Assessment of the Potential for the Formation of a Circular Phosphorus Cycle Using Substance Flow Analysis Based on Reports from Malaysia

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Assessment of the Potential for the Formation of a Circular Phosphorus Cycle Using Substance Flow Analysis Based on Reports from Malaysia

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ABSTRACT: Sustainability of phosphorus (P) requires detailed and serious key management strategies to control the P flow balance across the environmental systems. During the 1970s, the reserve of phosphate in Malaysia was at its highest level, which led to a decline in resources to the continuous demand increased the import trading of these resources from foreign countries. Consequently, the increased import rate led to imbalanced essential nutrient flow that could impact the national security. The depletion of P reserves initiated in the 1970s triggered the Malaysian government to act quickly by comparing the performance of P accounting indicators according to its primary flow in different ministries. However, the capital injections to Small Medium Industry (SMI) and non-SMI players that increased since the mid-2000s returned the imbalanced P loss to normal. This study utilised extant literature for the development of guidelines in identifying 'hotspots' in P flow return, with particular emphasis on national P security achievements. Based on the findings, this study successfully documented the current research patterns of P flow in various systems related to the main P problems, evaluated flow chain requirements and possible impacts of P inputs-outputs, apart from developing solutions to guide policymakers in considering the aspects of substance flow analysis (SFA) approaches in establishing the national P modelling. To reduce the P nutrient leaching down to the levels observed in the early 1990s, a fundamental and better understanding of nutrient management practices coupled with minimised uncertainty of the P catchment scale is required. Monitoring the dispersion of P nutrient can prevent environmental degradation. In conclusion, this review provided a potential approach to achieve new management targets by proposing P load reduction strategies which focuses on the current trend of P demand-production for long-term sustainability of non-renewable resources.

KEYWORDS: Phosphorus, substance flow analysis, material flow analysis, phosphorus flow, nutrient, sustainability

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Introduction

Anthropogenic, biogeochemical and unforeseen disaster agendas have since impacted creative solutions for nutrient loss in Asian countries, including Malaysia. Therefore, soil P accounting is imperative for maximizing build-up while minimizing productivity risks associated with modern agriculture of soluble P fertilizers (Withers et al., 2020). From the 1960s to the 1980s, the intensive use of P inputs in the agricultural sector with excessive enrichment led to high P leaching into water bodies and agricultural lands (Al-Badaii et al., 2013; Cordell et al., 2009; Sharip & Zakaria, 2007; Tang et al., 2020). Consequently, the increased biochemical oxygen demand (BOD) which reduced the dissolved oxygen (DO), subsequently triggered a eutrophication crisis affecting the aquatic life, and thus, led to food poisoning in humans (Bonsdorff, 2021; Brevik et al., 2020; Diatta et al., 2020; Hwang, 2020). Increased BOD also contributed to greenhouse gas emissions and declined economic-agricultural productivity (Liu et al., 2021; Pellerin et al., 2017; Ros et al., 2020). In short, the development of information, understanding and load control of P in such problematic systems should be documented in any temporal-spatial and non-spatial forms (Meadows & Wright, 2008; Wu et al., 2019).

Subsequently, the 'phosphorus usage efficiency' programme was initiated in the 1980s as part of the Principles of Sustainable Development before it was adopted to be realised in the Sustainable Development Goals (SDGs) namely, SDG-2 (ending hunger), SDG-6 (clean water and sanitation), SDG-11 (sustainable cities and communities), SDG-12 (responsible consumption and production), SDG-14 (healthy life below water) and SDG-16 (peace and justice) (Smol, 2019; Zowada et al., 2020). As such, an increase in P reserve mining resulted in the measurement of GDP, increase in total population (Zhang et al., 2008), the rising of metal and fertiliser prices (Daneshgar et al., 2018; Gupta et al., 2014), the technological innovations of high-grade concentrated P ore processing (Ma et al., 2018; Sarvajayakesavalu et al., 2018), multi-level socio-political interventions (Alewell et al., 2020; Heckenmüller et al., 2014; Rousselin, 2018), along with changes in dietary nutrition and agricultural practices (Metson et al., 2016).

The P exploration is primarily responsible for improving the well-being of the local population in terms of economic, social and environmental aspects. Due to the inception of Local Agenda 21 (LA21) of the Millennium Development Goals (MDGs) in 2000, the paradigm and perspective of sustainable P management magnified the changes within these aspects including nutrient recovery, recycling, closing the nutrient cycle and involvement of social actors (Chowdhury et al., 2017; Hermann et al., 2018; Reitzel et al., 2019). Afterwards, the development of several frameworks of P assessment and solution models according to different disciplines were achieved (Hollaway et al., 2018; Klinglmair et al., 2016). However, in the mid-2000s, P became a problem to the respective state governments in Malaysia (Department of Environment, 2020; Lee,

	SFA-P issue	SFA/MFA-non P issue
2011	Overall subsystem	Heavy metals in landfill
2012	X	Energy-biomass
2013	Wastewater subsystem	Livestock Subsystem
2014	X	Forestry Subsystem
2015	X	(2) E-Waste Subsystem
2016	X	Nutrient in landfill, Cities Subsystem
2017	X	Biomass-energy, (2) Solid waste, Cities, Carbon
2018	X	Nitrogen, Cities, Agriculture, E-Waste
2019	Water, Wastewater, Livestock, Crop subsystem	Cities
2020	Solid waste subsystem	Cities, Wastewater, Solid waste, energy, agriculture

Figure 1. Number of papers that were analysed using different approaches. The 'number' unit in parentheses in the figure refers to the number of articles that have the same theme or issue.

2020). As 43% and 11% of Malaysian rivers (out of 477 monitored rivers) were classified as slightly polluted and polluted, respectively (Department of Environment, 2020). The use of chemical fertilisers, disposal of manufacturing wastes and sewage (especially from onshore settlements, ie, urbanisation), together with the return of extensive consumption of domestic (non-free-P) products contributed to the water pollution level (Camara et al., 2019; Lee, 2020; Razali et al., 2018).

In Malaysian, several key institutions, departments, and administrative agencies involved in the country's nutrient management include Malaysian Agricultural Research and Development Institute (MARDI), Department of Chemical, Department of Environment (DOE), Department of Agriculture (DOA), Department of Veterinary (DOV), Department of Statistic (DOS), Ministry of Plantation Industries and Commodities (MPIC), Malaysia External Trade Development Corporation (MATRADE), etc. These institutions developed innovative research for safe material products, environmental conservation regulation, apart from implemented clear guidelines respective to their roles. Malaysia's pioneer strategy focussed on environmental conservation including phosphate fertiliser management introduced in the Third Malaysia Plan (1976–1980), which was then adaptively continued till the Twelfth Malaysia Plan (2021–2025) (Isa et al., 2021). Moreover, the establishment of the Environmental Quality Act 1974 brought robust solutions in curbing pollution and the release of nutrients to the environment (Al-Mamun & Zainuddin, 2013).

This review provides an overview on the synthesis of P flow research trends together with projects that were implemented at the national level, leading to socio-science-based P management guidelines to address P flow losses and diversions, particularly, on potential P recovery in Malaysia. This study documented the knowledge and understanding gaps of the SFA P method in available literature and evaluated the impacts of its implications on different sectoral domains in the following sections. A P load and safety challenge-response curve was developed against the guidelines and strategies of Management of P Nutrient in Malaysia as a potential framework to achieve SDG-6.

