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RoadMap

V4's resilience in the face of pandemic in raw materials & food sector

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1 INTRODUCTION

Phosphorus (P) is a fundamental, non-substitutable nutrient for all living organisms on Earth, including plants and animals. It plays a key role in binding deoxyribonucleic acid (DNA), regulating various enzymes, photosynthesis, and plants' respiration (Ding, Cong and Lambers, 2021). P is the second most crucial macronutrient in terms of limiting plant growth and productivity in agricultural systems (Lambers, 2022). Plants take up from soil P available as inorganic orthophosphate and transform it into organic forms. Absorbed P support fundamental processes of crop growth and maturity ensuring soil fertility. Since the lack of P in the soil reduces the yield and quality of agricultural produce, fertilisation is critical in agricultural practice (Turner and Raboy, 2019).

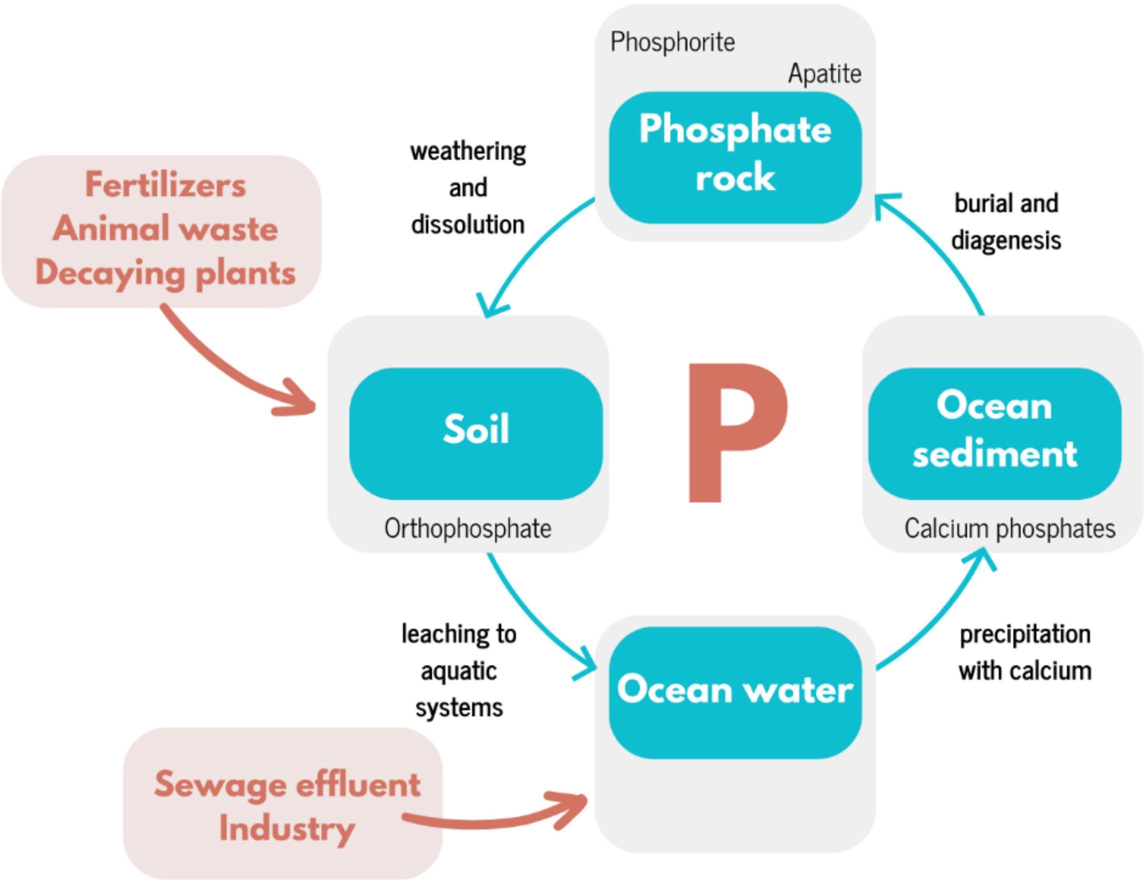

Figure 1 | P cycle flow (Turner and Raboy, 2019)

The use of phosphate fertilisers increased significantly in last decades, boosted crop yields, and contributed to feeding billions of people. It is estimated that 90% of the global demand for P is for food production, as a fertiliser or feed (Cordell, Drangert and White, 2009). Without this supply world food security cannot be maintained.

However, modern farming systems are dependent on mineral P fertilisers derived from non-renewable deposits of phosphate ores. The primary resources to produce phosphate fertilisers are phosphates, sparingly soluble sedimentary rocks, which form deposits in various parts of the globe. Approximately 60% of the P applied to cropland comes from this non-renewable resource (Wu et al., 2016).

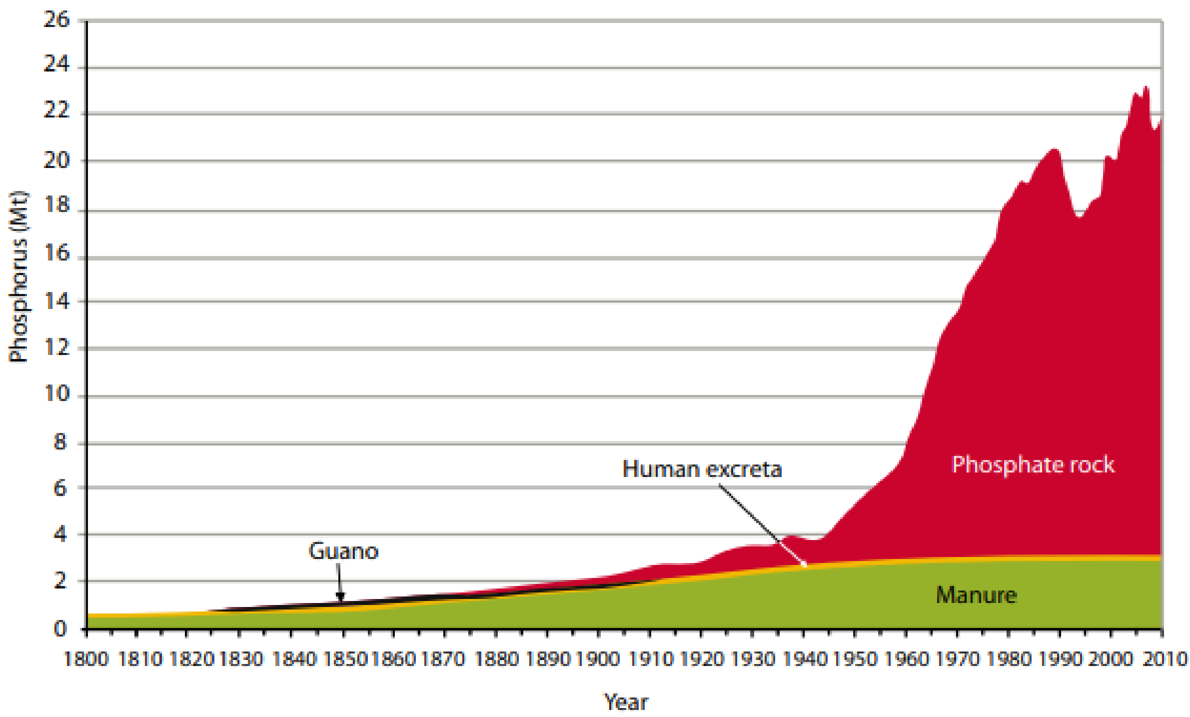

Figure 2 | Global sources of P fertiliser (Syers et al., 2011)

Due to the mining of P compounds for fertilisation, there has been an approximately fourfold increase in P inputs to the biosphere since the mid-1900s (Falkowski et al., 2000). Unsustainable P use has resulted in the dwindling supply of phosphate rock as a resource and the overabundance of phosphate in water systems leading to eutrophication. Both factors break the natural P cycle, creating a largely one-way flow resulting in nutrient imbalances (Jupp et al., 2021). Increasing P levels in the soil through fertilisation elevate the potential P excess leakage into water bodies with adverse consequences for aquatic life as well as the domestic and industrial water supply (Peng et al., 2018).

