sludge with a recovery rate of 80% from the ash route at 40,000 to 50,000 tonnes of P/year.[60] In a 2018 study, the German Federal Environment Agency (UBA) also estimated the market volume of phosphorus recovery from municipal sewage sludge at 50,000 tonnes of P/year. If the phosphorus were recovered from sewage sludge ash, the market volume is also estimated at 50,000 tonnes of P/year.[61] If the market potential is compared with fertiliser sales in Germany, it becomes clear that a large proportion of the phosphorus required for fertilising could be covered from the domestic source of sewage sludge.

The wastewater industry has a decisive role to play in phosphorus recovery

The EU Urban Wastewater Treatment Directive, which comes into force in 2025, calls on EU member states to commit to the recovery of valuable resources.[62] Germany already introduced an obligation to recover phosphorus in 2017 through the Ordinance on the Reorganisation of Sewage Sludge Utilisation (AbfKlärV).[63] This ambition was already enshrined in the 2013 coalition agreement. In it, the German government plans to phase out the agricultural use of sewage sludge for fertiliser purposes and recover phosphorus and other nutrients.

The storage of sewage sludge incineration ash in a longterm storage facility is permitted, provided that no mixing takes place and the possibility of later phosphorus recovery remains guaranteed.

Conclusion: The recycling of phosphorus harbours great potential

At EU level, phosphorus is categorised as a critical raw material whose recovery is essential for the security of supply of the Member States. As part of the European Green Deal, which is now being continued under the name EU Clean Industrial Deal [64], the New Circular Economy Action Plan (CEAP) deals with the sustainable use of resources along the entire value chain.[65]

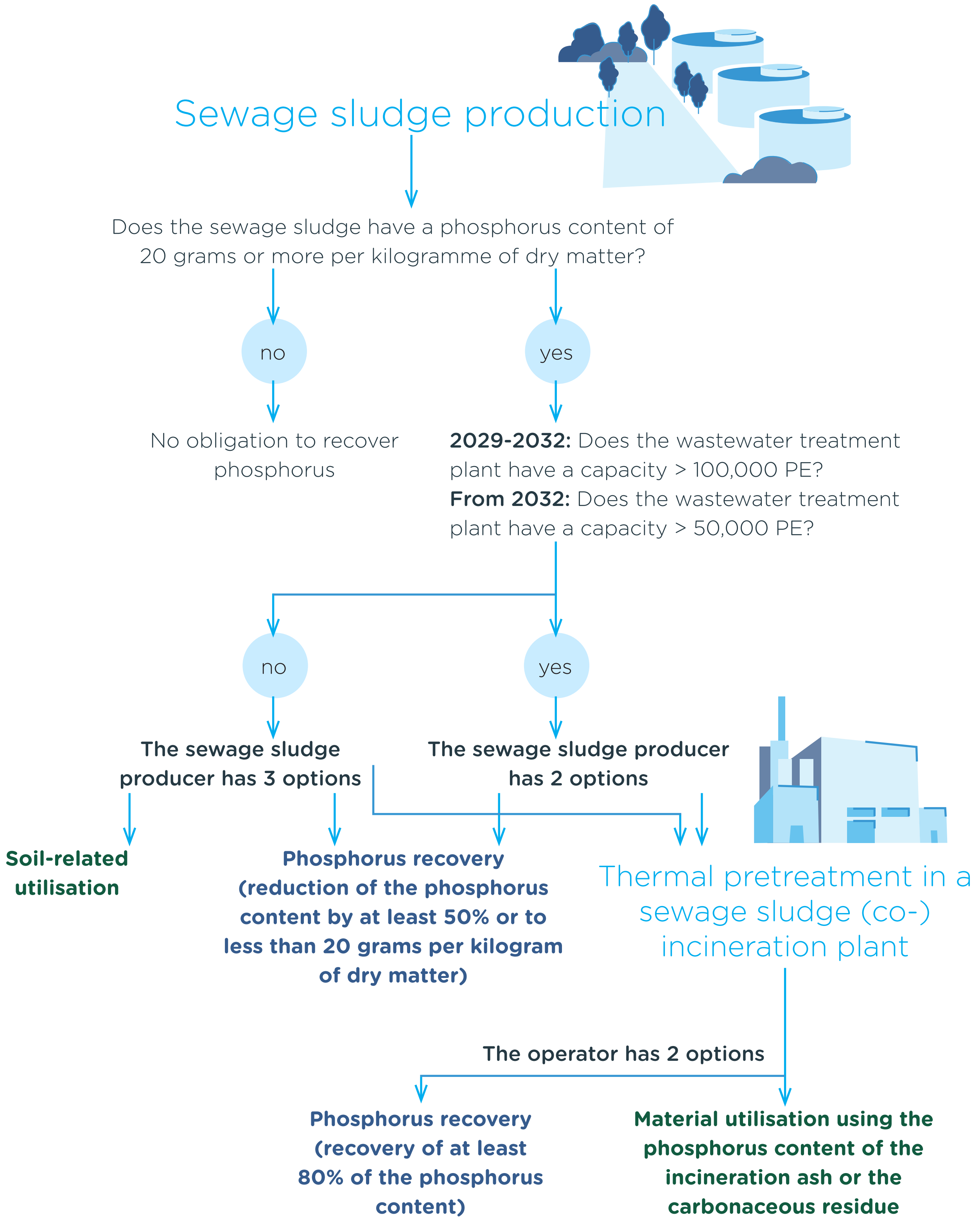
The Critical Raw Materials Act obliges member states to take measures to strengthen recycling.

In addition, the revision of the Urban Wastewater Directive requires member states to develop and implement measures to promote the production and acquisition of recovered nutrients such as phosphorus from wastewater and sewage sludge.

Germany passed this goal into law in 2017 with the Wastewater Treatment Ordinance (AbfKlärV). The 2021 coalition agreement formulates the goal of establishing a genuine circular economy and strengthening the recovery of strategic raw materials. This means that phosphorus recycling is moving more into the focus of political objectives than in previous legislative periods. The German government‘s National Circular Economy Strategy emphasises the importance of phosphorus recovery in reducing dependence on raw material imports and closing material cycles. A joint declaration by the federal government and 13 federal states provides for an immediate improvement in the conditions for the recovery of phosphorus.[66] This makes it clear that phosphorus recycling is both ecologically sensible and urgently needed to achieve political goals at EU, national and state level.

The storage of sewage sludge incineration ash in a longterm storage facility is permissible, provided that no mixing takes place and the possibility of later phosphorus recovery remains guaranteed.