Materials and Methods

Figure 1 illustrates the selection of boundaries and scope of the study objectives involving the reported data on P from various geographical scales and local P flow linkage. Global studies were excluded in this analysis because their scholarly corpus was pioneered by several leading scholars (Chowdhury & Zhang, 2021; Cordell et al., 2012; Metson et al., 2015; Rahman et al., 2019) whose studies were extensively expanded and robust as they provided a clear picture of P flow within various dimensions of SFA research. Therefore, a national study could fragment variabilities and increase the gaps in nutrient P management due to the differences in niche context which limits the possibilities to scrutinise matters unknown to researchers. In turn, it expanded the similarities and discrepancies in the basic information for further analyses.

The preliminary step included the techniques of systematic literature review (SLR) exploration method namely search, selection, critical evaluation and synthesis (Briner & Denyer, 2012). Documents that were gathered for characterisation

Table 1. Description of main keywords used in P mapping based on literature.

APPROACH	KEYWORDS	AND/OR
Material Flow Analysis (MFA) / SFA	Phosphorus; Nutrient: 'Fosforus' Detergent-Phosphorus Fertilizer-Phosphorus	P_Flow; P_Balance sheet; circular; MFA; SFA; P inflow; P outflow; P stock; Malaysia
Other environmental tool approaches/ non-SFA	P_Waste; P_wastewater, P_water, P_ household, P_rural-urban; P_environment; P_trade; P_human; P_agriculture P_food; P_ City	Flow; Balance sheet; circular; MFA; SFA; inflow; outflow; stock; Malaysia
General case studies in Malaysia	Phosphorus; Nutrient: 'Fosforus' Detergent Fertilizer	P pollution; P discharge; P in environment; P management; Malaysia

purposes were selected based on important terms, keywords, titles and abstracts including 'phosphorus' AND 'Malaysia' OR 'Material Flow Analysis (MFA/SFA)', 'phosphate' AND 'Region' OR 'nutrient cycle', 'Municipal/Local/District' AND 'Inflow', 'Outflow' AND 'Stock' in the titles, abstracts or keywords (Table 1). Scoping searches were performed using selected database platforms namely Web of Knowledge, Thomson Reuters, Science Direct, Scopus, Research Gate, PubMed, Google Scholar, Wiley, Taylor and Francis, IEEE, Ebsco, Interscience and Emerald Insight within the last 10 years, between 2011 and 2021. The search was also extended to several websites of government organisations for scientific reports from the grey literature such as the DOA, UPEN, MARDI, MARTRADE, DOV and PELADANG.

The P flow also included selected sector subsystems, processes, activities, stocks, inflows, outflows, recycling flows, losses, circulars, mass equilibrium principles and temporal scales of the study. The additional information selected from the reference list adhered to the following three criteria: (1) What is the development scale of local research for P flow analysis using the SFA approach in Malaysia and vice versa? (2) To what extent can P flow management analysis contribute to national nutrient sustainability? and (3) What is known about the governance practices of P management in Malaysia?

This case study also adopted continuity codes including the accelerator, repercussion and the practice of nutrient flow system as extraneous variables comprising of social, economic, environment (Béné et al., 2019; Jia et al., 2019), and other relevant 'hotspot' aspects. This review also focussed on the upstream and downstream data consisting of study objectives, system definitions, data sources, estimation calculation methods, data availability, data quality and data reliability analysis. Finally, the results for each phase of P flow were compared using the SFA and other supporting environmental assessment tools. To achieve the study objectives, the results were expressed in six main subsystems namely crop production, animal production, processing of by-product feed, waste and wastewater management, trade (marketing/consumption) and environment (others) for review and estimation. Besides that, the six scenarios proposed by Jama-Rodzeńska et al. (2021) for problem-solving and P recovery strategies were also considered in this review: P biogeochemical cycle, the importance of the food system, environmental pollution, industry, basic knowledge and P supply.

Results

SFA-P assessment and P assessment at national scale

The minor improvement in the use of SFA and non-MFA/SFA techniques in Malaysia is depicted in Figure 1. In 2020, the incorporation of SFA-P management in research articles gradually increased to two studies on the agricultural field (Ahmad et al., 2019; Ghani et al., 2019), this include; study on solid waste management and a study on water management (Ghani, 2019; Ghani et al., 2020). The pioneering SFA-P research in Malaysia encompassed the entire P system, including agriculture, waste, wastewater, trade, food-household and environment in 2011 (Mahmood & Ghani, 2011). However, SFA-P studies were absent for 6 years (2012, 2014, 2015, 2016 and 2018). Hence, this gap may provide a logical conclusion for local researchers to conduct further investigations regarding the P loop in other subsystems using the SFA trial approach (Figure 1).

A total of 23 studies were successfully identified using the MFA technique to assess the flow of materials other than P in the national context (Figure 1). The SFA/MFA-non P study assessment revealed that the number of research increased from 2011 to 2020 based on different geographical scales. A majority of the studies focussed on electronic waste management (Agamuthu et al., 2015; Mohammad, 2018; Shah et al., 2015), materials management in urban areas (Shafie et al., 2016, 2018, 2020; Sharib & Halog, 2017; Sharif, 2019), and crop subsystems (Ghani et al., 2012; Hariz et al., 2017; Ghani, 2018a, b; Ghani et al., 2017, 2020; Ghani et al., 2020). The SFA/MFA-non P study areas also included livestock subsystems (Ghani et al., 2013). Results from these studies indicated a moderate positive relationship between the efficiency of biomass energy consumption and waste (crop and livestock

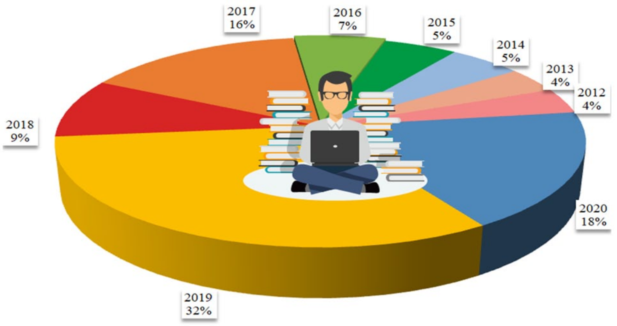

Figure 2. A comparative overview on the percentage contribution of P case studies in Malaysia.

subsystems). Externally imported mineral fertilisers were the highest contributor for material inflows (91%), followed by imported animal feed into the subsystem which accounted for 61% in 2011 to 2015. As for the MFA's assessment of electronic waste, it is normally disposed together with domestic wastes in landfills, with a steady increase over the past 5 years. Hence, awareness within the local community, apart from the ongoing support of 3R promotional campaigns from the administrators, could encourage the practice of material recycling and electronic waste recovery. For instance, the MFA assessment on urbanisation contributed significantly to the visualisation of inflow analysis such as electricity input, water and food input, along with the outflows of carbon dioxide, wastewater and solid waste (Figure 2).

The P study assessments in this review were only limited to main keywords containing the word P in the titles of the journals, theses or other articles as earlier mentioned in the methodology. A total of 97 P-related case studies were found within the local research context, with four major areas largely focussing on water, agriculture, wastewater and health contributing approximately 86% of the studies published within the 10 year observation period. The number of research publications regarding P also tripled from 2011 to 2020 as presented in Figure 2. Moreover, the last 4 years (2017–2020) also recorded the highest frequency of publications, mainly focussing on the mitigation of river pollution and industrial effluents, strategies to combat climate change and supporting nutrient balance in agricultural land including flux-stocks for forestry. The literature review also indicated that an integrated approach to technology and knowledge has become a major choice among local researchers in the biotechnology sector such as membrane biosynthesis, chemical processing industry which include cement, glass, nanoparticles and education involving awareness of detergent use (Ahmad et al., 2016; Danmalam et al., 2020; Hashim et al., 2019; Siwayanan et al., 2015).