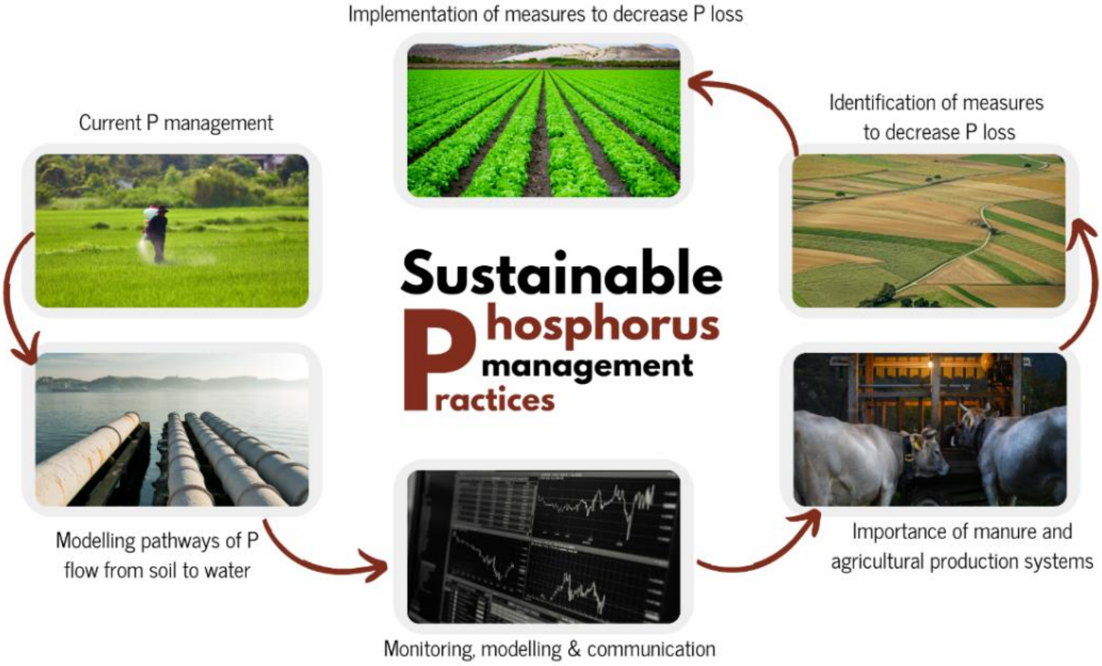

Figure 3 | Conceptual model of major research needs on P use (based on: (Sharpley et al., 2015))

Poor P management endangers both food security and healthy freshwater systems. Given the current situation in the P market, phosphate scarcity and water pollution due to P leakage require an integrated approach, that considers (Cordell, Drangert and White, 2009):

- minimising P losses from the farming sector and in the food commodity chain,
- explore recycling opportunities and search for alternative renewable P sources,
- other mechanisms to reduce overall demand (such as optimising soil carbon to improve P availability and influencing diets).

High supply risk of P and equally high economic significance lead to announce P and phosphate rock as a critical raw materials (CRMs) for the European Union (EU) economy. In 2014, the European Commission (EC) indicated P rock as one of the most important CRMs for the European economy and P rock was placed on the CRMs list (European Commission, 2014). Then, in 2017 and in 2020, phosphate rock and P were also included in the updated lists of CRMs (European Commission, 2017, 2020c).

In view of the depletion of non-renewable resources, which include P, the increase in its prices and the growing dependence of the Visegrad Countries (V4) - Poland, Czech Republic, Slovakia and Hungary - on their supplies from abroad, which poses risks to the further economic development of the V4 area and challenges in the context of environmental protection, it is necessary to take immediate action to support sustainable P management in the area of:

- sustainable production and consumption,
- waste management,
- education,
- monitoring framework.

It is essential that model of sustainable P management proceeds on a sustainable basis at all levels - from the EU, through the states and ending with voivodeships and communes. This document is a proposed scope of activities in the countries of the V4 Group.

The purpose of **RoadMap V4's resilience in the face of pandemic in raw materials & food sector** is to indicate a set of actions that concern the most effective, sustainable and circular management of P sources (primary and secondary) in the V4 countries. The indicated actions are intended to help secure sufficient P raw materials needed for food production in the V4 countries. The roadmap provides information on the situation and importance of P for the survival of people in the V4 and contains recommendations and algorithms for future actions. The developed roadmap shows where to look for sources of P in a situation of unstable imports. In addition, it presents the possibilities of creating new jobs in the development of P technology and construction or operation of installations. It will also help improve the secondary raw materials market in the region and make it more competitive in the EU.

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2 CIRCULAR AND SUSTAINABLE USE OF PHOSPHORUS SOURCES

The P mined from a small area and applied on agricultural soils in the form of phosphate has caused a geographical imbalance in terms of P global distribution (Alewell *et al.*, 2020). Significant P losses along the entire value chain show the necessity of transitioning towards a circular economy (CE) (European Commission, 2020a) to close the imbalanced P cycle. Moreover, CE implementation would ensure achieving P security in the domestic economy, making Europe more independent on mineral phosphate imports (European Commission, 2020b). The CE is characterised by maintaining the value of products, materials and resources within the economy for as long as possible and minimising the generation of waste. The concept of CE is closely tied to the sustainability of P and its use in food production (Smol *et al.*, 2020).

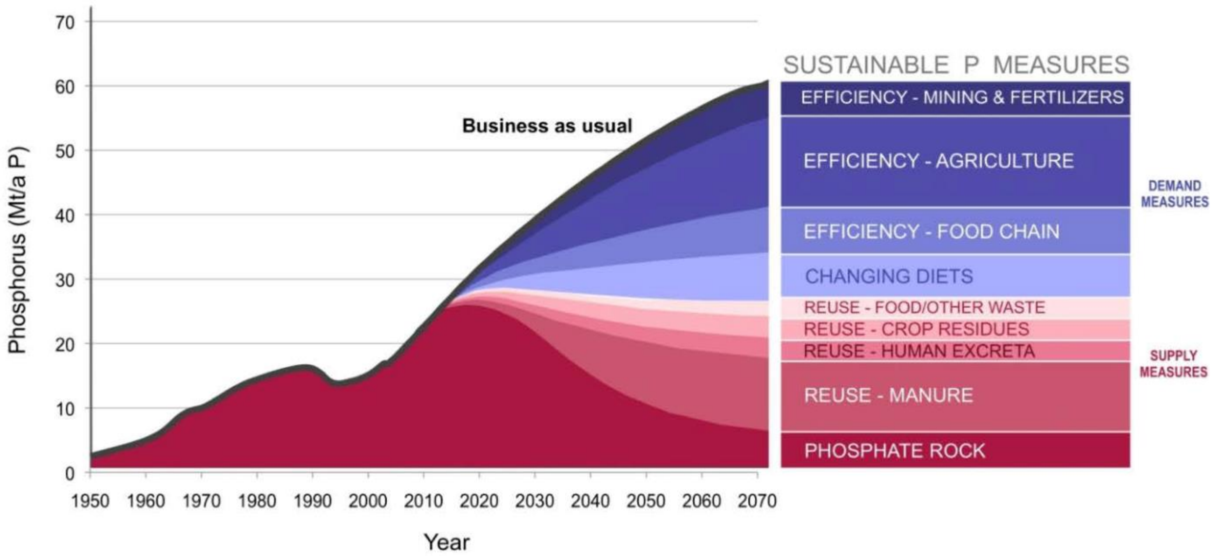

Figure 4 | Sustainable P supply and demand measures for meeting long-term future global food demand (Cordell and White, 2013)

CE approach refers to reducing demand by improving the efficiency of use in agriculture, reducing erosion and limiting losses at all stages in industries along the entire chain from the raw material to the consumer's plate and beyond (Smol, Adam and Preisner, 2020).

Approximately 80% of P is lost between mine and fork at all stages of the food production and consumption system (Cordell, Drangert and White, 2009). P losses from the consumption sector within EU-27 (Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden) were estimated at approximately 655 kilotons (kt), which was derived from wastewater (55%), food waste (27%), and pet excreta (11%) accordingly. Large quantities of P can be found in these waste streams, with a potential recovery (Zhu, Cakmak and Cetecioglu, 2023).