Fig. 6: Organisation of the recovery obligation



The consistent recycling of phosphorus is the solution to a number of political challenges and ties in with existing political ambitions. The recycling of phosphorus…

- can help to secure the supply of raw materials in Germany and strengthen the resilience of supply chains and the resilience of the economy. It reduces Germany's dependence on countries characterised by problematic governance,
- can contribute to the stabilisation of phosphorus prices and thus to the stabilisation of fertiliser and food prices,
- offers the opportunity to relocate parts of the phosphorus value chain to Germany, to protect itself more effectively against trade barriers and to strengthen the local economy,
- lowers the demand for primary phosphorus and thus reduces the environmental impacts associated with the production of primary phosphorus,
- lowers the demand for primary phosphorus and thus reduces the socio-political externalities associated with the production of primary phosphorus (e.g. human rights violations)[67],
- increases the amount of available phosphorus and contributes to the diversification of phosphorus sources. This is particularly relevant against the backdrop of a growing world population and a simultaneous shortage of fertile soils[68]
- offers Germany the opportunity to play a pioneering role and set standards for good practice with its phosphorus recovery obligation, which was introduced at an early stage compared to other European countries

3

The market for primary phosphorus is dominated by few producers

The demand for phosphorus in Germany was estimated at around 195,000 tonnes of phosphorus in 2014. Phosphorus is mainly used in agriculture as fertiliser and animal feed. Most of the phosphorus used in Germany is extracted in mining. The market is dominated by a few players that are vertically integrated and use the phosphorus extracted from their own mines to produce fertilisers. There is only one production site for P fertilisers in Germany.

Phosphorus is mainly used in agriculture, as fertiliser and animal feed

Comprehensive and up-to-date figures on phosphorus consumption in Germany are not publicly available. The UBA has compiled the main product groups of phosphorus-containing products for 2014 and estimated the annual amount of phosphorus required in Germany at around 195,000 tonnes of phosphorus. They are listed in descending order of quantity in Figure 7. Phosphorus is mainly used as a fertiliser and animal feed in agriculture. In industry, phosphorus is mainly used in soaps and detergents and in metal treatment. [69]

Phosphorus is processed into products in several steps

Phosphate ore is the first step in the processing of phosphate-containing (intermediate) products. 85% of the phosphates currently mined come from sedimentary deposits. The majority is excavated in industrial, open-cast mining[70]. The ore usually has a concentration of 5-25% P_2O_5.[71] In addition to phosphate, they also contain other elements that can have a positive or negative effect on the value and usability of the phosphate .[72] Using physical processes such as grinding, washing, sieving and flotation, it is usually processed into phosphate concentrates, so-called rock phosphate, close to the open-cast mine.[73] The P_2O_5 content of marketable rock phosphate is between 27-40%.[74,75] Rock phosphate is the starting material for rock phosphoric acid, which in turn can be further processed into phosphoric acid.[76] The processing route from rock phosphate to fertiliser or to basic materials for industrial use is explained further in the respective chapters.

The phosphorus industry is highly vertically integrated

Phosphorus is processed into various fertiliser products

Ground phosphate can be applied directly to arable land. This practice mainly takes place in rural areas without market links and is in decline worldwide[77].

The starting materials for the production of fertilisers are phosphate concentrate or phosphoric acid.[78] A distinction is made between phosphate-containing straight fertilisers and compound fertilisers. Straight fertilisers are divided into superphosphate (22% P_2O_5) and other phosphate fertilisers. Complex fertilisers can contain potash (PK fertiliser), nitrogen (NP fertiliser) or both (NPK fertiliser) in addition to phosphate.[79]

Superphosphates are produced by acid digestion of dry rock phosphate.[80] Ammonium phosphates (NP fertilisers) are produced by neutralising phosphoric acid with ammonia; depending on the mixing ratio, monoammonium phosphate (MAP) or diammonium phosphate (DAP) is produced.[81]

Complex fertilisers can be mixed from basic components centrally in large industrial plants or close to the farm at local agricultural dealers or cooperatives. The mixing of fertilisers close to the farm has become an important part of fertiliser logistics.[82] Around 300 fertiliser mixing plants are now in operation in Germany, producing an average of 3,000 tonnes of mixed fertiliser, most of which is delivered in bulk.[83] At a national level, fertiliser blenders are organised in the Bundesverband der Düngermischer e.V.[84] , and at a European level in the European Fertiliser Blenders Association[85].

Fig. 7: Use of phosphorus in Germany in 2014

Source: own representation according to UBA 2015

The most important manufacturers are international, vertically integrated companies

The most important companies involved in the extraction of phosphate include the Chinese state-owned company Yunnan Yuntianhua Co., Ltd.[86], the Moroccan state-owned company Office Chérifien des Phosphates (OCP)[87] and the US company Mosaic[88]. These companies are all vertically integrated and active in the production of phosphate fertilisers.[89,90,91]

In Germany, there is only one company that processes phosphate ore into fertilisers, ICL Fertilizers Deutschland GmbH with a plant in Ludwigshafen.[92] In 2023, the phosphate fertiliser capacities of ICL Fertilizers Deutschland GmbH amounted to 230,000 tonnes of goods.[93]

ICL Fertilizers Deutschland GmbH is part of the ICL Group, a global fertiliser and speciality chemicals group from Israel with over 12,000 employees and sales of around USD 7 billion (2024).[94] ICL is a vertically integrated company. It extracts phosphate rock in the Negev Desert in Israel and in Yunnan Province in China. Green phosphoric acid is produced in plants in Israel and China with the addition of sulphuric acid. Most of the green phosphoric acid is used to produce phosphate fertilisers and pure phosphoric acid.[95] P, PK, NP and NPK fertilisers are produced at the Ludwigshafen site. The markets in Germany, France, Switzerland, Austria and Eastern Europe are served from there[96]

In 2024, 86,920 tonnes of phosphorus-based fertilisers worth €46 million were exported. NP fertilisers also account for the largest share here.[97]

In Germany, phosphorus is predominantly sold as NP fertiliser

According to fertiliser statistics, 142,905 tonnes of P_2O_5 were sold in Germany in 2023/2024. The largest share (62%) was accounted for by NP fertilisers, followed by NPK fertilisers (16%) and super-phosphate (13%) (see Figure 5).[98] Domestic sales of phosphate fertilisers for 2023/2024 correspond to approx. 62 tonnes of P.[99] As can be seen from Figure 5, it fluctuates greatly from year to year. A key driver for the demand for phosphate fertilisers is the supply of P to the soil.