Discussion

Phosphorus and SFA in the local context

According to the extant literature, SFA on P flow balance can potentially contribute to the local nutrient cycle and uphold sustainable ecoefficiency-dementrialisation ideas (El Wali et al., 2021; Zhang et al., 2008). Several SFA studies also assessed the P flow controls from a stakeholder's perspective on decision-making. For example, a total of four SFA-P studies (Figure 1) focussed on two process of flows namely; wastewater treatment subsystem and solid waste management subsystem, which with high state-scale flow recovery potential for recycling. Subsequently, the loss of P to the environment was minimised (in the form of garbage, illegal disposal, incineration, wastewater overflow, contaminated effluent, etc.). Whereas, four other SFA-P studies focussed on agricultural subsystems and river management successfully visualised the understanding of trends in the use of fertiliser, management of carcass waste and crop waste, together with household sewage components (Ghani et al. 2019). For example, the use of compost as organic fertiliser by farmers is the most cost-effective and easy-to practise P recovery measure in local agricultural practices (Rosemarin et al., 2020).

The focus area chosen to compare the input and output values of P for the entire study mechanism using the SFA approach was beneficial in improving nutrient management efficiency and identifying P flow losses to close the circular loops. Therefore, SFA-P assessment interventions for flow, multi-year (not necessarily focussed on one static year only), and other subsystems (no SFA-P studies were found for organic food waste subsystems, food production, industrial processing, urban-rural, import-export of materials, etc.) are required on a national, state and regional scale within Malaysia. Moreover, the development of a reliable and consistent database may instigate scientific interest among local researchers to use this SFA-P approach to solve the present environmental issues (Asmala & Saikku, 2010).

On the other hand, there is little attention in the local literature for cross-disciplinary studies covering historical knowledge and the role of social actors in the SFA-P approaches. In which case, the concepts of P governance can contribute to industry players, consumers, administrators and society in improving the nutrient cycle in the environment (Ghani et al., 2020). The requirements for the development of the SFA-P research outlook should also consider the economic, technological and participatory aspects of stakeholders. For instance, reasonable doubts may arise with regards to the investment of funds and the selection of P waste recovery technologies such as incinerator plants for the production of combustion ash from animal and human waste, as commercially viable cement, cake or struvite products (Aditi, 2017). Therefore, further studies (using the SFA-P technique) can be beneficial for stakeholders to obtain quick and clear feedback for responses supporting the status of sustainable development for P management in areas within critical hotspots (van der Wiel et al., 2020). Furthermore, the understanding of P cycle equilibrium from a fundamental perspective of biogeochemical systems can avoid ambiguity caused by various translations used in other disciplines, as the initial goal is to promote 'understanding the role of P flow in three key pillars of social, economic and environmental'. In turn, it provides the basis for policy formulation, promoting the field of nutrient management (Palm-Forster et al., 2017), and funding for future research on the P system.

Recognising the research importance of P knowledge and other materials

This section presents the importance of research areas within the focus of two versions, the MFA/SFA-non P issue and other P issues on a national scale. In the former version, most of the research trials related to the MFA/SFA-non P issue involved the entire subsystem which was directly related to the user (Figure 1). Most researchers claimed that the properties of the materials constantly change in a system, which requires researchers to deal with problems of subjectivity and limitations in the study of material flow (Ghani et al., 2020). Hence, providing a broader knowledge accessibility platform through continuous support of technological innovations such as; e-virtual, modern transportation, the success of material mass research can be proposed as a strategy that promises the achievement of a sustainable management policy foundation. As such, it is important to realise that the amount of data reporting and development of MFA model frameworks for waste flow, electronic waste, sewage waste, timber waste, energy, biomass, nutrients and heavy metals can be perceived as restructuring relevance that needs to be strongly reinforced. Moreover, determining the root cause of the problem of material flow imbalance in metabolism through thorough scrutiny is very complex and should involve the submission of a single strived solution to an integrated and holistic solution (Jama-Rodzeńska et al., 2021).

Broader parametric and non-parametric knowledge is gained through various indicators and implicit factors which enhance colonisation mapping of more dispersed networks and influence certain important categories such as actor power, politics, supply-demand of physical materials, etc. For example, MFA mapping in densely populated city areas such as Ampang Jaya, Kuala Lumpur and Selayang successfully disseminated important views on material recycling, increased energy efficiency, and food waste reduction, excluding budgeting which is also regarded as an important factor (Metson et al., 2012; Shafie et al., 2016). The incorporation of various aspects including natural disasters (drought, flood, erosion, fire, etc.), socio-economic (ie, growth and improvement of population standards of living), technology, and politics over multi-years will assist researchers to apprehend the quality and knowledge on sustainable material management. The lack of research on the contribution of plot scale, city or regional scale and other sectoral interventions have long been understood in the field of environmental decision-making, which admittedly resulted in knowledge uncertainty. Hence, such limitations need to be balanced. Thus, a variety of reviews on the management of other materials (eg, resource procurement, material network processes, development of material inflow and outflow analytical frameworks, material flow network design and performance, etc.) can provide additional knowledge to specific stakeholders. The combination of spatial (sector) and temporal (multi-year) knowledge along with the literature review on the MFA/SFA-non P issue could provide promising and exciting future research opportunities for local scientists.

Despite the use of different computing technologies and aggregation-modelling simulations, the ultimate goal is to achieve 'P management solutions' beneficial to the interests of many social actors (Leinweber et al., 2018). Research papers involving a second version (MFA/SFA-non P) managed to solve several different problems in the areas of nutrient phosphate that has become a common practice in fulfilling the current research trends more effectively (Abd Roni et al., 2021; Kawasaki et al., 2016). The search for practitioners for MFA/SFA non-P has a more complicated epistemic knowledge base and is considered extremely relevant for a long-term transfer to problem solving in the real world. In short, the integrated incorporation of P research associated with various aspects of actor behaviour (knowledge, attitudes and interests) along with the predictions overlapping specific social practices can uniformly influence decision-making.

Overall, the findings on the P management topic could pave the way for smarter P-nutrient solutions. A few important areas of knowledge that are relevant and generic but are still not available by way of snowball sampling research, are found in religion, politics, psychology, economics, literature etc. (Figure 3), may require a new research exploration method to feature effective P management solutions (Rowe et al., 2016; Withers et al., 2015). For instance, P dynamics widely examined in water management studies (25 articles on P case) requires scientists to challenge and incorporate fields like microbiology, hydrology, ecology, geomorphology, biogeochemistry, analytical chemistry and biology to help establish a more collective and systematic knowledge-sharing relationships (Ajmera et al., 2019). Moreover, there is increased pressure to resolve the P nutrient loop risking the aquatic ecosystems apart from protecting human health (Withers et al., 2018). Having said that, cross methodological coherence can restructure and redesign the relationships between resource, water, energy and nutrient management with consumers through green-leaning policy-makers.