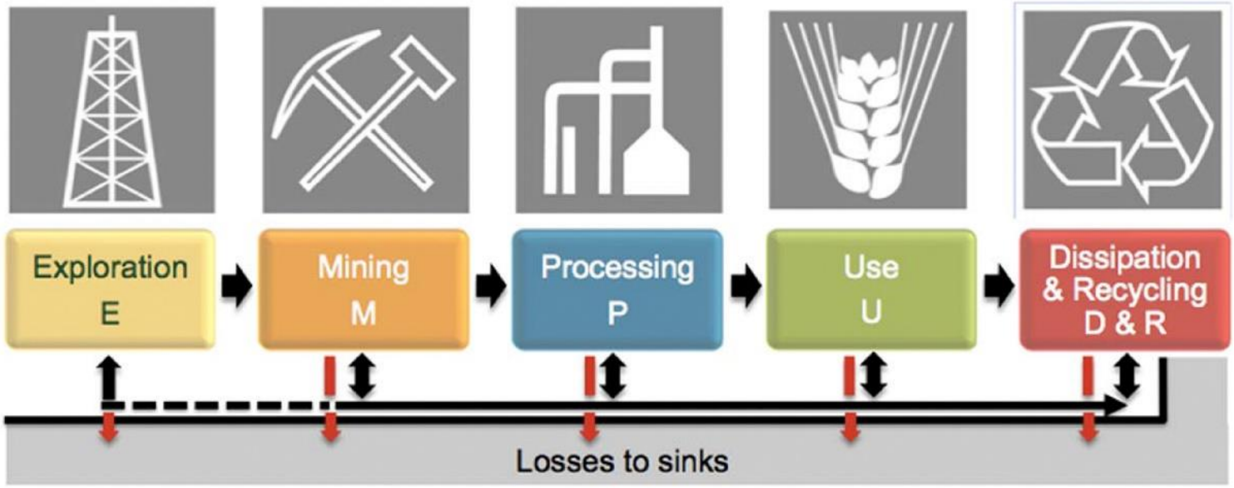

Figure 5 | The P losses along the supply-demand chain (Scholz and Wellmer, 2015)

Agricultural losses are the main result of inefficient practices. The results from 2005 show that the EU-27 imported 2392 gigagrams (Gg) P, half of which accumulated in agricultural soils (924 Gg) and half was lost as waste (1217 Gg) (van Dijk, Lesschen and Oenema, 2016).

Due to low mobility, P used in high doses, especially in the form of natural fertilisers, accumulates in the soil mainly in the layer into which it is introduced. When P fertilisation is greater than the removal of this element by the crop, most of the surplus P remain in the soil to add to the P reserve. Referring to available literature, the use of P from fertilisers is only 4-15%. After exceeding the sorption capacity of the soil, its losses to waters may occur, both in the form of soluble, reactive P compounds and in the form of compounds suspended on soil solid particles (Podleśna, 2019). P loss directly from the environment can occur through a variety of mechanisms, such as leaching from soil due to excessive rainfall or irrigation, or through the runoff of agricultural fertilisers into nearby waterways. Excessive soil P levels have been linked to high P losses in runoff and may increase the potential eutrophication of surface waters (Wu et al., 2016). Innovative initiatives should be taken to increase the efficiency of uptake of P from fertilisers by plants, e.g. improving microbiological activity of plants (Guelfi *et al.*, 2022). Losses that can be avoided in the first place are in the food chain (Wyant, Corman and Elser, 2013). The food production, processing, trade and retail system is a long and complex chain with substantial P losses in organic and food waste. Each year only one-fifth of the P used for food production is end up in food products globally generating unnecessary losses (Cordell, Drangert and White, 2009).

One of the key ways to promote sustainability in P and food production is to reduce overall reliance on this resource. Especially for farmers which need access to affordable sources of fertiliser to enhance and maintain the productivity of their agricultural systems and therefore ensure food security. This can be achieved through a variety of means, especially by promoting the use of P alternatives where possible.

Sustainable management of P raw materials includes processes of P recovery from waste and further reuse of the recovered products in other sectors, including agriculture (Barquet *et al.*, 2020). Over the past decade, alternative futures of P supply were investigated through various research. A promising way to tackle the shortage of P resources is P recovery from municipal wastewater. Urban populations are the motor driving the anthropogenic P cycle as cities receive P in form of food imports and concentrate emissions of P from waste or residue streams to the aquatic environment (Metson, Brownlie and Spears, 2022).

Additionally, nearly 100% of P eaten in food is excreted. It is estimated that every year global excretion reaches the level of around 3 million tones (t) of P in urine and faeces making cities P “hotspots” (Cordell, Drangert and White, 2009). Urban centers align with the “net-zero P” concept, where the inputs and outputs of P are minimised, simultaneously recovering P from the output stream. The major part, approximately 90%, of P from the wastewater is transferred to the sludge from where it can be effectively recovered, form liquid phase (wastewater) and solid phase (sewage sludge and sewage sludge ash (SSA)) (Smol, 2019). Thus, the infrastructure of centralised wastewater treatment has drastically reshaped the P cycle within modern cities preventing permanent P loss.

Overall, P recovery is a crucial area of research and development, as it has the potential to extend the life of this vital resource and reduce our dependence on mined P. Changes to the current linear approach require multidimensional innovations in the case of products, processes, structures, and decision-makers along the supply chain (Geissler et al., 2020). By continuing to invest in and support this field, we can help to ensure a sustainable and secure supply of P for generations to come.

3 AN OVERVIEW OF THE CURRENT SITUATION

3.1. THE INTERNATIONAL CONTEXT

P resources in the world are limited and P is typically obtained through the mining of minerals such as apatite and phosphorite. Both white P and phosphate rocks are listed as one few which primarily concerns agriculture and food security. One of the main challenges facing the P industry is the limited availability of high-grade reserves. Geographically discrete rock phosphate reserves are under the control of only a handful of countries, mainly Morocco, China and the United States, not only creating global imbalance but also full dependence on imports (Cordell, Drangert and White, 2009). Egypt, Algeria, South Africa and Brazil are also major phosphate rock reserves. This concentration of reserves in a small number of countries can lead to dependence on a small number of suppliers and potential supply disruptions.

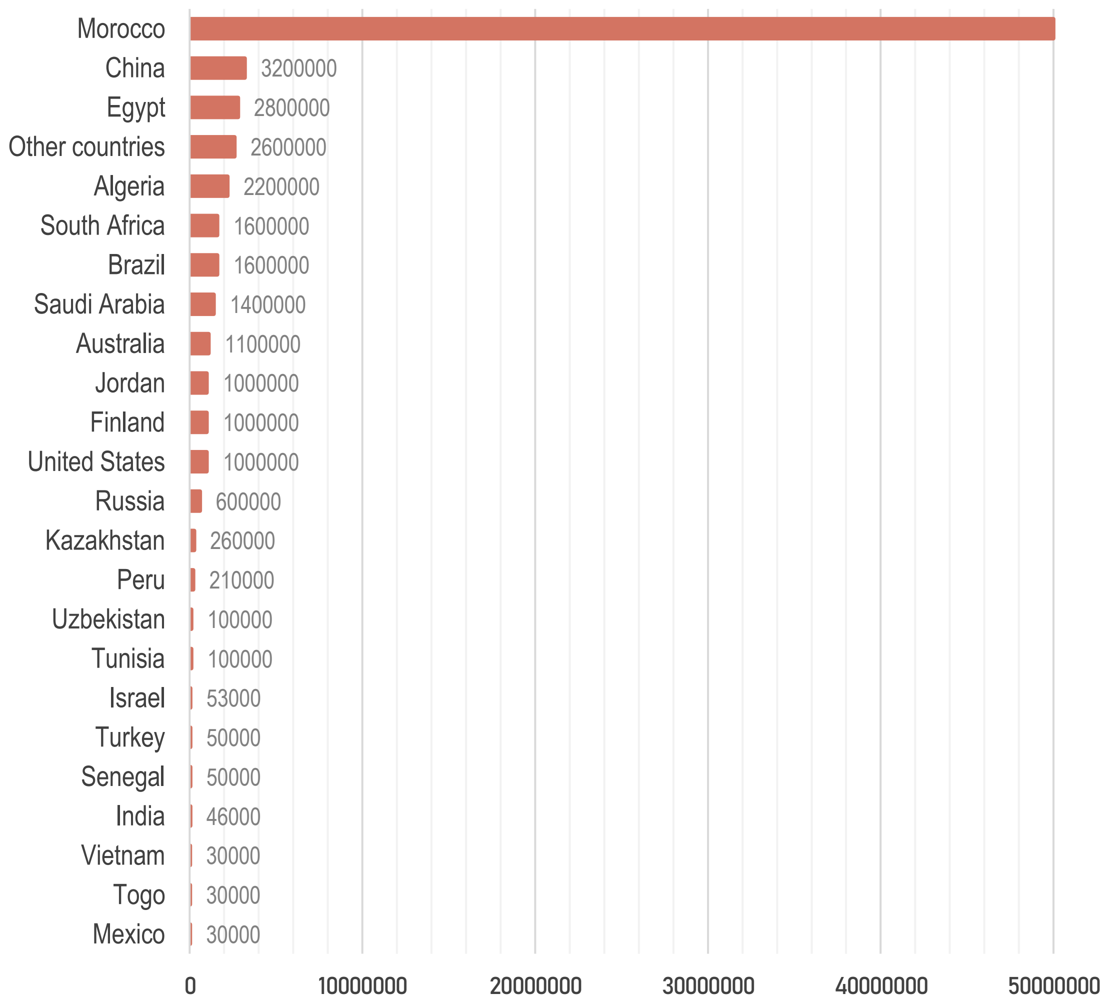

Figure 6 | Global phosphate rock reserves in billion tonnes (Geological Survey, 2022)

The current P situation is characterised by a number of key factors, including:

- limited reserves,
- environmental concerns related to mining and use,
- increasing global demand for food.