In 2024, 86,920 tonnes of phosphorus fertilisers worth €46 million were exported. NP fertilisers also account for the largest share here.[100]

The foreign trade statistics of the Federal Statistical Office provide information on the import quantities and value of fertilisers. In contrast to the fertiliser statistics, the quantity refers to the quantity of the product and not the nutrient. In 2024, 427,432 tonnes of phosphorus-containing fertilisers worth €231 million were imported into Germany. NP fertilisers (DAP, MAP and other NP fertilisers) accounted for the largest share (88% of the weight, 91% of the value). DAP was imported at an average price of 584 euros/tonne, MAP at an average price of 668 euros/tonne.[100]

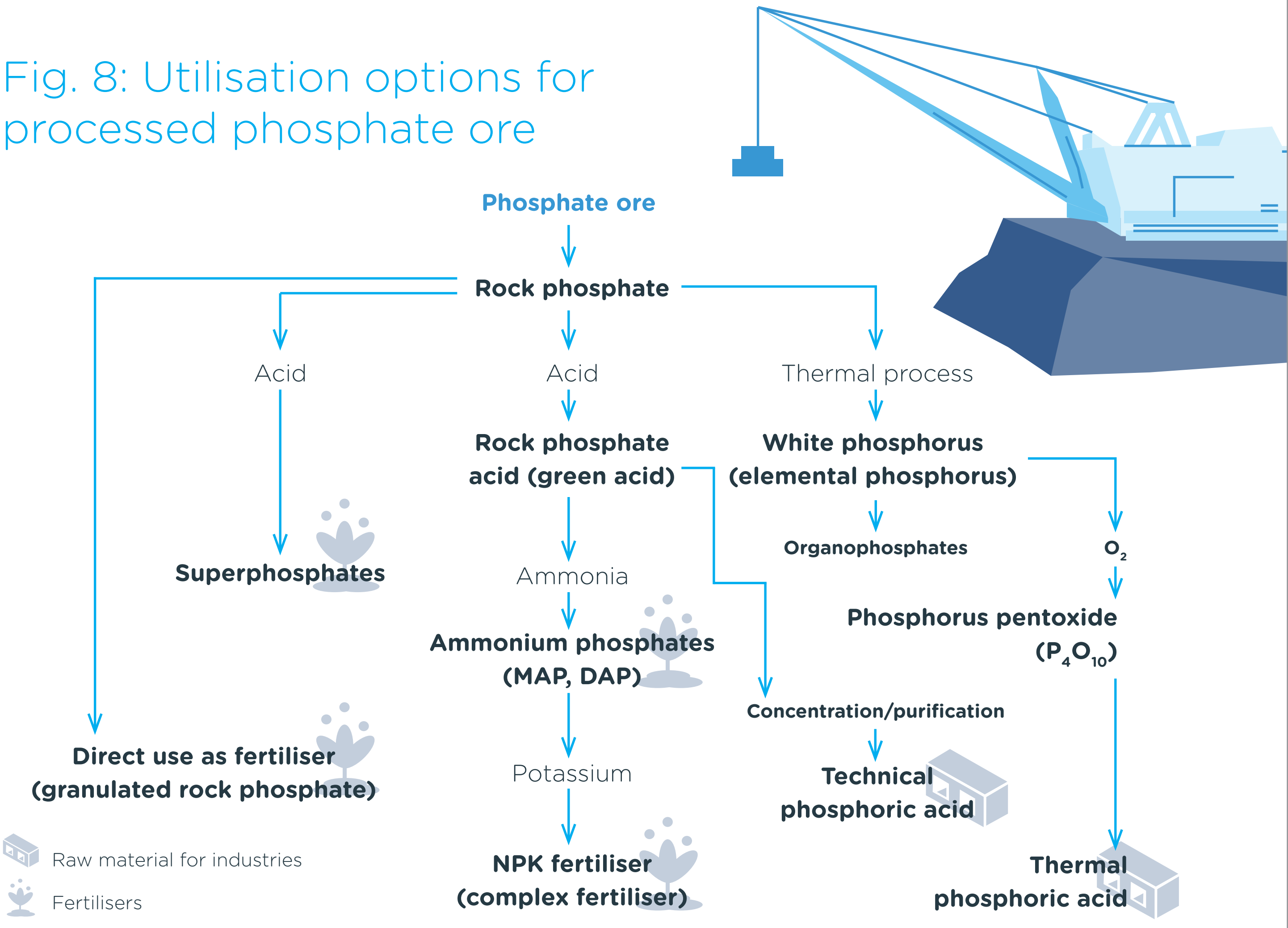
In agriculture, phosphorus is used as a feed supplement

Feed is supplemented with mineral phosphorus primarily via mono- and dicalcium phosphate.

Phosphorus is also used in industrial applications

Around 10% of the phosphorus extracted is used in industrial applications. Phosphorus is also known as the „nutrient of industry“ due to its wide range of uses in various manufacturing processes. The basis for these numerous applications is technical phosphoric acid or white phosphorus, which are also obtained from rock phosphate.[101]

Fig. 8: Utilisation options for processed phosphate ore



Source: own representation based on BMK 2021

In industry, phosphorus is mainly processed into phosphoric acid

Figure 8 shows the utilisation possibilities of processed phosphate ore (rock phosphate) for industrial applications.

Rock phosphate can be digested with hydrochloric, sulphuric, nitric or phosphoric acid in the so-called wet process. This produces rock phosphoric acid (also known as green acid), an acid that is heavily contaminated with heavy metals in particular. For industrial applications, this must be purified and concentrated. This produces what is known as technical phosphoric acid. T Phosphoric acid is the starting product for a wide range of technical applications.

Alternatively, rock phosphate can be further processed into white phosphorus using a very energy-intensive thermal process. White phosphorus is required for special applications.

Soaps and detergents are the main areas of application

In addition to agriculture (fertiliser, animal feed), soaps and detergents are the largest area of application for phosphorus. The amount of P used annually is estimated at 10,000-20,000 tonnes of phosphorus. Machine dishwashing detergents account for a significant proportion. They contain up to 35% phosphate in the form of polyphosphates .[102] The use of phosphates in detergents and fabric softeners is declining due to stricter environmental regulations.[103]

The demand for phosphates is increasing in other areas of the chemical industry, including for electromobility[104]. The demand for lithium for batteries, for example, is estimated to be around 215,000 tonnes of lithium carbonate equivalent in 2025. This corresponds to around 20,000 tonnes of lithium and requires around 100,000 tonnes of phosphorus worldwide.[105]

In 2017, 2.25 million tonnes of flame retardants were used, 20% of which are phosphorus-based with a global use of around 50,000 tonnes of phosphorus annually. The situation is similar for fire extinguishers.[106]

Global consumption of glyphosate, the most widely used herbicide, amounts to around 826,000 tonnes per year. The phosphorus content in the molecular formula of glyphosate is 18%.[107]

Phosphonates are used in water purification, water treatment (for example in cooling systems, osmosis and general water treatment), oil production and drilling, medicine, cosmetics and other areas. Global consumption amounts to around 60,000 tonnes of phosphonates per year, with a phosphorus content of less than 30%, which corresponds to around 20,000 tonnes of phosphorus per year.[108]

Industrial producers are no longer located in the EU

White phosphorus is no longer produced in the EU. The last European producer, Thermphos International BV, which accounted for the Union‘s total production[109] , went bankrupt in 2012[110].