Education (three research article), waste management (four research article), and agricultural production (four research article) are the research areas that were given the least attention in the second version of the literature (P-Non MFA/SFA). Despite the least attention, these subsystems are considered important in the context of SFA-P research due to the variability of inflows, outflows and P stock diversions which can contribute to significant savings of P source compared to the other subsystems. Thus, this study suggests that Malaysia requires a transdisciplinary multi-party approach to help unify these epistemics through dialogue and shared learning (either face-to-face or vice versa) to mend the gaps in P literacy

Figure 3. A comparative overview on the percentage contribution of P case studies in Malaysia.

education. The involvement of stakeholders including the government, academia and NGOs in approaching the 'unsustainable' parties to promote P education is required using any method available (Seibert et al., 2020). In a case study based on municipal and agricultural wastes management, knowledgeable bodies should channel information of high certainty to high-level decision-makers to improve the coordination of people's well-being on the aspects of economic, social and environmental. In the future, the MFA/SFA method may be considered in investigating P study within the local context since the inclusion of spatial and temporal boundaries is a basic prerequisite for scientists to fulfil before initiating their research. Although it may be difficult to find the exact rhythm to drive a better research development for P management among local researchers, it could contribute to the global sustainability of nutrient management.

Implications of P research strategies on local nutrient management

The SDG-17 sets out the need for action in every country to ensure the sustainability of non-renewable resources, human health security and minimise the deterioration of climate change. In a national-level study, Ghani (2010) recommended a periodic reporting of P flow data, taking into account the different P variables. Such recommendation is made considering the major implications for Malaysia as the country has no phosphate deposits, and is dependent on import trade (China, Morocco, Russia, the United States of America and other countries) to meet the domestic market demand. Moreover, the implications of material management theories like MFA are known outside the research world among the global community due to the recent concerns on risks of P to health, economic loss, social degradation and environmental damages (Chen et al., 2015). It may be possible that the combination of acquiring SFA-P flow assessments from separately altered temporal and spatial subsystems within different scales could, in turn, contribute to more accurate P management decisions for SFA-P comparisons between states or urbanisations, such as the lost, wasted and missing P flow calculations from the black box. Hence, the expansion of field-based research can help policy-makers to refine applicable regulations and laws according to the implications of local nutrient management policies. Nevertheless, studies on P at industry level is also very commendable (Mahmood & Ghani, 2011), since it reflects the implications of industrial symbiosis being practised in the portfolio of Ministry of Energy and Natural Resources (2020) covering energy, economic, environmental and social components such as; the use of green technology in industrial sectors (Neves et al., 2019; Teh et al., 2014). The most important implication extensively addressed in the literature is 'security challenge' which includes continued sustainability of Earth's life ecosystem such as nutrient content security, life expectancy, safety, utilisation and environmental conservation.

The strategy to introduce P-network at the national level should focus on the following high-priority system areas including agricultural productivity outcomes, food security, waste management, wastewater and water management, trade, together with the environment. However, Table 1 also indicated targets in other areas covering the economic spectrum (demand and supply of P), social (stakeholder engagement) and the environment (phosphate pollution). Nonetheless, the effects of material flow from system imbalance that can be influenced by several drivers require comprehensive research and recommendations to identify effective and strategic solutions for P system management (Figure 4). Social network and agent analysis tests (Lyon et al., 2020) based on social sciences, are perhaps the best example confirming that scientists from multidisciplinary backgrounds can work together to set better nutrient management rules and policies locally. Thus, the

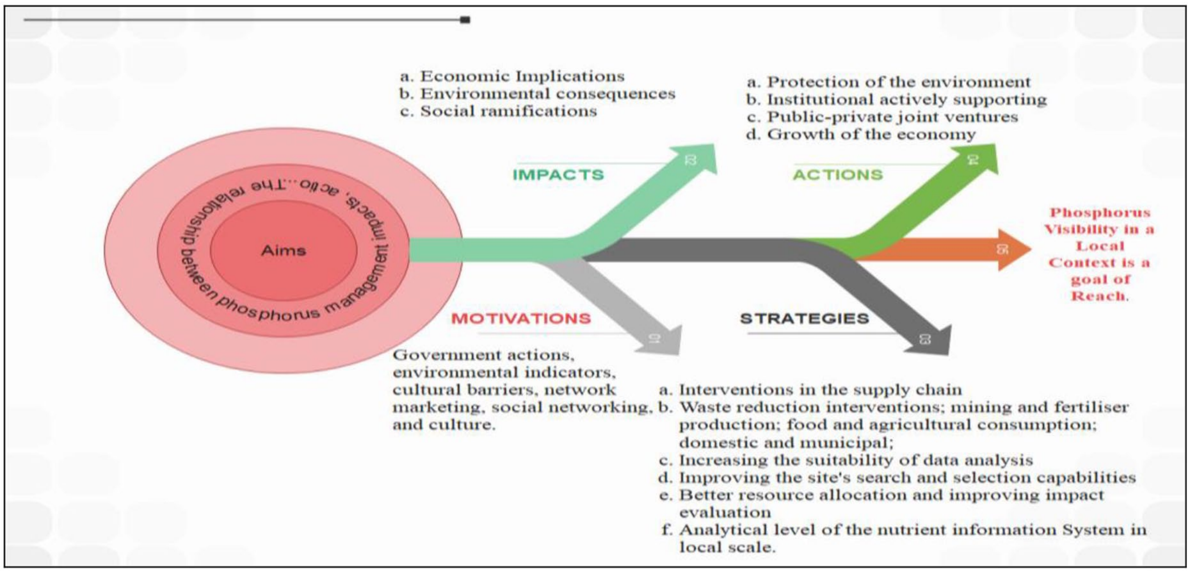

Figure 4. The interaction of phosphorus management impacts, drivers and strategies.

development of proven tools such as databases, mass balance research, modelling (with the latest software technology such as UMBERTO, SIMAPRO etc.), indicators, and cost-benefit analyses are crucial to support the advancement of P flow management research. P research is also paramount in improving consumers understanding of soil improvement, food safety and personal health (Figure 3), as several SFA-P studies in food systems demonstrated the intervention of well-planned P inflow control to achieve product and environmental quality targets (Kadir et al., 2016; Papangelou et al., 2020). For example, the maximum limit of P input value for agricultural land is less than 3 kg of P fertiliser per capita and around 0.26% to 0.29% P of Dry Matter for P-fodder input through animal intake routes to protect the human food chain. Such limitations are necessary because almost 90% of the P is taken up by humans as a result of agro-input dissipation into the environment (Kebreab et al., 2013; Rothwell et al., 2020). Therefore, it can be concluded that the proposed measure, key findings from SFA-P, MFA-non P research and other P case studies can stimulate the development and application of new strategies and innovations to prevent, treat and restore P flow affected by associated destruction.

Conclusion and recommendations

There is an enormous research expansion potential in P nutrient management study area, especially involving relevant subsystems and the use of other environmental decision-making support tool approaches. The use of SFA tools for the P research across national literature in the past 10 years revealed the absence of consistent SFA-P research (for 6 years) has lead to knowledge gap. Therefore, more studies should be conducted to identify hotspots by proposing solutions to develop procedures and important P loop restoration measures in local areas. Gaining a better understanding of livestock density, crop density, amount of fertiliser accumulation in the soil in agriculture, soil erosion, food import and export, farmers' agronomic practices, consumer diet, urban waste, human and animal waste management, along with various paths of P in other subsystems can increase the efficiency of P usage in a given period. The main variable influencing the excessive accumulation of P in soil mineralogy is triggered by the demand for meat and dairy products (Schroeder, 2018). Hence, research on the influence of additional nutrients such as Carbon, Nitrogen, Potassium, Sulphur and other elements on the dispersion of P in a web nexus is required to enable better modelling implementation and estimation of related 'mass' interactions. P databases for research, performance monitoring, consensus assessment, framing of member views, together with the provision of P recovery and recycling options from other local-scale contexts need to be expanded beyond the studies reported here.