While P demand is calculated to gradually increase, phosphate rocks are expected to be depleted in the next 50-100 years (Daneshgar *et al.*, 2018). The estimations may vary on assumptions such as demand rate, P concentrations and economic viability. Global P scarcity will be continuously driven by long-term food demand resulting from a growing population. Maximum production of P called **"peak phosphorus"** is predicted to occur in 2033, after this moment demand could outstrip supply due to the depletion of viable phosphate deposits (Szaja, 2013).

The market for phosphate raw materials can be affected by factors such as global demand for food, trade policies, and political instability in major producing countries. In recent years, a decrease in the availability of high-grade phosphate rock, leading to an increase in prices for the raw material was observed. This could have significant consequences for food production and security. To address this risk, governments, companies and scientists are working on developing new technologies and practices that can support sustainable P management, such as:

- improving the efficiency of P use in agriculture, which includes practices such as precision farming and using P-efficient crops, which can reduce the amount of P needed for food production,
- P recycling as a way to close the P cycle, which involves recovery of P from waste streams such as sewage sludge and animal manure, and using it as a fertiliser – this can reduce dependence on primary resources and decrease negative environmental impacts associated with P mining,
- discovering new deposits, which is a challenging task but are several methods that can be used to locate new deposits, including geologic mapping, geophysical surveys, remote sensing, drilling, exploration.

It is worth noting that the implementation of new practices and technologies is not a simple task and can be costly and time-consuming. In addition, it may also encounter significant barriers such as social, environmental and legal.

3.2. The European Context

In accordance with the current EU raw materials policy, the security of raw materials is crucial for the further development of the EU, therefore the factors affecting the security of P supply in the EU should be monitored. In addition, dynamic price volatility was observed; in 2008, the prices of phosphate rock increased by 700% in a period of little more than a year, which contributed to a significant increase in the price of fertilisers (Smol and Kulczycka, 2018).

As Europe has no P mines and phosphate rock is finitely available in the EU, over 90% of the fossil phosphate inputs in forms of phosphoric acid, phosphate rock and fertilisers are imported. In 2015, 480 kt of mineral P were exploited in EU (76% fertiliser, 17% feed, 7% others (including phaseout of detergents)). Mineral resources are mainly imported from Morocco and Russia, other countries such as Algeria and Syria also take the lead as European importers. European production is only carried out in Finland, but it is less than 1% of overall resources. The main suppliers of UE are considered politically risky thus securing of P supply is the primary goal of P management (Nättorp *et al.*, 2019).

In accordance with the assumptions of the CE, alternative sources of P in nature should be sought. By increasing the use of recycled P in the EU and worldwide, it would be possible to secure the supply of this critical raw material and encourage a more even distribution of P at regional as well as global levels. From an economic point of view, diversifying the supply of phosphates to EU companies that depend on it would make them more resilient to any future price fluctuations and other trends that could increase their import dependency (Smol and Kulczycka, 2018).

In Europe, various advanced technologies have been developed where P can be extracted from different streams such as industrial effluents, municipal wastewater from wastewater treatment plants (WWTPs) and agricultural effluents. The most widely used are P compounds recovered from sludge, animal manures and industrial waste that have been successfully implemented in small scale in several countries (Zhu, Cakmak and Cetecioglu, 2023).

The P-rich waste resources are significant – as it comes to the amount of sewage sludge generated in municipal and industrial WWTPs in Poland was 947.2 thousand megagram (Mg) of dry solids in 2016 (Smol, 2019), approximately 27 thousand Mg of SSA per year (in 2018) was produced in mono-incineration plants (Smol, 2020) and 4.2 million Mg of biomass ash was produced from which a significant amount of P could be recovered (Smol, 2019). In spite of its high potential, P recycling practices are not commonly used on a bigger scale. One of the barriers in P recovery is a lack of explicit legislation for promoting P recovery in Europe. However, recently, some European countries have started to implement legislative approaches at the national level.

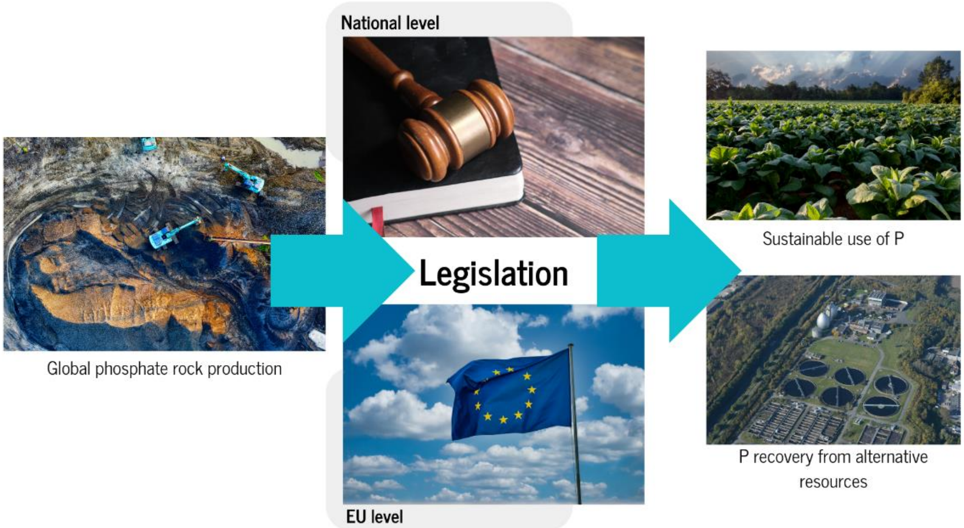

Figure 7 | Assessed P potential recovery in the EU (Zhu, Cakmak and Cetecioglu, 2023)

In last years, few European countries have been presented to spread the reclamation of P for the overcome of external P dependency. Switzerland was the first country which maked P recovery mandatory and proposed the Ordinance on the Avoidance and the Disposal of Waste in 2016. Germany has also published regulation on obligatory P recovery form WWTPs. Similarly, Finland plans to implement *National Waste Plan* in 2023, which aims to reuse fertiliser products and reclaim nutrients from wastes to realise CE.

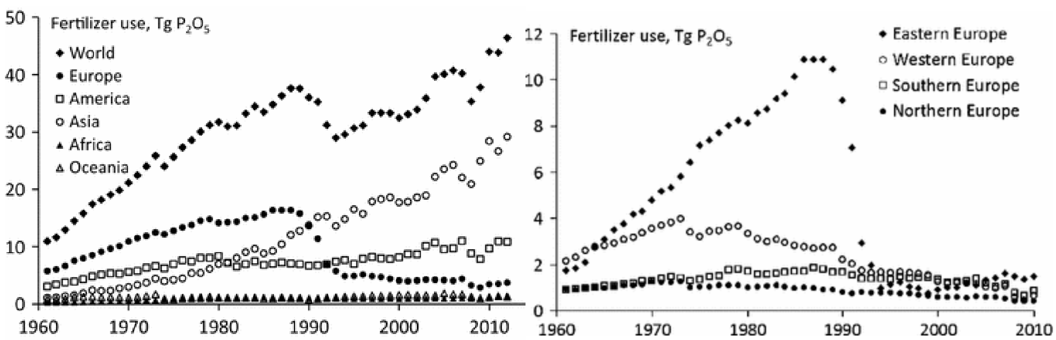

Figure 8 | Consumption of phosphate fertilisers in Tg P_2O_5 in the world per continent (left) and per European region (right) during the period 1960–2012 (Schoumans et al., 2015)

3.3. The V4 Context: Necessity and Opportunity

The Visegrad Group countries also known as the V4 contains four countries – the Czech Republic, Hungary, Poland and Slovakia. The number of residents in this region it is above 63 million in 2022, with the higher number in Poland (37 654 247 people), followed by the Czech Republic (10 516 707 people), Hungary (9 689 010 people) and Slovakia (5 434 712 people) (Population on 1 January, 2022).

Figure 9 | The V4 Group

The area of the EU countries currently covers 4 215 000 km^2, 5.2% of which is occupiedby the V4 countries. Poland is the largest country belonging to the group of V4 countries with an area of 312 700 km^2. Next is Hungary, with an area of 93 000 km^2, the Czech Republic at 78,900 km^2 and Slovakia, at 49 000 km^2, is the country in the region with the smallest area (Main indicators of the Visegrad Group countries, 2023).

In the EU, P resources are limited, which means that most of the P in the EU is imported. The EU imports around 6 million Mg of natural phosphate annually and around 1.2 million Mg of P fertilisers from Russia, Morocco and Tunisia (Rahimpour Golroudbary, El Wali and Kraslawski, 2020). The EC presents 100% as the reliance percentage on P imports and 84% as the reliance percentage on phosphate rock (European Commission, 2020c). Based on the available data, there are no P deposits mined in V4 countries at present. Thereby sustainable management of this nutrient is especially important in V4 region.