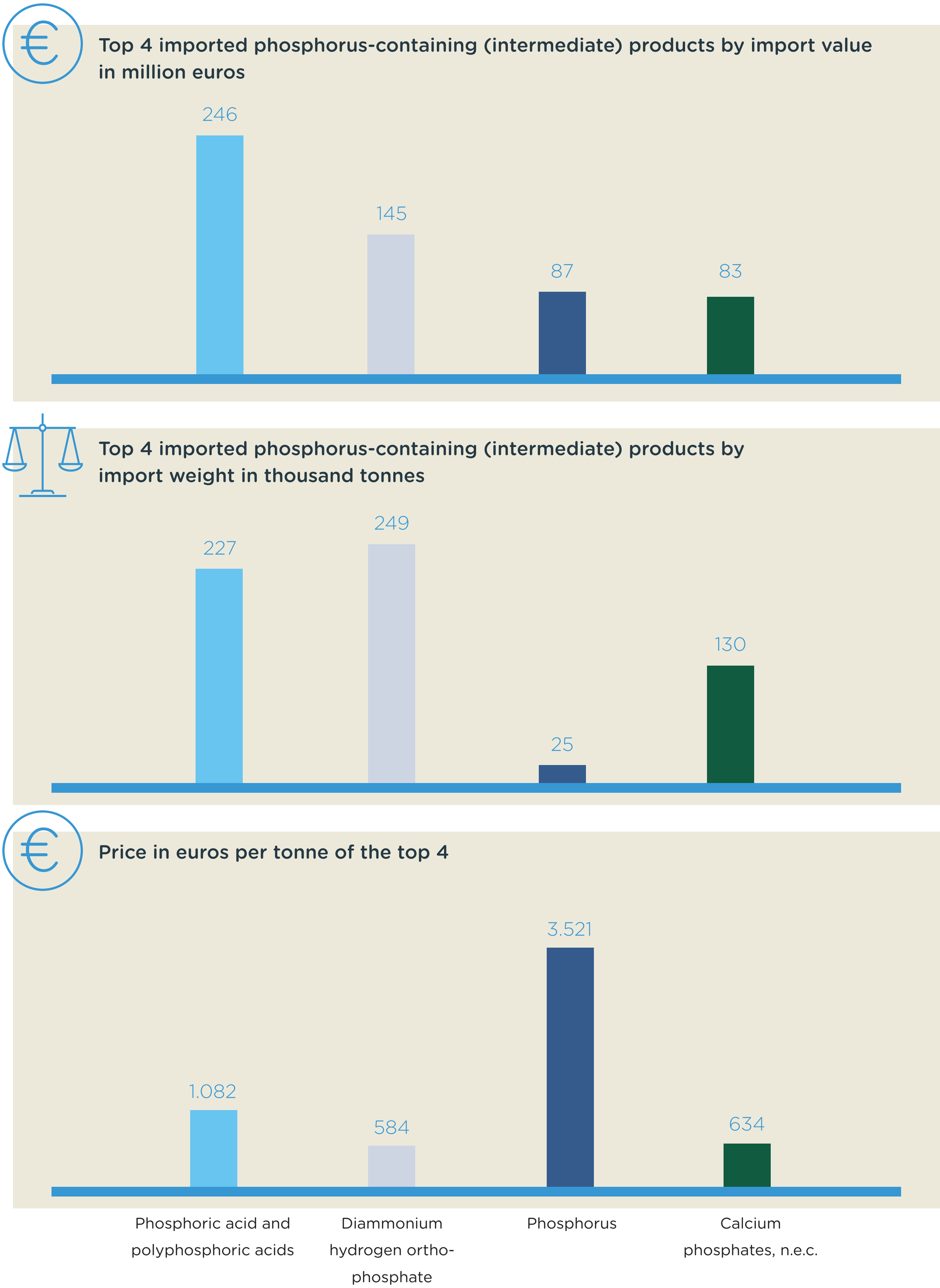
Prices

Foreign trade statistics provide information on the import of (intermediate) products containing phosphorus to Germany. As can be seen in Figure 9 , imports of phosphoric acid and polyphosphoric acids dominate in terms of import value in 2024, with an import volume of approx. 227 thousand tonnes at an average price of EUR 1,082/tonne. The second most important product is the fertiliser diammonium hydrogen orthophosphate (DAP) with an import volume of 249 thousand tonnes at an average price of EUR 584/tonne. In third place is phosphorus, with an import volume of 25 thousand tonnes at an average price of EUR 3,521, followed by calcium phosphates with an import volume of 130 thousand tonnes at an average price of EUR 634/tonne.

Figure 4 shows the price development of phosphoric acid and polyphosphoric acids, DAP and phosphorus between 2008 and 2024. Strong price increases can be seen in 2021-2022: +110% for phosphoric acid and polyphosphoric acids, +89% for DAP, +70% for phosphorus.[111]

The price of primary phosphorus does not reflect environmental externalities (mining consequences, radioactive pollution, energy consumption, CO_2 emissions from transport and processing) or social costs (e.g. human rights violations in mining regions). Geopolitical dependencies and the longterm scarcity of resources are also not priced in.

Fig. 9: Imports to Germany in 2024



Source: Destatis 2025

4

Technological and strategic issues need to be clarified when developing phosphorus recovery

Phosphorus recovery within the meaning of the AbfKlärV can start with sewage sludge or sewage sludge ash. Recovery from sewage sludge ash has proved successful. Technologies should be selected here that fulfil the ambition of the AbfKlärV amendment: Reducing the input of pollutants into the soil and establishing a genuine circular economy. The technologies with so-called matrix extraction achieve this. However, no technology has yet been implemented in regular commercial operation. This makes it difficult for sewage sludge producers to make a decision. It is to be feared that not enough capacity will be available by 2029.