This study also suggested that stakeholder involvement and representation from all levels for overall P governance in Malaysia needs to be presented in a clear and transparent organisational chart. The failure of interdisciplinary involvement (P practitioners) due to the conflict of interest could undermine the official homogeneous and epistemic P data reporting. The review of literature concurrently reported the lack of conference and dialogue discourse on P management at the grassroots' level contributed by the absence of the National Phosphorus Platform or P project management commission councils or special P organisations in the urban areas, neither in state nor national level. Hence, strengthening the Teaching and Learning (PnP) approach in the future could promote social responsibility in a shared orientation to improve the efficiency of P usage and prevent P pollution.

On the other hand, the use of techniques from local literature (MFA/SFA-non P issue findings) such as the GIS to determine the geographical boundaries of phosphate nutrients through laboratory and field tests. Such techniques can help determine chemical extraction methods for soil tests, precipitation and streamflow collection, water quality index parameter testing, etc. in estimating and modelling the phosphate flow from biophysical-chemical aspects. However, additional research development is still required. The rapid globalisation along with green economic/financial approaches used for quantity and intensity mapping of 'virtual materials' such as the 'green block chain' is an example of determining the existence of unsustainable management on state/national scale or global boundaries. Therefore, linking integrated system analysis tools such as MFA techniques along with Life Cycle Assessment (LCA), Geographic Information System (GIS) and Cost Benefit Analysis (CBA), allow simulation models towards better decision making and create opportunities for researchers from other disciplines.

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REFERENCES

Abd Roni, N., Adnan, S. H., Hamidon, N., & Tuan Ismail, T. N. H. (2021). The efficacy of recycled concrete aggregate for removal phosphorus in synthetic wastewater with different pH value. *Journal of Advanced Industrial Technology and Application*, 2(1), 24–30.

Aditi, B. (2017). *Recovery of phosphorus from incineration of sewage sludge* [Degree thesis, KTH, School of Chemical Science and engineering (CHE)].

Agamuthu, P., Kasapo, P., & Mohd Nordin, N. A. (2015). E-waste flow among selected institutions of higher learning using material flow analysis model. *Resources, Conservation and Recycling*, 105, 177–185. https://doi.org/10.1016/j.resconrec.2015.09.018

Ahmad, A., Osman, S. M., Cha, T. S., & Loh, S. H. (2016). Phosphate-induced changes in fatty acid biosynthesis in Chlorella sp. KS-MA2 strain. *BioTechnologia*, 4(4), 295–304. https://doi.org/10.5114/bta.2016.64547

Ahmad, R. A., Ghani, L. A., & Amir, H. S. (2019). The flow of phosphorus on dairy cattle livestock by using material flow analysis (MFA) Taman Pertanian Universiti Putra Malaysia, Selangor. In M. K. Faradiella & Normala (Eds.), *Socio-ecological prospects in environmental studies* (Vol. 2, pp. 63–80). UPM Press.

Ajmera, I., Hodgman, T. C., & Lu, C. (2019). An integrative systems perspective on Plant phosphate Research. *Genes*, 10(2), 139. https://doi.org/10.3390/genes10020139

Al-Badaii, F., Shuhaimi-Othman, M., & Gasim, M. B. (2013). Water quality assessment of the Semenyih River, Selangor, Malaysia. *Journal of Chemistry*, 2013, 1–10. https://doi.org/10.1155/2013/871056

Alewell, C., Ringeval, B., Ballabio, C., Robinson, D. A., Panagos, P., & Borrelli, P. (2020). Global phosphorus shortage will be aggravated by soil erosion. *Nature Communications*, 11, 4546. https://doi.org/10.1038/s41467-020-18326-7

Al-Mamun, A., & Zainuddin, Z. (2013). Sustainable river water quality managementt in Malaysia. *IIUM Engineering Journal*, 14(1), 1–10. https://doi.org/10.31436/iiumej.v14i1.266

Asmala, E., & Saikku, L. (2010). Closing a loop: Substance flow analysis of nitrogen and phosphorus in the rainbow trout production and domestic consumption system in Finland. *Ambio*, 39(2), 126–135. https://doi.org/10.1007/s13280-010-0024-5

Béné, C., Prager, S. D., Achicanoy, H. A. E., Toro, P. A., Lamotte, L., Cedrez, C. B., & Mapes, B. R. (2019). Understanding food systems drivers: A critical review of the literature. *Global Food Security*, 23(4), 149–159. https://doi.org/10.1016/j.gfs.2019.04.009

Bonsdorff, E. (2021). Eutrophication: Early warning signals, ecosystem-level and societal responses, and ways forward: This article belongs to Ambio's 50th Anniversary Collection. Theme: Eutrophication. *Ambio*, 50, 753–758. https://doi.org/10.1007/s13280-020-01432-7

Brevik, E. C., Slaughter, L., Singh, B. R., Steffan, J. J., Collier, D., Barnhart, P., & Pereira, P. (2020). Soil and human health: Current Status and future needs. *Air Soil and Water Research*, 13, 1–23. https://doi.org/10.1177/1178622120934441

Briner, R. B., & Denyer, D. (2012). Systematic review and evidence synthesis as a practice and scholarship tool. In D. M. Rousseau (Ed.), *Handbook of evidence-based management: Companies, classrooms and research* (pp. 112–129). Oxford University Press.

Camara, M., Jamil, N. R., & Abdullah, A. F. B. (2019). Impact of land uses on water quality in Malaysia: A review. *Ecological Processes*, 8(1), 0. https://doi.org/10.1186/s13717-019-0164-x

Chen, M. P., Guo, B. L., Liu, Y., Xia, X., & Chen, J. N. (2015). Research on phosphorus flow analysis. *Progress and perspectives*, 35, 6891–6900. https://doi.org/10.5846/stxb201404210793

Chowdhury, R. B., Moore, G. A., Weatherley, A. J., & Arora, M. (2017). Key sustainability challenges for the global phosphorus resource, their implications for global food security, and options for mitigation. *Journal of Cleaner Production*, 140(2), 945–963. https://doi.org/10.1016/j.jclepro.2016.07.012

Chowdhury, R. B., & Zhang, X. (2021). Phosphorus use efficiency in agricultural systems: A comprehensive assessment through the review of national scale substance flow analyses. *Ecological Indicators*, 121, 107172. https://doi.org/10.1016/j.ecolind.2020.107172

Cordell, D., Drangert, J.-O., & White, S. (2009). The story of phosphorus: Global food security and food for thought. *Global Environmental Change*, 19(2), 292–305. https://doi.org/10.1016/j.gloenvcha.2008.10.009

Cordell, D., Neset, T. S., & Prior, T. (2012). The phosphorus mass balance: Identifying 'hotspots' in the food system as a roadmap to phosphorus security. *Current Opinion in Biotechnology*, 23(6), 839–845. https://doi.org/10.1016/j.copbio.2012.03.010

Daneshgar, S., Callegari, A., Capodaglio, A., & Vaccari, D. (2018). The potential phosphorus crisis: Resource conservation and possible escape technologies: A review. *Resources*, 7(2), 37. https://doi.org/10.3390/resources7020037

Danmalam, I. M., Ibrahim, B., Ghoshal, S. K., & Ariffin, R. (2020). Correlation of optical and mechanical properties of silver nanoparticles sensitized europium doped magnesium zinc sulfophosphate glasses. *Open Journal of Science and Technology*, 2(2), 147–155. https://doi.org/10.31580/sps.v2i2.1276

Department of Environment. (2020). *Media statement, Air and river water quality status throughout the duration of the movement control order.* Retrieved March 10, 2020, from https://www.doe.gov.my/portalv1.

