Phosphorus Stock and Flows in the Northern Ireland Food System

RePhOKUs

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1. Overview

The purpose of this report is to present the results from the Phosphorus (P) Substance Flow Analysis (SFA), carried out as part of the Rephokus project (Text Box 1). **An SFA is an analytical tool** used to quantify the stocks and flows of any material within a defined system. For the purposes of this study the system is the food system within the geographical border of Northern Ireland (NI) for the year 2017. The focus of the SFA is on P due the significant challenges that NI faces in its sustainable management in the context of achieving agronomic and environmental targets. The SFA was developed using a combination of publicly available national statistics or industry annual reports data, outputs from previous scientific studies and expert's input from stakeholders within the NI agri-food industry. The SFA quantifies the stocks and flows of P in four main sub-systems namely; livestock, crops & soil, waste management and waste water treatment. Further details on the SFA methodology can be found in Rothwell *et al* (2020).

This report is the third phase of NI stakeholder engagement within the Rephokus project, starting with one to one meetings, and followed by a stakeholder workshop in February 2020, where the completed SFA was presented to stakeholders and future scenarios for sustainable P management within the NI food system were discussed. **The aim of this report** is to present the findings of the SFA and associated stakeholder engagement so as to provide the agri-food industry with information and data to inform and stimulate transformative discussions for the development of strategies for the sustainable management of P in NI.

The **structure of this report** is as follows: First it provides an introduction to P in NI since the implementation of the Nitrates Directive and Phosphorus (Use in Agriculture) Regulation in 2004 and 2006 respectively (Section 2). Details of the SFA are then presented (Section 3) followed by an overview of the stakeholder workshop, future P SFA scenarios and a summary of the key points in the stakeholder discussion (Section 4). In the final section (Section 5), the findings of the SFA and stakeholder inputs are discussed in the context of our current understanding of strategies for sustainable P management in intensive livestock systems.

The RePhoKUs Project- Re-Focusing Phosphorus with the UK Food System

PROJECT AIM:

The aim of RePhoKUs is to enhance the resilience and sustainability of the UK food system by developing and prioritising adaptive strategies that reduce the vulnerability of UK farming to future P scarcity at multiple scales, and that enhance the balanced delivery of multiple ecosystem systems for future food and water security

WHY:

There is an important gap in knowledge as to the current state of P within UK agriculture, the wider food system, and the natural environment. While P is nationally abundant due to historic prices and food production practices, on a global scale it is a finite and scarce resource, with the vast majority of the known deposits located in Morocco and China. The UK has no known deposits of rock phosphate (RP) and so is completely dependent on imports of P to support food production. In addition, eutrophication caused by excessive P entering our waterbodies is very costly to society and devalues many ecosystem services linked to water quality including quantity for drinking, biodiversity and recreation. Therefore, improving how efficiently P is used contributes to two objectives simultaneously – reducing (1) vulnerability to sudden or extreme changes in the global supply and price of P, and, (2) pollution caused by a build-up of P beyond what is needed for immediate food production and the subsequent negative impacts on the natural environment.

RePhoKUs Project participants pictured at AFBI Hillsborough

Partners

Funders

WHAT:

The RePhoKUs project combines different biophysical, social and economic approaches to examine the synergies and conflicts arising from how P is currently distributed within the food system to stimulate discussion and provide evidence for potential policy approaches. The project involves an extensive stakeholder engagement process at farm, catchment and national scale. In addition to the P SFA for NI, key outputs from the project will include (1) a national strategy to reduce the vulnerability of the food system to shocks and stress due to P availability or price fluctuations. (2) P SFA of the UK food system and the regional imbalance between P demand and supply, (3) assessment of catchments for their vulnerability to P loss to water and options for more sustainable P management (4) economic optimisation model highlighting the impact of sustainable P management on farm profitability.

WHO:

The project is a collaboration between Lancaster University, AFBI, Leeds University, University of Technology Sydney, and Centre for Ecology and Hydrology and is funded by the Global Food Security's 'Resilience of the UK Food System Programme' with the UK's Biotechnology and Biological Science Research Council (BBSRC), the Economic and Social Research Council (ESRC), the Natural Environment Research Council (NERC) and the Scottish Government.

More information at: [http://wp.lancs.ac.uk/rephokus/.](http://wp.lancs.ac.uk/rephokus/)

2. Phosphorus in Northern Ireland

2.1 Introduction

The emphasis on P management in NI has focused mainly on improving agricultural efficiency and reducing losses to water, with Rock Phosphate (RP) availability and its potential impact on feed and fertiliser import, only recently entering the debate. Agriculture plays a vital role in the NI economy, contributing around 5% of Gross Value Added (GVA) and 5% of total employment (DAERA 2019a). In addition, 75% of NI land is used for agriculture, with grassland accounting for 93% and only 7% arable. Agri-food outputs have increased in recent years driven by demographic change combined with changing consumption patterns and increasing global incomes, stimulating global demand for meat and dairy products. This has been reinforced by changes in European policy, specifically the removal of milk quotas in 2015 and the NI agri-food strategy 'Going for Growth' (AFSB 2013).

2.2 Phosphorus Balance in NI

In 2017, the national agricultural P surplus was 12.3 kg P ha^{-1}, up from a low of 8.7 kg P ha^{-1} in 2008 (Figure 1).