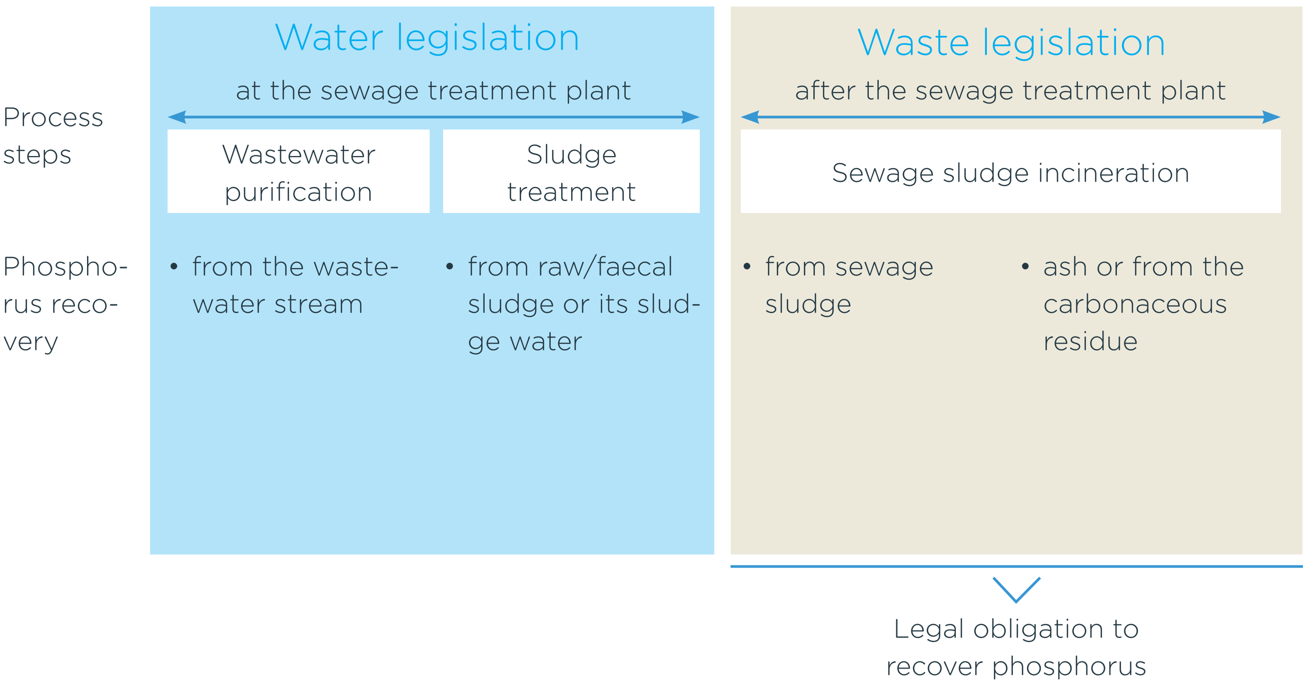
Extraction from sewage sludge ash is the most sensible way to efficiently recover phosphorus

As a special regulation under waste legislation, the AbfKlärV does not specify any particular technology for phosphorus recovery. According to the legislator, this should leave *„sufficient room for manoeuvre for the use or development of innovative recovery processes“*.[112] However, requirements regarding the recovery rate and a threshold value for the P content in sewage sludge are specified, which limits the actual possibilities for certain technical approaches.

Technically, phosphorus can be recovered using precipitation, crystallisation, adsorption, wet-chemical digestion, thermochemical and metallurgical processes. Recovery can take place at various points both at the sewage treatment plant during the wastewater treatment process or sludge treatment and after the sewage treatment plant from the sewage sludge or after thermal pretreatment from the ash or carbonaceous residue. Phosphorus recovery at the wastewater treatment plant from the wastewater stream or from raw/digested sludge or its sludge water is covered by water legislation, while recovery after the wastewater treatment plant is covered by waste legislation (Figure 10). The legal obligation to recover phosphorus is regulated exclusively by waste legislation. Recovery technologies within the meaning of the AbfKlärV are only those that start with sewage sludge or its by-products after thermal pre-treatment.

Processes at the wastewater treatment plant in accordance with water law only fulfil the obligation to recover phosphorus if the technology can remove sufficient phosphate during the wastewater treatment process. For this purpose, the threshold value of 2% in the sewage sludge dry mass applicable to the obligation must be reliably undercut (see Figure 6). These process approaches do not constitute recovery technologies within the

Fig. 10: The obligation to recover phosphorus is regulated in waste legislation



Source: own illustration

meaning of the AbfKlärV. Due to technological limitations, the use of such processes will only be utilised in individual cases in order to avoid the recovery obligation.

Processes for recovering phosphorus from sewage sludge have proven to be too complex or inadequate. Here, at least 50% of the phosphorus must be recovered or the phosphate content in the residue (in relation to the initial mass) must be less than 2% (see figure 6). Due to its organic content, the remaining residue would have to be sent for thermal waste treatment, so that there is no recognisable advantage over recovery from ash.

A distinction can be made between 3 approaches for processes with thermal pre-treatment :

- Thermo-chemical conversion under oxygen-reducing conditions (pyrolysis)
- Thermal oxidation (incineration) and
- Gasification

Some processes are also combined.

Technologies for recovery should be measured against the political ambition of the AbfKlärV: Reduction of pollutants and conservation of resources

In technologies with matrix decoupling, the phosphorus is extracted from the structure in which it is bound (the so-called ash matrix) and separated as a defined substance, e.g. as calcium phosphate or phosphoric acid. In this way, it is also efficiently separated from heavy metals. In technologies with so-called matrix retention, the phosphorus remains in the ash matrix, which is merely modified and remains part of the product. Although the AbfKlärV does not specify a technology, it was amended with the aim of increasing environmental and resource protection and, in particular, further reducing the input of pollutants into the soil. Only technologies with matrix decoupling fulfil the environmental protection ambition of the AbfKlärV. Technologies for the recovery of phosphorus should also be scrutinised in terms of their resource consumption. The use of primary phosphorus for the production of secondary phosphorus must be critically scrutinised.