Diatta, J., Waraczewska, Z., Grzebisz, W., Niewiadomska, A., & Tatuśko-Krygier, N. (2020). Eutrophication induction via N/P and P/N ratios under controlled Conditions—Effects of temperature and water sources. *Water Air & Soil Pollution*, 231, 149. https://doi.org/10.1007/s11270-020-04480-7

El Wali, M., Golroudbary, S. R., & Kraslawski, A. (2021). Circular economy for phosphorus supply chain and its impact on social sustainable development goals. *The Science of the Total Environment*, 777, 146060. https://doi.org/10.1016/j.scitotenv.2021.146060

Ghani, L. A. (2010). *An application of Material Flow Analysis (MFA) as a tool for sustainable regional management: phosphorus as a case study in Malaysia. Master Thesis.* Universiti Malaya, Kuala Lumpur.

Ghani, L. A. (2018a). Biomass energy flow screening for good governance in agricultural system: A case study in Terengganu state. *Malaysian Journal of Society and Space*, 14(4), 27–41.

Ghani, L. A. (2018b). Potential use of substance flow analysis to recount the nitrogen flux in agriculture soils system in Terengganu. *Malaysian Journal of Soil Science*, 22, 117–131.

Ghani, L. A. (2020). Potensi kaedah analisis aliran bahan dalam pemerkasaan tadbir urus sisa buangan pertanian; kajian kes di Terengganu. In N. Hashim, L. A. Ghani, & R. M. Jamin (Eds.), *Governan isu-isu pembangunan komuniti dan alam sekitar*, (pp. 147–156). UMT Press. (In Malay).

Ghani, L., Aini, N., & Mahmood, N. (2012). *Analisis Aliran Bahan (MFA) Bagi Penilaian Tenaga Biojisim Dalam Sistem Pertanian di Terengganu*. Persidangan Kebangsaan Pembangunan & Pendidikan Lestari. IPG Kampus Tunku Bainun, Bukit Mertajam, Pulau Pinang 19–20 September 2012, Malaysia. (in Malay)

Ghani, L. A., Khairunnisa, B., & Amir Hamzah, S. (2019). The flow of phosphorus for sustainable wastewater management in Quail Production Process. In M. K. Faradiella & H. Normala (Eds.), *Socio-ecological prospects in environmental studies* (Vol. 2, pp. 79–98). UPM Serdang, UPM Press.

Ghani, L. A., Noor, Z. M., & Faridah, O. (2019). Assessment of phosphorus load in Water River using substances flow analysis (SFA). *Journal of Engineering Science and Technology*, 14, 1289–1300.

Ghani, L. A., Mahmood, Z. M., Saputra, J, Bahri, S., & Muhammad, Z. (2020). The effectiveness of the Gidden's structural theory in creating the Eco-Friendly, sustainable and green economy through energy flow for maize production management. *International Journal of Advanced Science and Technology*, 29(7), 1686–1698.

Ghani, L. A., Noor, Z. M., & Nora'aini, A. (2013). Biomass energy flow assessment using the material flow analysis (MFA) method for Livestock Production System. *World Applied Sciences Journal*, 27(8), 961–969.

Ghani, L. A., Noor, Z. M., & Nora'aini, A. (2017). Coupling material flow analysis (MFA) and geographic information system (GIS) methodologies for screening flow and emission of biomass energy in the agricultural system. Proceedings of the international conference on imaging, signal processing and communication (ICISPC 2017). Association for Computing Machinery (pp.180–185), New York, NY.

Ghani, L. A., Norfaryana, M. I., & Amir Hamzah, S. (2019). The flow of phosphorus on pineapple cultivation by using material flow analysis (Mfa). In M. K. Faradiella & H. Normala (Eds.), *Socio-ecological prospects in environmental studies* (Vol. 2, pp. 48–62). UPM Serdang, UPM Press.

Ghani, L. A., Saputra, J., Muhammad, J., Zulkarnaen, I., & Alfiady, T. (2020). An investigation of waste management (phosphorus) and its relationship to the local economic circulars in Terengganu, Malaysia. *International Journal of Advanced Science and Technology*, 29(7), 1675–1685.

Gupta, D. K., Chatterjee, S., Datta, S., Veer, V., & Walther, C. (2014). Role of phosphate fertilizers in heavy metal uptake and detoxification of toxic metals. *Chemosphere*, 108, 134–144. https://doi.org/10.1016/j.chemosphere.2014.01.030

Hariz, Z., Noor, Z. M., & Wan, A. M. (2017). Material flow analysis of carbon in palm oil mill and Oil Palm plantation: Towards low carbon Industry. *Journal of Advanced Research in Engineering Knowledge*, 1(1), 30–39.

Hashim, S. N., Rodzali, N. N., Muhammad, N. A., Abdullah, S. N. A., Hasmi, N. A., Kamarudin, A. A., Nor Azlan, S. N. A., Saharudin, N. S., & Nor Rahim, N. F. A. (2019). Optimization for detection of On-Site phosphate contamination qualitatively. *Journal of Science and Mathematics Letters*, 7, 26–33. https://doi.org/10.37134/jsml.vol7.3.2019

Heckenmüller, M., Narita, D., & Klepper, G. (2014). *Global availability of phosphorus and its implications for global food supply: An economic overview*. Kiel Working Paper, No. 1897, Kiel Institute for the World Economy (IfW), Kiel.

Hermann, L., Kraus, F., & Hermann, R. (2018). Phosphorus Processing—Potentials for higher efficiency. *Sustainability*, 10, 1482. https://doi.org/10.3390/su10051482

Hollaway, M. J., Beven, K. J., Benskin, C. M., Collins, A. L., Evans, R., Falloon, P. D., Forber, K. J., Hiscock, K. M., Kahana, R., Macleod, C. J., Ockenden, M. C., Villamizar, M. L., Wearing, C., Withers, P. J., Zhou, J. G., Barber, N. J., & Haygarth, P. M. (2018). The challenges of modelling phosphorus in a headwater catchment: Applying a 'limits of acceptability' uncertainty framework to a water quality model. *Journal of Hydrology*, 558, 607–624. https://doi.org/10.1016/j.jhydrol.2018.01.063

Hwang, S.-J. (2020). Eutrophication and the Ecological Health Risk. *International Journal of Environmental Research and Public Health*, 17, 6332. https://doi.org/10.3390/ijerph17176332

Isa, N. M., Sivapathy, A., & Adjrina Kamarruddin, N. N. (2021). Malaysia on the way to sustainable development: Circular economy and green technologies. In B. S. Sergi & A. R. Jaaffar (Eds.), *Modeling economic growth in contemporary Malaysia (Entrepreneurship and Global Economic Growth)* (pp. 91–115). Emerald Publishing Limited.