In Poland, there are phosphorite deposits that were mined in the past. P occurs at the north-eastern margin of the Holy Cross Mts. (vicinities of Radom-Iłża-Annopol-Gościeradów-Modliborzyce) in the form of calcium phosphate-rich nodules in the various types of sediment (Burkowicz *et al.*, 2014). The exploitation of phosphate phosphorites began in the country between the First and the Second World Wars. Currently, due to economic aspects, no deposits are exploited. The last exploited phosphorite deposit, located in Chałupki, was closed in 1961 and ten years later, the same was also done in Annopol (Polish Geological Institute – National Research Institute, 2022).

All deposits from which phosphate rock was obtained in Poland were removed from the national resource balance in 2006. Currently, the domestic demand for phosphate rock raw materials is fully covered by imports, e.g. from Morocco, Algeria and Egypt, where the availability of the described raw materials is much greater and more economical (Burkowicz *et al.*, 2014).

In Slovakia, there is one deposit of phosphate, however, it also is not mined at the moment. The demand for phosphate raw materials is fully covered by imports. Slovakia's dependence on imported P is a concern, as it makes the country vulnerable to supply disruptions and fluctuations in international prices. In addition, due to the environmental impact of P mining, the country is trying to promote sustainable management of P (Bakalár *et al.*, 2022).

In the Czech Republic, there are no P deposits. The domestic demand for phosphate rock raw materials is fully covered by imports (Smol *et al.*, 2022). Like in Slovakia, the Czech Republic's dependence on imported P is a concern, as it makes the country vulnerable to supply disruptions and fluctuations in international prices.

Hungary, there are five sedimentary phosphate deposits, but there is no information available on what P contents there are and whether they will ever be used (Smol *et al.*, 2022). Hungary is also working on developing CE initiatives, to decrease its dependency on imported CRMs, including P.

It is worth mentioning that V4 countries are also members of the EU, they should comply with EU regulations and policies regarding the management of CRMs such as P. Moreover, the EU has been working to reduce dependence on imported CRMs, including P, through the promotion of resource efficiency and CE (Smol *et al.*, 2020).

4 V4'S PHOSPHORUS RESOURCE USE

4.1. RAW MATERIAL PRODUCTIVITY

Material productivity is expressed as the amount of economic output generated (in terms of gross domestic product - GDP) per unit of materials consumed (in terms of 18. Domestic Material Consumption - DMC). This indicator is measured in United States dollar (USD) constant prices using 2010 base year and Purchasing Power Parities (PPPs) (OECD, 2023).

The V4 countries should be working to improve raw material productivity in order to reduce their dependency on imported P resources. This can be achieved through several means:

- Life Cycle Assessment (LCA) and P footprinting - these tools can be used to evaluate the environmental impact of different P products and to identify opportunities for more sustainable management of P.
- Research and development - continued research is needed to develop new technologies and practices that can support sustainable P management, such as finding alternative sources of P or developing new methods for P recovery.
- Market-based mechanisms - they can be used to promote sustainable P management by creating financial incentives for sustainable practices, such as carbon markets.

Overall, the V4 countries should be working to improve raw material productivity by promoting sustainable and efficient use of P, as well as through recycling and research and development of new technologies and practices.

4.2. CUMULATIVE RESOURCES USE IN IMPORT AND EXPORT

Cumulative resource use in imports and exports refers to the total amount of resources used in the production and transportation of imported and exported goods over a certain period of time. In the case of P, it includes the resources used in the mining, processing and transportation of P raw materials and products, such as fertilisers.

In terms of exports, the V4 countries are not major exporters of P raw materials. However, they do export some P-containing products such as fertilisers, but the quantity is limited compared to the amount of P they import.

In terms of imports, the V4 countries are heavily dependent on imported P to meet their needs. The imports of P raw materials and P-containing products such as fertilisers have been increasing over the years to meet the growing demand for food production.

4.3. Savings in primary raw material due to the use of secondary raw materials

The use of secondary raw materials, such as recycled P, can lead to significant savings in primary raw materials, such as phosphate rock. When primary raw materials are used, they must be mined, processed, and transported, which requires significant energy and resources (Geissler *et al.*, 2018). In contrast, secondary raw materials, such as recycled P, are obtained from waste streams and have already undergone some level of processing. This means that the energy and resources required to obtain them are significantly less than those required for primary raw materials.

In addition, the use of secondary raw materials can also reduce the environmental impact of raw material extraction. For example, the mining of phosphate rock can cause habitat destruction and water pollution. However, the use of recycled P from waste streams such as sewage sludge can reduce the need for mining and the associated environmental impacts.

Furthermore, using secondary raw materials can also increase the security of supply and reduce dependence on a small number of primary raw material suppliers, which can decrease the volatility of prices and ensure stable access to raw materials.

Overall, the use of secondary raw materials can lead to significant savings in primary raw materials, as well as reducing environmental impact, increasing security of supply and decreasing dependence on a small number of primary raw material suppliers.

5 SUSTAINABLE PRODUCTION AND CONSUMPTION

Whilst P is essential element to humanity, yet current management and governance is unsustainable. To ensure the sustainable management of global P resources for future food security it will be necessary to ensure effective governance. It was found that the basic condition, in case of rational management of P resources, is better quantification of all flows globally, regionally, nationally and locally (Dawson and Hilton, 2011). The main flows of P are related to production and usage of mineral fertilisers, however up to two thirds of P is wasted in agriculture. Urban areas are the main point of P accumulation, containing about a third of mined P (Kalmykova *et al.*, 2012). The points of the P cycle where there is the potential for implement recovery technologies and further environmental savings, were shown on Figure 10.

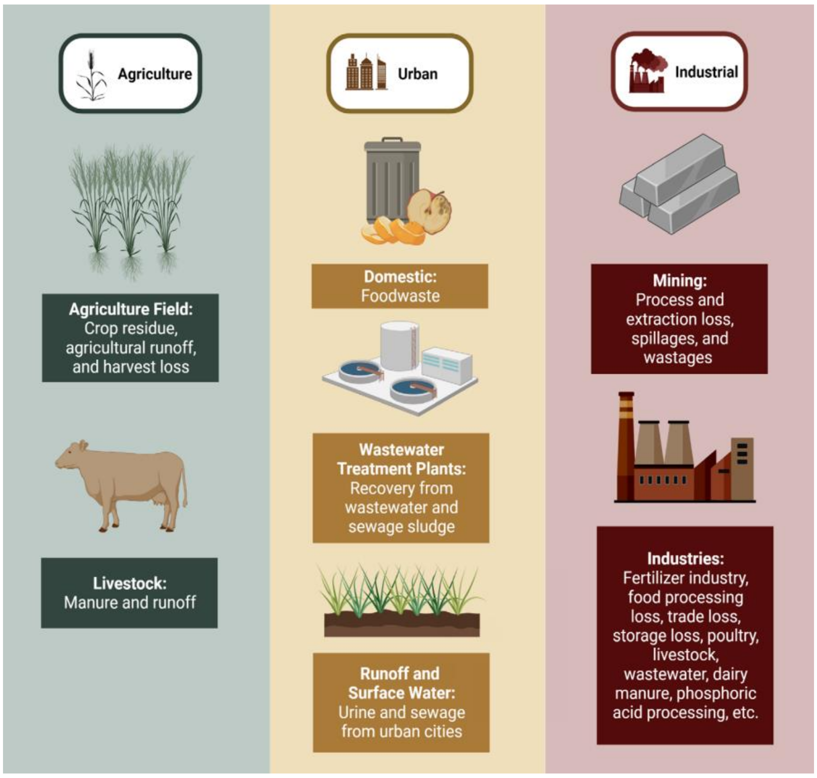

Figure 10 | Recovery options in the P cycle

Like in most of the European countries, V4 countries' dependence on imported P is a concern, as it makes them vulnerable to supply disruptions and fluctuations in international prices.

The phosphate rock import quantity to Poland during the last 18 years is presented in Figure 11. The largest amount of the P was imported in 2004 and the lowest amount in 2009, which is directly related to the global economic crisis that occurred in 2008.