No technology has yet been implemented in regular commercial operation. The HPHOR phosphorus recycling plant in Hamburg went into trial operation in 2021. Hamburg Wasser planned this with Remondis. According to Hamburg Wasser, the plant will produce 7,100 tonnes of phosphoric acid per year from 20,000 tonnes of sewage sludge ash in regular operation.[113] A plant is being built at the Schkopau Chemical Park in Saxony-Anhalt, in which EasyMining and Gelsenwasser are involved. The plant is scheduled to go into operation in 2027 and will have a capacity of 30,000 tonnes of sewage sludge ash per year.[114] A demonstration plant with a capacity of 1,000 tonnes per year was inaugurated in Bottrop in 2024. The plant was planned and built by Parforce Technology Cooperation GmbH (PTC) using PARFORCE Technology®. It is the first realisation on an industrial scale. The water management associations Ruhrverband, Wupperverband, Linksniederrheinische Entwässerungsgenossenschaft (LINEG), Emschergenossenschaft and Lippeverband (EGLV), all based in North Rhine-Westphalia, are involved.[115]

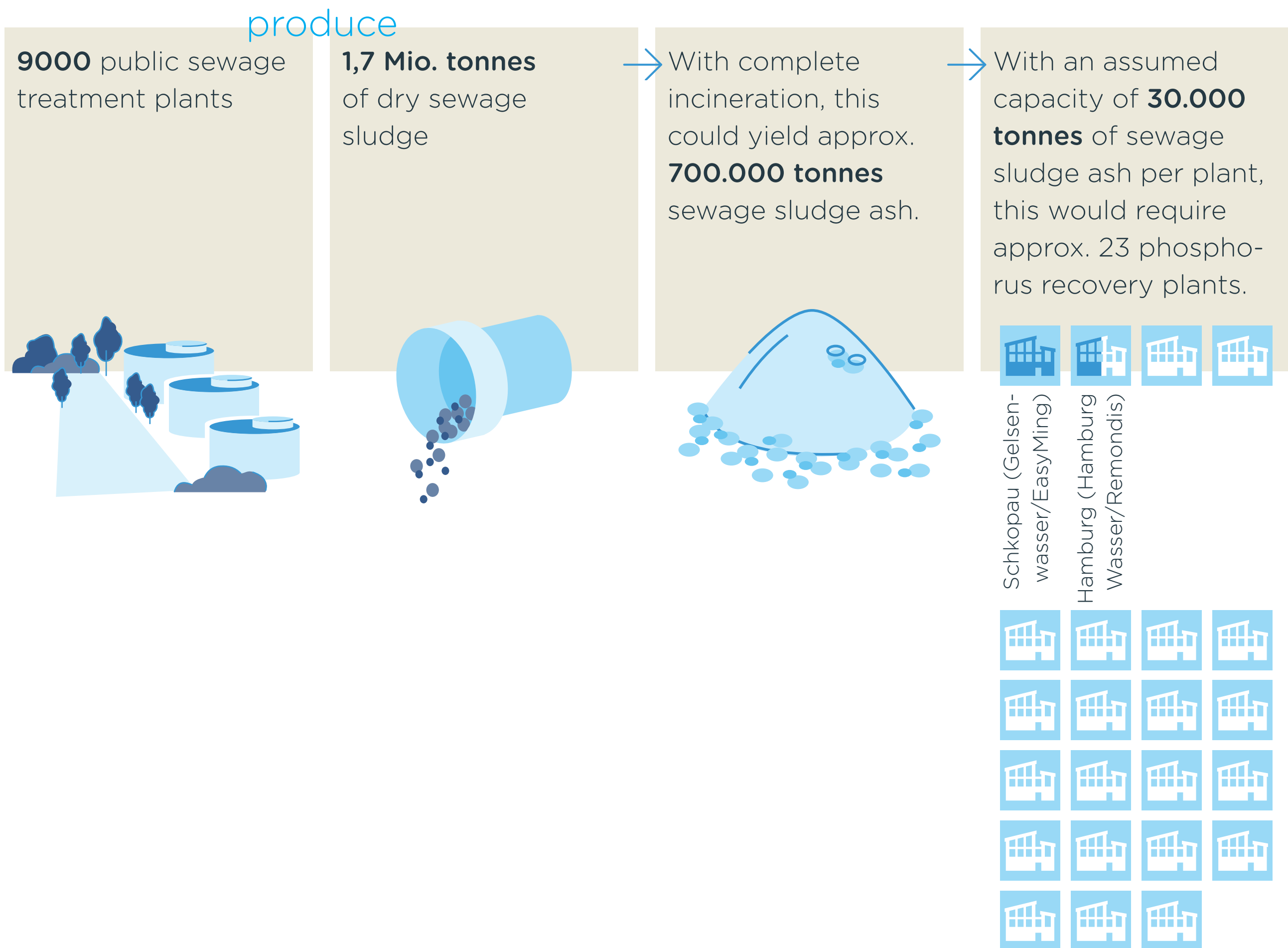
Sewage treatment plant operators must develop strategies for sewage sludge incineration and phosphorus recovery

Wastewater disposal companies are faced with the question of how to strategically position themselves with regard to phosphorus recycling, which is becoming mandatory for them. Strategic, technological, economic and financial criteria, as well as disposal security, are all taken into consideration.

The production and sale of secondary phosphorus and the associated assumption of product responsibility require resources and expertise that are not part of the core business of wastewater companies. In addition, the market demands minimum purchase quantities that do not correlate with the production capacities of individual sewage sludge producers. Sewage sludge incineration already shows that only very large wastewater disposal companies have their own sewage sludge incineration facilities. The remaining wastewater disposal companies decide in favour of participating in incineration plants or tendering the quantities to be disposed of. Similar developments are to be expected for the market structure in phosphorus recycling, so that wastewater disposal companies produce the sewage sludge and the ash is then sold directly or via the sewage sludge incinerators to the process providers for phosphorus recovery, who then also market the phosphorus. It is conceivable that the wastewater disposal companies will participate in these providers.

As things stand at present, this business cannot be fully financed from the marketing revenues from secondary phosphorus. In this context, the level of the world market price for phosphorus, the question of the extent to which quality differences compared to the raw material extracted in the mines have a positive effect on the price, operating processes of the recovery plants that are still being developed and not yet optimised, etc. play a role.

Fig. 11



The cost recovery principle applies when calculating wastewater charges. However, the costs of phosphorus recycling cannot be fully allocated to marketing prices, as the secondary phosphorus would then not be marketable. However, as sewage sludge disposal is an integral part of wastewater disposal, it is not necessary. The product offered to sewage sludge producers is therefore the legally compliant disposal of sewage sludge ash with integrated phosphorus recovery. Proceeds from the commercialisation of secondary phosphorus reduce the price of this service.

It is to be feared that the necessary capacities will not be available when the obligation comes into force in 2029

The obligation to recover phosphorus restricts established disposal paths, as thermal co-treatment, i.e. the incineration of sewage sludge together with other materials (e.g. coal, cement or waste), does not allow phosphorus to be recovered economically. Of the 1.7 million tonnes of sewage sludge disposed of in 2023, 37% was sent for thermal co-treatment.[116] Sewage sludge producers are therefore faced with the task of organising future sewage sludge disposal with phosphorus recovery in mind. The main obstacle here is that there is currently no important basis for decision-making. No phosphorus recovery technology has yet been implemented on a commercial scale. This presents sewage sludge producers and incinerators with the challenge of making technology decisions under uncertainty. It is still unclear which technology will work in a high-quality and cost-efficient manner. There is a concern about committing to technologies in the long term that will not be successful or that are comparatively expensive in the long term. In addition, only a few transparent publications are available for reasons of intellectual property protection. Stakeholders describe the situation as „muddled“: Compliance with the recovery obligation from 2029 already requires long-term decisions now, for which the basis is lacking. If these decisions are not made, process providers have no planning certainty and the probability that the capacities will be built on time decreases.