Jama-Rodzeńska, A., Białowiec, A., Koziel, J. A., & Sowiński, J. (2021). Waste to phosphorus: A transdisciplinary solution to P recovery from wastewater based on the TRIZ approach. *Journal of Environmental Management*, 287, 112235. https://doi.org/10.1016/j.jenvman.2021.112235

Jia, F., Hubbard, M., Zhang, T., & Chen, L. (2019). Water stewardship in agricultural supply chains. *Journal of Cleaner Production*, 235, 1170–1188. https://doi.org/10.1016/j.jclepro.2019.07.006

Kadir, A. A., Ismail, S. N. M., & Jamaludin, S. N. (2016). Food waste composting study from Makanan Ringan Mas. IOP Conference Series Materials Science and Engineering, 136, 012057.

Kawasaki, N., Kushairi, M. R. M., Nagao, N., Yusoff, F., Imai, A., & Kohzu, A. (2016). Release of nitrogen and phosphorus from Aquaculture farms to Selangor River, Malaysia. *International Journal of Environmental Science and Development*, 7(2), 113–116. https://doi.org/10.7763/ijesd.2016.v7.751

Kebreab, E., Hansen, A. V., & Leytem, B. (2013). *Feed management practices to reduce manure phosphorus excretion in dairy cattle* (Vol. 1483). Publications from USDA-ARS / UNL Faculty.

Klinglmair, M., Zoboli, O., Laner, D., Rechberger, H., Astrup, T. F., & Scheutz, C. (2016). The effect of data structure and model choices on MFA results: A comparison of phosphorus balances for Denmark and Austria. *Resources, Conservation and Recycling*, 109, 166–175. https://doi.org/10.1016/j.resconrec.2016.03.009

Lee, G. C. (2020). The river water quality before and during the Movement Control Order (MCO) in Malaysia. *Case Studies in Chemical and Environmental Engineering*, 2, 100027. https://doi.org/10.1016/j.cscee.2020.100027

Leinweber, P., Bathmann, U., Buczko, U., Douhaire, C., Eichler-Löbermann, B., Frossard, E., Ekardt, F., Jarvie, H., Krämer, I., Kabbe, C., Lennartz, B., Mellander, P. E., Nausch, G., Ohtake, H., & Tränckner, J. (2018). Handling the phosphorus paradox in agriculture and natural ecosystems: Scarcity, necessity, and burden of P. *Ambio*, 47(Suppl 1), 3–19. https://doi.org/10.1007/s13280-017-0968-9

Liu, Z., Tang, J., Ren, X., & Schaeffer, S. M. (2021). Effects of phosphorus modified nZVI-biochar composite on emission of greenhouse gases and changes of microbial community in soil. *Environmental Pollution*, 274, 116483. https://doi.org/10.1016/j.envpol.2021.116483

Lyon, C., Cordell, D., Jacobs, B., Martin-Ortega, J., Marshall, R., Camargo-Valero, M. A., & Sherry, E. (2020). Five pillars for stakeholder analyses in sustainability transformations: The global case of phosphorus. *Environmental Science & Policy*, 107, 80–89. https://doi.org/10.1016/j.envsci.2020.02.019

Ma, S., Luo, Z., Hu, S., & Chen, D. (2018). Promoting information technology for the sustainable development of the phosphate fertilizer industry: A case study of Guizhou Province, China. *Royal Society Open Science*, 5(11), 181160. https://doi.org/10.1098/rsos.181160

Mahmood, N., & Ghani, L. A (2011). Balance sheet for phosphorus in Malaysia by SFA. *Australian Journal of Basic and Applied Sciences*, 5(12), 3069–3079.

Meadows, D., & Wright, D. (2008). *Thinking in systems: A Primer*. Chelsea Green Publishing.

Metson, G. S., Bennett, E. M., & Elser, J. J. (2012). The role of diet in phosphorus demand. *Environmental Research Letters*, 7(4), 044043. https://doi.org/10.1088/1748-9326/7/4/044043

Metson, G. S., Cordell, D., & Ridoutt, B. (2016). Potential impact of dietary choices on phosphorus recycling and global phosphorus footprints: The Case of the average Australian city. *Frontiers in Nutrition*, 3, 35. https://doi.org/10.3389/fnut.2016.00035

Metson, G. S., Iwaniec, D. M., Baker, L. A., Bennett, E. M., Childers, D. L., Cordell, D., Grimm, N. B., Grove, J. M., Nidzgorski, D. A., & White, S. (2015). Urban phosphorus sustainability: Systemically incorporating social, ecological, and technological factors into phosphorus flow analysis. *Environmental Science & Policy*, 47, 1–11.

Ministry of Energy and Natural Resources. (2020). Retrieved April 11, 2020, from https://www.ketsa.gov.my/en-my/Pages/default.aspx

Mohammad, I. R. (2018). *Material flow analysis of household e-waste in Kuala Lumpur. Master Thesis*. Universiti Kebangsaan Malaysia.

Neves, A., Godina, R., G. Azevedo, S., Pimentel, C., & C.o. Matias, J. (2019). The potential of industrial symbiosis: Case analysis and main drivers and barriers to its implementation. *Sustainability*, 11(24), 7095. https://doi.org/10.3390/su11247095

Palm-Forster, L. H., Swinton, S. M., & Shupp, R. S. (2017). Farmer preferences for conservation incentives that promote voluntary phosphorus abatement in agricultural watersheds. *Journal of Soil and Water Conservation*, 72(5), 493–505. https://doi.org/10.2489/jswc.72.5.493

Papangelou, A., Achten, W. M. J., & Mathijs, E. (2020). Phosphorus and energy flows through the food system of Brussels Capital Region. *Resources, Conservation and Recycling*, 156, 104687. https://doi.org/10.1016/j.resconrec.2020.104687

Pellerin, D., Charbonneau, E., Fadul-Pacheco, L., Soucy, O., & Wattiaux, M. A. (2017). Economic effect of reducing nitrogen and phosphorus mass balance on Wisconsin and Québec dairy farms. *Journal of Dairy Science*, 100(10), 8614–8629. https://doi.org/10.3168/jds.2016-11984

Rahman, S., Chowdhury, R. B., D'Costa, N. G., Milne, N., Bhuiyan, M., & Sujauddin, M. (2019). Determining the potential role of the waste sector in decoupling of phosphorus: A comprehensive review of national scale substance flow analyses. *Resources, Conservation and Recycling*, 144, 144–157. https://doi.org/10.1016/j.resconrec.2019.01.022

Razali, A., Syed Ismail, S. N., Awang, S., Praveena, S. M., & Zainal Abidin, E. (2018). Land use change in highland area and its impact on river water quality: A review of case studies in Malaysia. *Ecological Processes*, 7(1), 17.