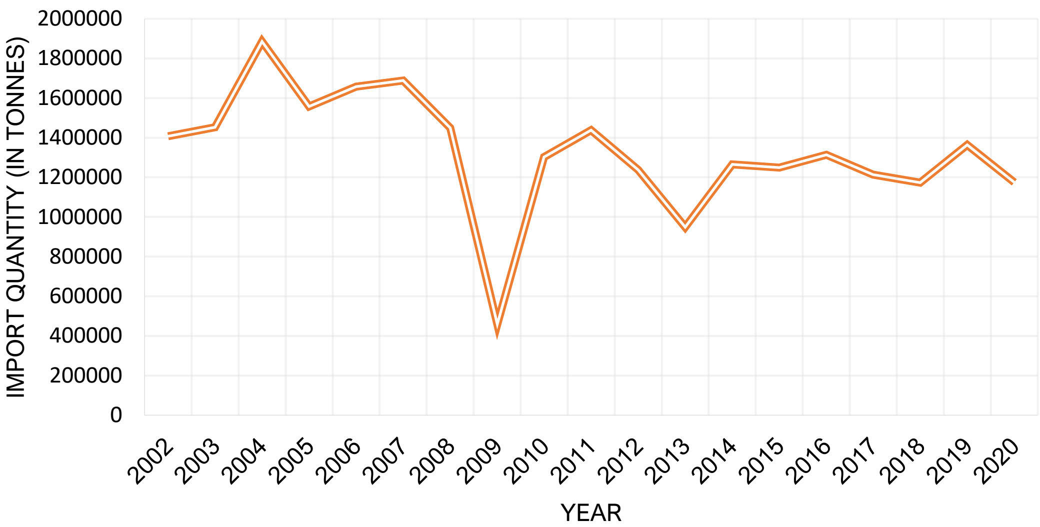

Figure 11 | Phosphate rock import quantity to Poland

In Slovakia, like in the Poland the demand for phosphate raw materials is fully covered by imports. The phosphate rock import quantity to Slovakia during the last 18 years is presented in Figure 12. The highest amount of P raw materials was imported to Slovakia from Italy (68%) and Czech Republic (31%). There is also limited import from Germany (0,2%), United Kingdom, Belgium, Japan and other countries (<0,1%) (*Statistical Office of the Slovak Republic: Phosphorus Export/Import, Livestock Inventory 2010–2019.*; Bakalár *et al.*, 2022).

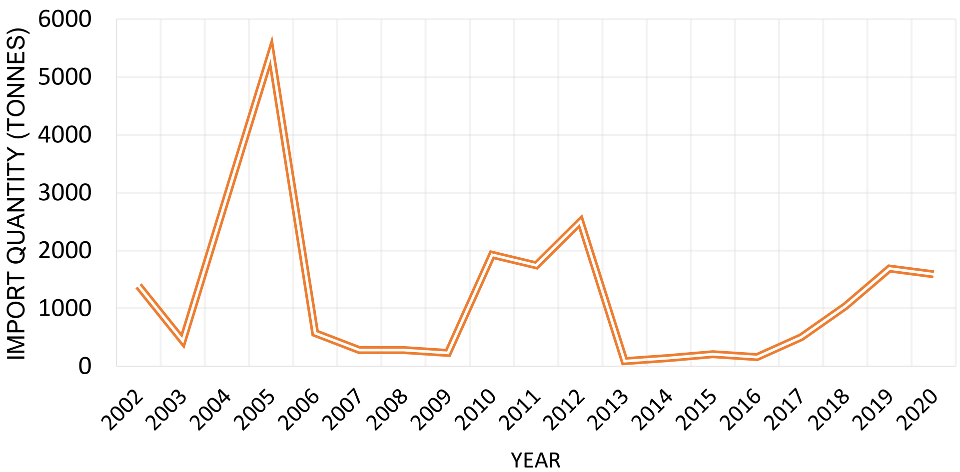

Figure 12 | Phosphate rock import quantity to Slovakia

The domestic demand for phosphate rock raw materials in the Czech Republic is also fully covered by imports. The phosphate rock import quantity to the Czech Republic during the last 18 years is presented in Figure 13. The largest amount of the P was imported in 2008 and the lowest amount in 2012.

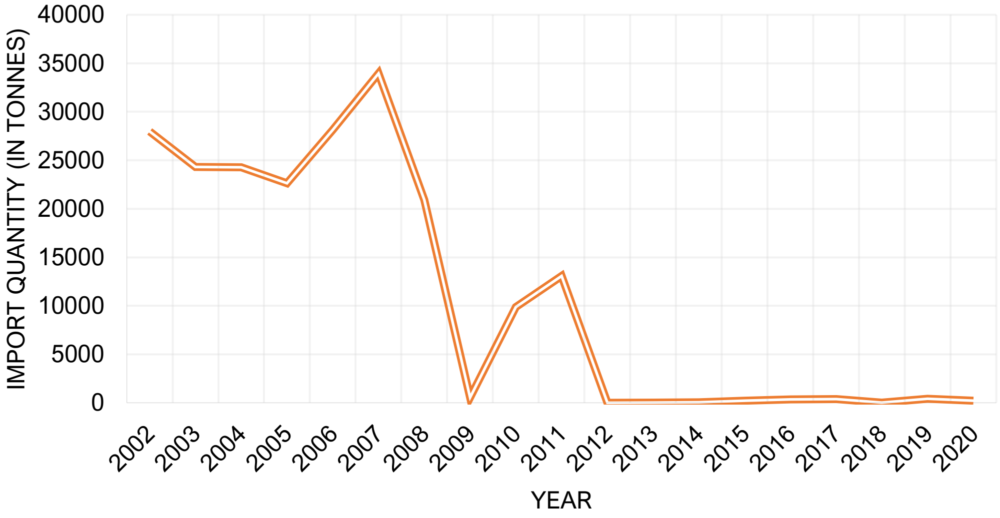

Figure 13 | Phosphate rock import quantity to Czech Republic

In Hungary, there are five sedimentary phosphate deposits, but there is no information available on what P contents there are, and whether they will ever be used. The phosphate rock import quantity to Hungary during the available 10 years is presented in Figure 14. The largest amount of the P was imported in 2020 and the lowest amount in 2014.

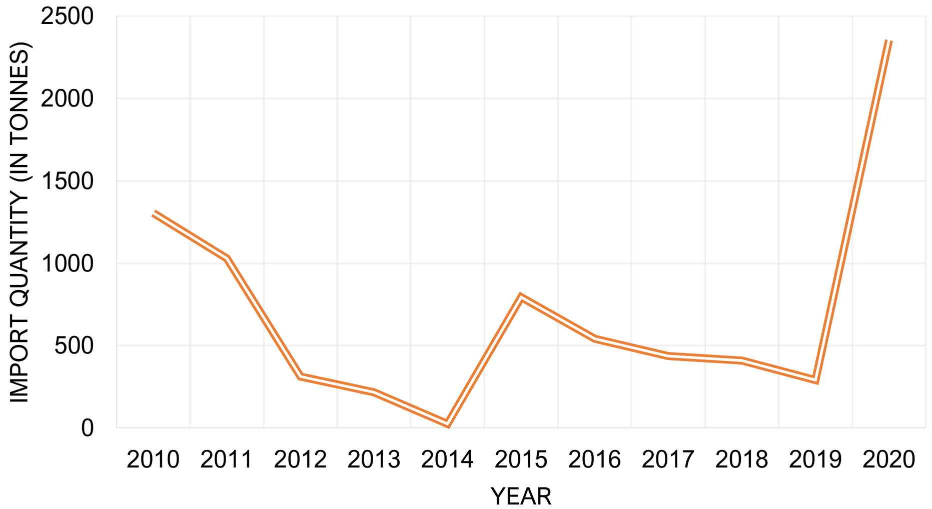

Figure 14 | Phosphate rock import quantity to Hungary

In addition, due to the environmental impact of P mining, the countries are trying to promote sustainable management of P. There are many activities that can help to sustainably manage P in the area of production and consumption.

Table 1 | Recommended actions in the area of SUSTAINABLE PRODUCTION AND CONSUMPTION

Action	Areas of responsible body (e.g. ministries in V4 countries)	Calendar
1. Efficiency in the use of P: Improving the efficiency of P use in agriculture, e.g. through better planning of fertilisation and the use of technologies that allow for better use of P.	Agriculture Rural Development	2023-2030
2. Substitution solutions: Development and use of substitution solutions, such as biophosphorus, which is of biological origin and is more resistant to resource depletion than traditional mineral P.	Economy Development Education, Science & Research Energy Environment Circular Economy	2025-2030
3. Regulations and standards: Creating and implementing regulations and standards for the sustainable management of P, which will be aimed at reducing waste and increasing the efficiency of P use.	Environment Circular Economy Agriculture	2025-2030
4. Technological solution: Recovery and recycling (from surface water, un/treated wastewater, sewage sludge, sewage sludge ash) or alternative (from urine, manure, slaughter waste, steelmaking slag).	Private sector Research	2023-2030
5. Extraction of raw materials: Mining the phosphorus deposit.	Mining Economy Development Education, Science & Research Energy Environment	2023-2030
6. Supporting programs: Creation of supporting project from regional operational programs.	Economy Development Education, Science & Research Environment	2023-2025
7. Sustainable supply chains: Sourcing and distribution of P based on optimised route with the consideration of the carbon emission footprints from transportation, supported by environmentally sustainable packaging.	Agriculture Economy Development Education, Science & Research Environment	2025-2030

6 WASTE MANAGEMENT

6.1. MUNICIPAL WASTEWATER AND SEWAGE SLUDGES

Municipal wastewater has the high potential to substitute a significant portion of the demand for phosphate rocks, as it is recognised as major part unexploited P source. P recovery from municipal wastewater could decrease global dependency on the non-renewable resources and simultaneously increase CE by reducing environmental impacts from current use (Amann et al., 2018). Various innovative technological approaches have been developed and some implemented at full scale in recent years to recover wastewater P at different stages in wastewater treatment plants.