Assuming that it takes around 7 years from planning to commissioning to build recovery capacities,[117] it can already be said today that the recovery obligation set out in the AbfKlärV will not be met from 2029. Experts estimate that only 20% of the necessary capacities will be available when the recovery obligation is met in 2029.[118,119]

5

In order to be used on the market, secondary phosphorus must be turned from waste into a product

The EU Waste Framework Directive (EU WFD) implemented in Germany with the Closed Substance Cycle Waste Management Act sets out general principles for the end of waste management. In the fertiliser sector, the more specific provisions of the EU Fertiliser Products Regulation replace the provisions of the EU Waste Framework Directive. In addition to obtaining product status, the market also places requirements on the recyclates. For industrial fertiliser manufacturers, price, quality and quantity are crucial. Phosphorus must be continuously available in reliable quality and quantity.

Only in the fertiliser sector is there a product-specific end-of-waste regulation

The EU Waste Framework Directive forms the legal framework for the development of a circular economy. It was implemented in Germany with the Act to Promote the Circular Economy and Ensure the Environmentally Sound Management of Waste (Closed Substance Cycle Waste Management Act - KrWG). The EU WFD and KrWG do not focus on specific substances, but rather set out general principles.[120]

Art. 5 para. 1 of the EU WFD and Section 4 para. 1 of the KrWG regulate the distinction between by-products and waste. Accordingly, phosphorus from wastewater, sewage sludge and sewage sludge ash is waste. The termination of waste status and the return to product status is determined by Art. 6 Para. 1 EU WFD and § 5 Para. 1 KrWG. Accordingly, four requirements must be met. It is assumed that the recycled phosphorus is used for certain purposes (1) and that there is a market for recycled phosphorus or a demand for recycled phosphorus (2). Legal difficulties arise as to whether the recycled phosphorus fulfils the technical requirements for the specific purposes and complies with existing legislation and standards for products (3) and whether the use of the recycled phosphorus as a whole does not lead to harmful environmental and health impacts (4). In other words, whether and when recycled phosphorus loses its waste status can only be determined on the basis of the intended use and the applicable product and substance legislation.

In the fertiliser sector, the more specific provisions of the EU Fertiliser Product Ordinance replace the provisions of the EU Waste Framework Directive. The EU Fertiliser Products Regulation, which came into full force in 2022, laid the foundations for establishing a phosphorus circular economy, from the removal of phosphorus from the waste stream to obtaining the status of a fertiliser product.[121]

The EU Fertiliser Products Regulation stipulates that the substance first undergoes a recycling process, at the end of which it is contained in a compliant EU fertiliser product for which an EU declaration of conformity has been issued. This results in release into product status. Among other things, an EU fertiliser product must meet the requirements for the relevant product function category and for the relevant component material category. The requirements for the relevant product function category include minimum nutrient content and pollutant limits. The requirements for the relevant component material categories also include pollutant limits.[122] REACH registration is required for all substances used in EU fertiliser products.[123]

In addition to European fertiliser legislation, national fertiliser legislation continues to apply.[124] The German Fertiliser Ordinance (DüMV) defines not only the types of fertilisers but also the substances from which fertilisers may be manufactured. For residual materials and waste that are used as input and output materials for production, limit values and further requirements are defined depending on the type and origin. If sewage sludge ashes are used, both the ashes themselves and the sewage sludge before thermal oxidation must comply with the limit values specified in the DüMV. The limit values according to DüMV and AbfKlärV apply here. This also includes organic pollutants, which are usually no longer present in ashes. In addition to the limit values for pollutants, the amendment to the AbfKlärV on 1 January 2029 will also limit the return of pollutants by banning the soil-related utilisation of sewage sludge for larger sewage treatment plants and the use of ashes. For the majority of sewage sludge ashes, the direct use of ashes as or in fertilisers is therefore only possible to a very limited extent under current national regulations.[125]

Beyond the EU Fertiliser Products Regulation, there is no product-specific end-of-waste regulation for phosphorus recyclates, meaning that German recycling management law regulates industrial applications

In the EU, only substances that are registered for the respective intended use in accordance with REACH are authorised. In addition, industrial users, provided they are not waste recyclers, define chemical and physical requirements for their respective technical applications. Regardless of the degree of purity, secondary raw materials are generally not used if they still have the legal status of waste. Furthermore, they must be available as basic materials that do not require any adjustments to authorisations or processes.

For various waste materials such as glass, scrap metal, building rubble, etc., there are individual regulations that govern the end of waste status. For other waste, the requirements of the AbfRR or the KrWG apply. The decisive factor here is that a recycling process is carried out in each case and that a REACH-registered substance is created at the end or that its use is explicitly authorised under certain conditions by other product regulations. In the latter case, the waste is incorporated into a product.

The use of secondary phosphorus is not permitted in food and animal feed

EU Regulation No. 767/2009 (Annex III) prohibits the use in animal feed of all waste obtained from the treatment of waste water, regardless of whether this waste has been further processed. This means that the use of secondary phosphorus as animal feed is currently prohibited in the EU.[126] The use of secondary phosphorus as food is also currently prohibited.

The market also has product requirements for secondary phosphorus

Secondary phosphorus must be supplied as homogeneously as possible and in large quantities for fertiliser production

Price, quality and quantity are crucial for industrial fertiliser manufacturers. Phosphorus must be continuously available in reliable quality and quantity.

The minimum purchase quantity relevant for industrial fertiliser manufacturers is estimated by one market participant at 10,000 tonnes of calcium phosphate per year.[127]

Industrial fertiliser manufacturers are interested in secondary phosphorus that is as homogeneous as possible. Homogeneity is promoted by a centralised approach. The larger the bundled quantities from which the phosphorus is recovered, the better the heterogeneity of the initial sludge and seasonal fluctuations can be equalised.[128] Quality also includes low levels of pollutants.[129]

Market players are interested in secondary phosphorus in animal feed; however, this is not yet legally possible in the EU

According to market participants in the animal feed industry, the offer of secondary phosphorus has met with a favourable response. The decisive factors are the possibility of higher quality than primary phosphorus (low level of pollutants) and aspects of supply security.[130]

According to market participants, the supply of secondary phosphorus has also met with a favourable response in the industry

Security of supply is particularly important.[131] In the food industry, in addition to the current ban, it is questionable whether the use of secondary phosphorus could be accepted at all.[132]

6

The development of other secondary raw materials markets provides case studies

A look at the development of markets for other secondary raw materials (e.g. biowaste, plastics) can provide inspiration for the development of a market for secondary phosphorus. Instruments that have proven their worth in other secondary raw material markets include quality assurance through quality seals and handouts for procurers in the public sector.