Reitzel, K., Bennett, W. W., Berger, N., Brownlie, W. J., Bruun, S., Christensen, M. L., Cordell, D., van Dijk, K., Egemose, S., Eigner, H., Glud, R. N., Grönfors, O., Hermann, L., Houot, S., Hupfer, M., Jacobs, B., Korving, L., Kjærgaard, C., Liimatainen, H., . . . Metson, G. S. (2019). New training to meet the Global phosphorus Challenge. *Environmental Science & Technology*, 53(15), 8479–8481. https://doi.org/10.1021/acs.est.9b03519

Rosemarin, A., Macura, B., Carolus, J., Barquet, K., Ek, F., Järnberg, L., Lorick, D., Johannesdottir, S., Pedersen, S. M., Koskiaho, J., Haddaway, N. R., & Okruszko, T. (2020). Circular nutrient solutions for agriculture and wastewater – A review of technologies and practices. *Current Opinion in Environmental Sustainability*, 45, 78–91. https://doi.org/10.1016/j.cosust.2020.09.007

Ros, M. B. H., Koopmans, G. F., van Groenigen, K. J., Abalos, D., Oenema, O., Vos, H. M. J., & van Groenigen, J. W. (2020). Towards optimal use of phosphorus fertiliser. *Scientific Reports*, 10(1), 17804. https://doi.org/10.1038/s41598-020-74736-z

Rothwell, S. A., Doody, D. G., Johnston, C., Forber, K. J., Cencic, O., Rechberger, H., & Withers, P. J. (2020). Phosphorus stocks and flows in an intensive livestock dominated food system. *Resources, Conservation and Recycling*, 163, 105065. https://doi.org/10.1016/j.resconrec.2020.105065

Rousselin, M. (2018). A study in dispossession: The political ecology of phosphate in Tunisia. *Journal of Political Ecology*, 25, 20. https://doi.org/10.2458/v25i1.22006

Rowe, H., Withers, P. J. A., Baas, P., Chan, N. I., Doody, D., Holiman, J., Jacobs, B., Li, H., MacDonald, G. K., McDowell, R., Sharpley, A. N., Shen, J., Taheri, W., Wallenstein, M., & Weintraub, M. N. (2016). Integrating legacy soil phosphorus into sustainable nutrient management strategies for future food, bioenergy and water security. *Nutrient Cycling in Agroecosystems*, 104(3), 393–412. https://doi.org/10.1007/s10705-015-9726-1

Sarvajayakesavalu, S., Lu, Y., Withers, P. J. A., Pavinato, P. S., Pan, G., & Chareonsudjai, P. (2018). Phosphorus recovery: A need for an integrated approach. *Ecosystem Health and Sustainability*, 4(2), 48–57. https://doi.org/10.1080/20964129.2018.1460122

Schroeder, J. (2018). Phosphorus impacts from meat- dairy- and plant-based diets. *Consilience: The Journal of Sustainable Development*, 19, 17–35.

Seibert, J., Schmoll, I., Kay, C. W. M., & Huwer, J. (2020). Promoting Education for Sustainable Development with an interactive digital learning companion students use to perform collaborative phosphorus recovery experiments and Reporting. *Journal of Chemical Education*, 97, 3992–4000. https://doi.org/10.1021/acs.jchemed.0c00408

Shafie, F. A., Mohd Aris, M. F., Karuppannan, S., Masngut, M. I., Md Rashid, R. I., & Ishak, A. R. (2020). *Metabolism of Shah Alam, Klang and Petaling Jaya: Insights from Material Flow Analysis*. The Official Research Book of Faculty of Health Sciences. UiTM Press.

Shafie, F. A., Omar, D., Karuppannan, S., & Ismail, N. (2016). Urban-scale material flow analysis: Malaysian Cities Case Study. *The International Journal of Environmental Sustainability*, 5, 1927–9566. https://doi.org/10.24102/ijes.v5i2.679

Shafie, F. A., Omar, D., Karuppannan, S., & Shariffuddin, N. (2018). Urban material flow analysis: An approach for Greater Kuala Lumpur. *Asian Journal of Quality of Life*, 3(11), 193. https://doi.org/10.21834/ajqol.v3i11.135

Shah, G. L., Yusof, M. B., & Ming, N. G. (2015). Material flow analysis and awareness on E-Waste Management. *Malaysian Journal of Civil Engineering*, 27(2), 275–289.

Sharib, S., & Halog, A. (2017). Enhancing value chains by applying industrial symbiosis concept to the rubber city in Kedah, Malaysia. *Journal of Cleaner Production*, 141, 1095–1108. https://doi.org/10.1016/j.jclepro.2016.09.089

Sharif, S. (2019). Analisis Bandar Teknik Material Flow Analysis (MFA) sistem ekologi bandar. Gangguan terhadap persekitaran. The National Conference on Local Government and Development (NCLGD2019) 25–26 November 2019, Universiti Utara Malaysia. (in Malay).

Sharip, Z., & Zakaria, S. (2007). Lake and reservoir in Malaysia: Management and research challenges. Proceedings of Taal 2007: The 12th World Lake Conference, Jaipur, Rajasthan. India (pp. 1349–1355).

Siwayanan, P., Bakar, N. A., Aziz, R., & Chelliapan, S. (2015). Exploring Malaysian household consumers acceptance towards eco-friendly laundry detergent powders. *Asian Social Science*, 11(9), 125–137. https://doi.org/10.5539/ass.v11n9p125

Smol, M. (2019). The importance of sustainable phosphorus management in the circular economy (CE) model: The Polish case study. *Journal of Material Cycles and Waste Management*, 21(2), 227–238. https://doi.org/10.1007/s10163-018-0794-6

Tang, X., Li, R., Han, D., & Scholz, M. (2020). Response of eutrophication development to variations in nutrients and hydrological regime: A case study in the Changjiang River (Yangtze) Basin. *Water*, 12(6), 1634. https://doi.org/10.3390/w12061634

Teh, B. T., Ho, C. S., Matsuoka, Y., Chau, L. W., & Gomi, K. (2014). Determinant factors of industrial symbiosis: Greening Pasir Gudang industrial park. IOP Conference Series Earth and Environmental Science, 18, 012162.

van der Wiel, B. Z., Weijma, J., van Middelaar, C. E., Kleinke, M., Buisman, C. J. N., & Wichern, F. (2020). Restoring nutrient circularity: A review of nutrient stock and flow analyses of local agro-food-waste systems. *Resources, Conservation and Recycling*, 160, 104901. https://doi.org/10.1016/j.resconrec.2020.104901

Withers, P., Doody, D., & Sylvester-Bradley, R. (2018). Achieving sustainable phosphorus use in food systems through circularisation. *Sustainability*, 10(6), 1804. https://doi.org/10.3390/su10061804

Withers, P. J., van Dijk, K. C., Neset, T. S., Nesme, T., Oenema, O., Rubæk, G. H., Schoumans, O. F., Smit, B., & Pellerin, S. (2015). Stewardship to tackle global phosphorus inefficiency: The case of Europe. *Ambio*, 44 (Suppl. 2), S193–S206. https://doi.org/10.1007/s13280-014-0614-8

Withers, P. J. A., Forber, K. G., Lyon, C., Rothwell, S., Doody, D. G., Jarvie, H. P., Martin-Ortega, J., Jacobs, B., Cordell, D., Patton, M., Camargo-Valero, M. A., & Cassidy, R. (2020). Towards resolving the phosphorus chaos created by food systems. *Ambio*, 49, 1076–1089. https://doi.org/10.1007/s13280-019-01255-1

Wu, J., Hartmann, T. E., & Chen, W.-S. (2019). Toward sustainable management of phosphorus flows in a changing rural–urban environment: Recent advances, challenges, and opportunities. *Current Opinion in Environmental Sustainability*, 40, 81–87. https://doi.org/10.1016/j.cosust.2019.09.012

Zhang, W., Ma, W., Ji, Y., Fan, M., Oenema, O., & Zhang, F. (2008). Efficiency, economics, and environmental implications of phosphorus resource use and the fertilizer industry in China. *Nutrient Cycling in Agroecosystems*, 80, 131–144. https://doi.org/10.1007/s10705-007-9126-2

Zowada, C., Gulacar, O., Siol, A., & Eilks, I. (2020). Phosphorus – A “political” element for transdisciplinary chemistry education. *Chemistry Teacher International*, 2(1), 20180020. https://doi.org/10.1515/cti-2018-0020