In V4 countries, municipal WWTPs have the greatest potential for P recovery because P can theoretically be recovered at every stage of the treatment process, i.e. from sewage and leachates in the liquid phase, from dehydrated sewage sludge, from the solid phase of ashes after thermal transformation of municipal sewage sludge. In the successive stages of wastewater treatment and sewage sludge treatment, a smaller volume of the substrate used for P recovery is observed, while at the same time P concentration per unit volume is increasing.

Despite the fact that many researchers have been working on the development of technological solutions for efficient P recovery, in V4 P recycling is not a common industrial practice.

6.2. FOOD WASTE

Even though P is returned to the environment after consumption or from losses, the time gap between the environment sink and the source is approximately 10 million years, and in the intervening time, it causes major pollution and resource scarcity (Cordell, 2010).

It is estimated that a significant portion of the food produced in Europe is never consumed, with estimates suggesting that around 30% of food produced is wasted. This amounts to approximately 88 million metric tons of food waste per year. Like in other regions, the majority of food waste in Europe occurs at the consumer level, with households and restaurants being the largest sources of waste. However, food waste also occurs at other stages of the food supply chain, including during production, processing, distribution and retail. The causes of food waste in Europe can vary, but common factors include overproduction, excess purchasing, inadequate storage and lack of awareness about the issue. Reducing food waste can have numerous benefits, including conserving resources, reducing greenhouse gas emissions and reducing the burden on landfills and other waste management systems.

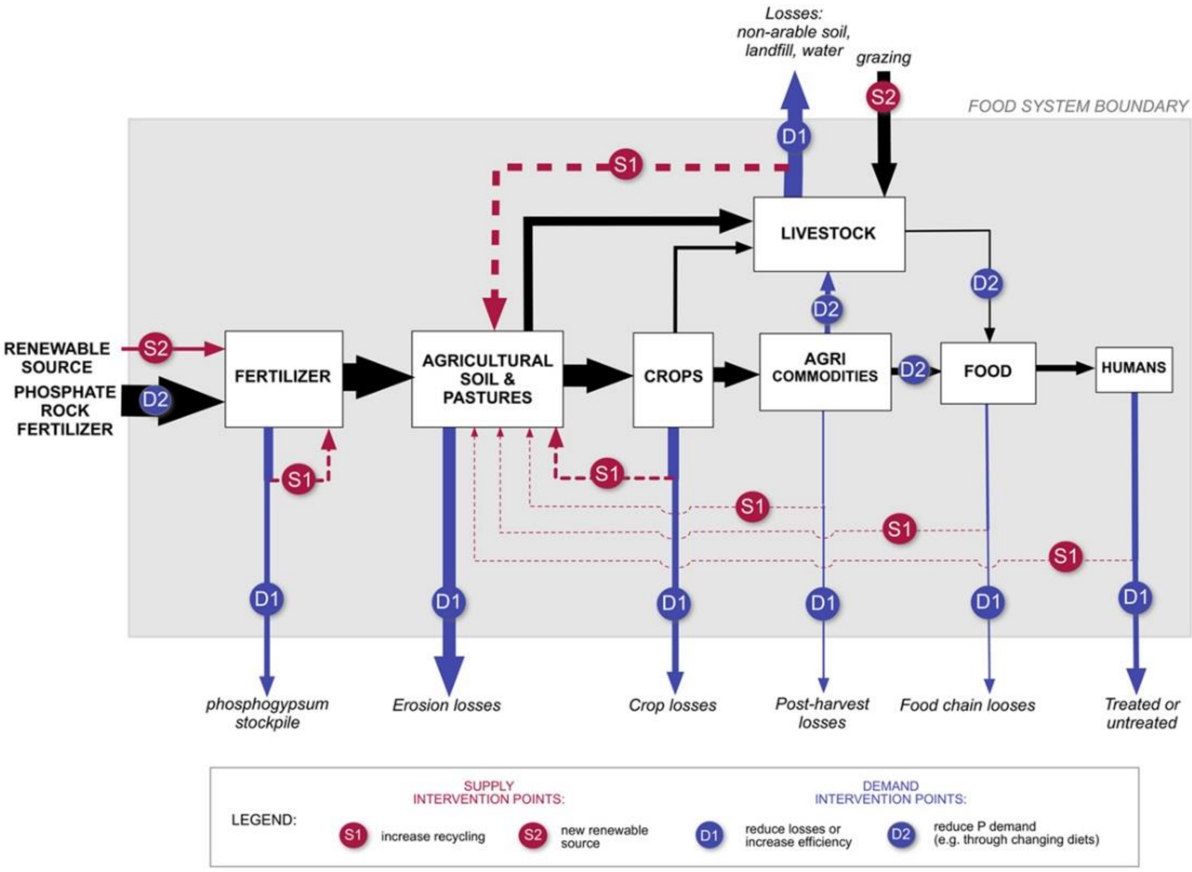

Figure 15 | The flow of P through the food system (Neset *et al.*, 2016)

The increasing volume of food waste results in inadequate resource usage and environmental degradation which can be partially avoidable. Food commodities for human consumption constitute a major flow of P due to their relatively high P content and the high turnover rate (Kalmykova et al., 2012). If the food waste is reduced, lower demand for food production will be noticed. In consequence, there will be much less pressure on the non-renewable phosphate rock resource (Li et al., 2020).

Table 2 | Food waste by sector of activities, 2020 (kilograms per capita)

Country	Total food waste	Primary production	Processing and manufacturing	Retail and other distribution of food	Restaurants and food services	Total activities by households
EU	**127**	**14**	**23**	**9**	**12**	**70**
Bulgaria	86	33	23	2	2	26
Czech Republic	**91**	**3**	**9**	**6**	**4**	**69**
Denmark	221	11	102	17	11	79
Germany	131	2	19	9	22	78
Estonia	125	18	24	15	8	61
Ireland	155	14	44	12	36	48
Greece	191	35	35	14	21	87
Spain	90	18	30	7	4	30
France	133	16	29	12	16	61
Croatia	71	10	2	1	4	53
Italy	146	21	9	6	3	107
Cyprus	397	49	190	56	30	71
Lithuania	137	29	10	`10	2	86
Luxembourg	147	12	17	14	14	91
Hungary	**93**	**2**	**19**	**4**	**2**	**66**
Netherlands	161	27	59	12	5	59
Austria	136	2	19	9	23	83
Poland	**106**	**18**	**14**	**8**	**5**	**60**
Portugal	184	10	6	21	23	124
Slovenia	68	0	5	7	20	36
Slovakia	**83**	**13**	**1**	**3**	**1**	**65**
Finland	116	9	29	10	14	53
Sweden	87	2	5	9	9	61
Norway	143	30	5	11	18	78

The V4 countries should take measures aimed at minimising food waste through specific, long-term actions.

Table 3 | Recommended actions in the area of WASTE MANAGEMENT

Action	Areas of responsible body (e.g. ministries in V4 countries)	Calendar
1. **EU regulations:** On requirements for P recovery	European Commission	2025-2030
2. **Information campaign:** To disseminate among consumers and producers of knowledge on scarcity and importance of P and their roles on this issue.	Education Environment Circular Economy	2025-2030
3. **Investments in research:** Investments in research and development of technologies that will help increase the durability of products and improve processing processes.	Agriculture Economy Development Education, Science & Research Environment Circular Economy	2023-2028
4. **Technological solution:** Recovery and recycling (from surface water, un/treated wastewater, sewage sludge, sewage sludge ash) or alternative (from urine, manure, slaughter waste, steelmaking slag).	Economy Development Education, Science & Research Environment Circular Economy	2023-2028
5. **Supporting programs:** Creation of supporting project from Operational program Quality of Environment.	Economy Development	2023-2030

7 EDUCATION

Education is an important aspect of sustainable management of P. It is important to raise awareness among key stakeholders, such as farmers, policymakers, and the general public, about the importance of sustainable P management and the actions that can be taken to promote it.

One way to promote education on sustainable P management is through public outreach and education campaigns. These can include workshops, seminars, and other events that educate the public on the importance of sustainable P management and the actions that can be taken to promote it.