The quality assurance for compost products has created a high-quality product standard that facilitates the utilisation of biowaste

Biowaste can be used to generate energy and heat as well as for agricultural purposes. Utilisation depends on the quality of the compost. Depending on its consistency and moisture content, bio-waste can be turned into compost, fertiliser (fermentation residue or ash) or energy, e.g. in the form of biogas.[136] As part of the Circular Economy Act, the separate collection of biowaste became mandatory for all waste producers and public waste management organisations from 2015 in order to enable targeted recycling for energy and heat generation as well as for agricultural use.[137]

In Germany, 14.09 million tonnes of biowaste were recycled in 2022.[138] Of this, 7.44 million tonnes were processed in fermentation or combined fermentation and composting plants. The rest was treated in pure composting plants.

The majority of sales of compost and digestate go to conventional agriculture (50.7%).[139] The market for organic farming (5.9%), hobby gardening (6.8%) and e.g. earth works (24.2%) is growing.

In 2024, around 5.2 terawatt hours of electricity could be generated from biowaste[132] , which accounts for just over 1% of electricity consumption in Germany.[140] The demand for compost and digestate currently exceeds the supply.[141]

Fig. 12: Utilisation of the recycling potential of biowaste for successful sales b[133,134,135]

Criteria for success	Challenges	Measures
Quality of the compost	• Partial contamination by foreign substances and heavy metals • Consumers' persistent reservations about compost due to the content of foreign substances and heavy metals	• Quality criteria for compost as proof of quality (RAL quality assurance, voluntary application) • Introduction of standardised assessment methods such as batch analyses or organic waste bin inspections
Product development along the value chain	• Variation in the composition and consistency of biowaste • Energy losses during composting	• Realising the full recycling potential by strengthening fermentation plants • Increasing the proportion of further processing products (e.g. topsoil material)

Criteria for success	Challenges	Measures
Customer groups	• Conventional agriculture as the primary customer • High costs due to services (e.g. transport)	• Diversification of products to open up a broader range of customers (e.g. organic farms in addition to conventional agriculture through co-operations, e.g. with Bioland) • Development of markets without a need for services (e.g. hobby gardening and landscaping) • Targeted market segmentation, e.g. consideration of settlement structures (lower demand in urban centres)
Political and legal framework	• Lack of clarity about pollutant and nutrient content in compost • Lack of availability of biowaste	• Criteria for the utilisation of biowaste in the Biowaste Ordinance of 1998 • Introduction of the separate collection obligation for municipalities (§20 KrWG) 2015[144] • Introduction of the Fertiliser Ordinance[145,146] for the regulation and presentation of pollutants and nutrient content in compost • Requirements for farmers, e.g. minimum organic matter content in the soil to receive subsidies

Practical examples I Quality assurance: trust on the market through recognised quality assurance

The Bundesgütegemeinschaft Kompost e.V. (BGK) offers voluntary RAL quality assurance for manufacturers of compost products, which is coordinated with institutions from science, specialised authorities and consumers. Quality-assured products include finished compost, fresh compost and substrate compost in various grain sizes. These products are used for soil improvement and fertilisation; substrate compost and finished compost are also used for the production of soils and growing media. BGK is an independent, neutral organisation recognised by RAL (German Institute for Quality Assurance and Labelling). Quality assurance creates a high-quality product standard that creates trust in the market, guarantees legal certainty and points the way from waste to product.[143]

A key measure to promote the recycling of plastic is a recyclate utilisation rate

Plastic waste can be processed into new products through mechanical recycling.[137] The quality of the recyclates depends on the purity and pollutant content of the source material. Depending on their purity and composition, recyclates are used in various areas, for example in the manufacture of packaging, construction products or consumer goods.

Under the German Packaging Act (VerpackG), manufacturers and distributors are obliged to collect and recycle packaging waste. The aim is to increase recycling rates and promote the use of recyclates.

35% of plastic waste is mechanically recycled, 0.4% is recycled as raw material or chemically.[148] A further 64% can be processed for energy recovery, i.e. thermally utilised to generate heat and electricity. Material processing, i.e. new plastic goods such as packaging, are the more valuable reuse. Almost 100% of the approx. 5.7 tonnes of plastic waste disposed of each year is recycled. Plastic recyclates in Germany are mainly used for construction (40%), but also for packaging (28%) and in agriculture (12%), as well as for vehicles and electronics, furniture and household and leisure goods.

Fig. 13: Utilising the recycling potential of plastic waste for successful distribution

Criteria for success	Challenges	Measures
Quality: High material quality and purity[149]	• Challenging plastic sorting due to mixing with adhesives, etc. • Necessity of sorting purity for high-quality recycling	• Use of modern sorting technologies • Strengthening financial incentives for recycling-friendly packaging design[150] • Utilisation of quality standards such as DIN standards[151]
Reliable market conditions and demand [152]	• Lack of price competitiveness compared to primary plastics	• Introduction of minimum use quotas for recyclates in certain products[153] • Obligation of public institutions to prioritise recyclates in procurement since (Section 45 (2) KrWG) • Guidance on increasing the demand for plastic recyclates from the Federal Environment Agency[154] • Possible use of special levies and excise duties or CO_2 taxes on plastic products[156]

Criteria for success	Challenges	Measures
Legal/political framework	• Low recycling rates for plastic • High CO_2 emissions from plastics • Environmental pollution	• Introduction and implementation of the Packaging Act from 2022: obligation for manufacturers to offer reusable packaging; strengthening of separate collection and deposit, recyclate quotas [157]

Case study of plastic products: Guidance for procurers of plastic products

According to Section 45 KrWG, the public sector must, among other things, give preference to products that have been manufactured by recycling waste. There are concerns and hurdles in procurement practice. As part of the research project „Examination of specific measures to increase demand for recycled plastics and plastic products containing recycled plastics", a guide for procurement officers was developed. As an information and tendering aid, it explains ecological, political and legal motives, provides information on technical possibilities and limitations and explains the procurement law regulations and design options for procurement. It also contains specific formulation suggestions for awarding contracts, some of which are backed up with examples and evaluation matrices. [155]

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