In Poland, many activities are undertaken that are dedicated to sustainable and circular management of P. There are several projects in the country, the aim of which is P recovery.

Table 4 | **Projects supporting sustainable P management in Poland**

Project Name	Description of Project
Sustainable management of P in the Baltic region (InPhos)	The main objective of the InPhos project was to develop a strategy for sustainable P management including identification of the P recovery potential in the Baltic Sea Region by a working group of experts from the Baltic countries — Poland, Germany, Sweden, Finland, Latvia, Lithuania, Estonia and Italy.
Market ready technologies for P-recovery from municipal wastewater (PhosForce)	The main objective of the PhosForce project was to develop innovative technology for the recovery of P from wastewater. The Struvia® technology has been used to recover P in the form of struvite crystals from wastewater generated in municipal waste disposal facilities.
Towards CE in wastewater sector: Knowledge transfer and identification of the recovery potential for Phosphorus in Poland (CEPhosPOL)	The main goal of the CEPhosPOL project was to conduct research works focused on the identification of the recovery potential for P in Poland and the development of the sustainable model of the P management, based on the CE assumptions.
Polish Fertilisers form Ash (PolFerAsh)	The main goal of the PolFerAsh project was to develop an environmentally-friendly technology for SSA utilisation as a source of fertilisers and construction materials.

Monitoring of water and sewage management in the context of the implementation of the CE assumptions (MonGOS)	The main goal of the project MonGOS was to develop the CE monitoring framework for the European water and sewage sector.

In Slovakia, has undertaken actions aimed at sustainable P management, for example, through the project "Drinking water supply, sewerage and wastewater treatment" or the Slovak Grant Agency for Science (Grant No. 1/0563/15). These activities are presented in Table 5.

Table 5 | Projects supporting sustainable P management in Slovakia

Project Name	Description of Project
Drinking water supply, sewerage and wastewater treatment	The project contributed to reducing pollution and improving wastewater collection. The project also brought drinking water to people struggling to find regular or reliable supplies. As part of the project, the existing facilities were modernised and a new central pumping station was constructed. Improvements to existing facilities included making it easier to remove nitrogen and P from the water. These actions resulted in a radical increase in the capacity and efficiency of the existing wastewater plant
Slovak Grant Agency for Science (Grant No.1/0563/15)	The project focused, among other things, on the biochemical treatment of sewage sludge and phosphogypsum under conditions reducing sulphates with the release of P. A schematic model of the dephosphatation process under aerobic stabilisation of sewage sludge and phosphogypsum was developed.

In the Czech Republic, there are projects that support he sustainable development of P management. It is worth noticing that there is a national platform dedicated to P management – Czech Phosphorus Platform, which is an organisation that allows its members to act in the field of, inter alia, reducing dependence on imports and recycling of P from waste, from crop and livestock production in agriculture, from industry and municipal sewage.

Table 6 | Projects and organisation supporting sustainable P management in Czech Republic

Project Name / Organisation	Description of Project
Implementation of Measures at the Brno Valley Reservoir & Implementation of measures at the Brno Valley Reservoir, IVth stage 2023–2027	The Brno Lake is the largest reservoir in Brno. The main problem of Brno Lake for a long time was green cyanobacteria, which polluted the entire water area and made recreation impossible. Water purification and treatment in the lake began in 2007. The project on how to stop and improve the gradual deterioration of water quality at Brno Lake is called “Implementation of Measures at the Brno Valley Reservoir”. The aeration system, in combination with ferric sulphate dosing, ensures the precipitation of P, which sinks to the bottom and becomes (so far) its harmless part. Results show an improvement in water quality in the lake. These measures have proved very successful over the years and therefore continue during the next stage of the project “Implementation of measures at the Brno Valley Reservoir, IVth stage 2023–2027 “. The next significant necessary steps are the removal of precipitated P from the bottom of the Brno Lake and the recovery of P by recycling.
Czech Phosphorus Platform	Czech Phosphorus Platform is an organisation that brings together private companies, government agencies, academic institutions, and individuals. The organisation creates conditions for various activities of members in the areas of recycling, CE, waste management, sustainable agriculture, and water management to reduce dependence on imports and to recycle P from waste, from crop and animal production in agriculture, from industrial and municipal wastewater.

In Hungary, there are several companies and project that are being implemented to support sustainable P management. Moreover, the leading Hungarian fertiliser partner network is called Genezis. This partner network includes five large companies.

Table 7 | Project supporting sustainable P management in Hungary

Project Name / Company	Description of Project
Implementation of nutrient balances in Hungarian agriculture: a management tool towards sustainability	Both the prevention of soil mining and the reduction of nutrient losses to water and air are important issues in light of the development of a sustainable agricultural structure in Hungary. The project calculated nutrient balances at the farm level, which helped bring insight into this duality and provides a tool for the optimisation of farm nutrient management (including P).

Another way to promote education on sustainable P management is through extension programs, which can provide farmers and other stakeholders with information and training on best practices for efficient and sustainable use of P. This can include information on precision farming, P-efficient crops, and the use of recycled P.

Furthermore, education on sustainable P management can be included in school curriculums, as well as in higher education, such as in agricultural, environmental, and sustainability-related fields of study.

Overall, education is a critical component of sustainable P management and can help to raise awareness among key stakeholders, promote best practices, and inspire individuals to take action to promote sustainable P management.

Table 8 | Recommended actions in the area of EDUCATION

Action	Areas of responsible body (e.g. ministries in V4 countries)	Calendar
1. **Raising awareness among key stakeholders**, such as farmers, policymakers, and the general public, about the importance of sustainable P management.	Agriculture Economy Development Education, Science & Research Environment Circular Economy	2023-2027
2. **Preparing extension programs**, which can provide farmers and other stakeholders with information and training on best practices for efficient and sustainable use of P.	Agriculture Rural Development Economy Development Education, Science & Research Environment Circular Economy	2025-2030
3. **Popularising social and educational campaigns** about sustainable P management.	Education, Science & Research Environment	2023-2030
4. **Inclusion** of the issue in existing study programs within subjects dealing with sustainable development, critical raw materials, processing, etc.	Universities Secondary schools Elementary schools	2025-2030

5. Establish scientific training or courses, include the P recovery technologies training and experiment, as well as the P production methods to the students in related field (e.g. agriculture).	Universities Educational and vocational institutions	2025-2030
6. Provide IoT training, to enhance the technical skill and interest for precise farming	Universities	2025-2030

8 MONITORING FRAMEWORK

A monitoring framework for P can be used to track and assess the use and management of P resources in a given area. It can provide valuable information on how resources are being used, how efficiently they are being used, and where improvements can be made to promote sustainable management of P.

A monitoring framework for P can include several components:

- data collection - this can include monitoring the extraction and production of primary raw materials, such as phosphate rock, as well as the use and disposal of P-containing products, such as fertilisers;
- indicator development - a set of indicators can be developed to measure and track the performance of the P management system, such as the total amount of P used per unit of agricultural production, or the amount of recycled P used as a percentage of total P used;
- analysis and reporting - data collected and indicators developed can be analysed to identify trends, patterns and areas for improvement in P management. The results of the analysis can be reported to relevant stakeholders, such as policymakers and the general public;
- evaluation and review - monitoring framework should be periodically evaluated and reviewed to ensure it is meeting its objectives and to identify any necessary adjustments or improvements;
- stakeholder engagement - it is important to involve stakeholders such as farmers, industry and policymakers in the development, implementation and review of the monitoring framework.

Overall, a monitoring framework for P can provide a valuable tool for tracking and assessing the use and management of P resources and can help to promote sustainable management of these resources by identifying areas for improvement and encouraging stakeholder engagement.

Proposed **INDICATORS** to monitor progress:

- ⇒ level of phosphate raw material consumption,
- ⇒ share of phosphate raw materials from recycling,
- ⇒ efficiency level in the use of phosphate raw materials,
- ⇒ energy consumption and carbon dioxide emissions in the extraction and processing of phosphate raw materials,
- ⇒ safety and health level at phosphate raw material extraction and processing sites,
- ⇒ amount of imported phosphate raw materials,
- ⇒ database for domestic strategies related to P development: number of strategies in effect,
- ⇒ database for domestic funded projects supporting P development, especially CE: number and list of domestic projects funded covering the P development; amount of funding covering the P development,
- ⇒ amount of P recovery from waste (absolute in t/y and relative to total P fertilization in %)
- ⇒ energy intensity (kJ/kg) and Greenhouse Gas - GHG intensity (kg CO2 eq/kg) of P fertilisers from primary raw materials and from waste materials,
- ⇒ amount of P nutrient leakage to ecosystems and to the environment (absolute in t/y and relative to the carrying capacity of the monitored ecosystem).

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