The 2008 surplus was achieved following implementation of the EU Nitrates Directive (91/676/EEC) in 2004 and Phosphorus (Use in Agriculture) Regulation 2006 (Northern Ireland), which helped reduce the P surplus from 17.7 kg P ha^{-1} (2003), without negative impacts on agricultural productivity. Within NI, the stated P surplus objective in the government's roadmap for improving farm nutrient efficiency and profitability is 5 kg P ha^{-1} yr^{-1} (DAERA 2016); however, in recent years the agri-food industry has moved further away from achieving this target. Despite continuing improvements in P use efficiency, the upward trend in the P surplus since 2008 has largely been due to the gradual increase in the use of imported feed from 13.4 to 16.8 kg P ha^{-1} between 2008 and 2017 and a slight increase in inorganic P fertiliser use from 3.1 to 4.5 kg P ha^{-1} during the same period.

2.3 P Source Pressure

Recent government soil sampling schemes have demonstrated the impact of this agricultural surplus on soil P levels, with 38% of soils having Olsen P concentrations above the optimum for grassland (Higgins *et al* 2020). In addition to the risk posed to water quality from these high P soils (Cassidy *et al* 2016), the spatial and temporal distribution of manure P is a critical issue for the future sustainability of NI agriculture. The combination of localised intensive livestock production, limited availability of arable land, cost of transporting slurry, limited infrastructure for processing manure and the fact that 57% of soils are classed as high risk for runoff, all pose significant challenges for the agri-food industry in terms of balancing agronomic and environmental objectives.

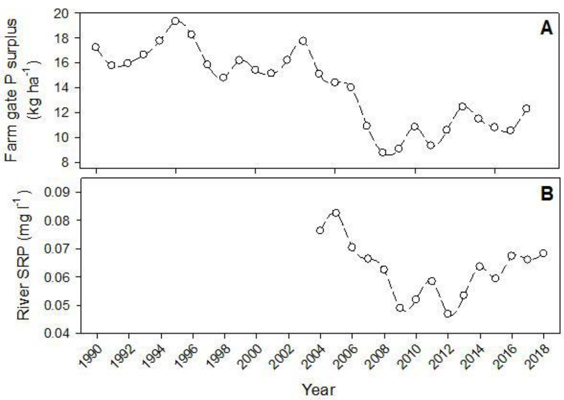

Figure 1: Changes in the national farm gate P surplus and average soluble reactive P in Northern Ireland Rivers

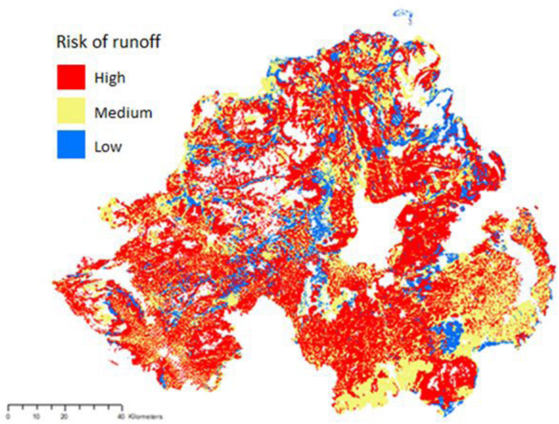

Figure 2: Runoff Risk Map for NI soils

2.4 Water Quality

Mirroring the improvements in the national P surplus, there has been a significant reduction in the P concentrations recorded in rivers across NI since the 1990's (Barry and Foy 2016). However, recent monitoring indicates that since 2012-13 this trend has been reversing (Figure 1) and so within the context of growth in the NI agri-food industry (AFSB 2013), there remains major uncertainty related to achieving the targets of the Water Framework Directive (WFD) (2000/60/EC). Currently only 31.3% of river waterbodies and 24% of lakes are achieving the target of 'Good Status' required under the WFD, with agriculture contributing the majority of the annual P load to waterbodies and the remainder coming from Waste Water Treatment Plants (WWTP), septic tanks and industrial sources. At present only 39% of NI's waterbodies are at P concentrations below the targets required for good water quality due to elevated P levels.

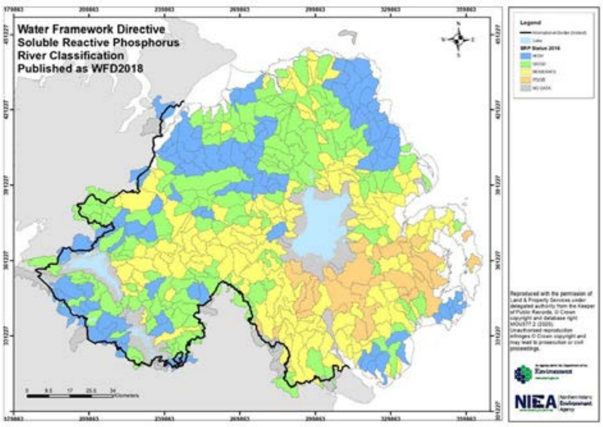

Figure 3: Waterbodies failing the targets of the Water Frame Directive due to Phosphorus

2.5 Need for Action

Sustainable P management has been the focus of ongoing discussion in the agri-food industry and policy arena for the past 20 years in NI. While there has been significant improvement in P use efficiency and reductions in losses to waterbodies (Barry and Foy 2016), the recent upward trend in the agricultural P surplus and P concentrations in many waterbodies, means that further steps are required if the twin objectives of the WFD and protecting rural livelihoods are to be achieved. To date, collaboration and cooperation between policy, agri-food and science stakeholders has resulted in the implementation of many beneficial measures, however recent evidence suggests that more transformative change is required if the targets of both agriculture and the environment are to be achieved. This, and the opportunity provided by Brexit to adopt new approaches to agri-environmental policy in NI, mean there is currently a need to stimulate and facilitate new thinking and discussion on how sustainable P management can be achieved in the NI food system.

2.6 Key messages

- Significant improvements have been made over the past 20 years as indicated by the reduction in the national P surplus and the decrease in SRP concentration in many waterbodies.
- However, recent trends have shown an increase in both the national P surplus and SRP concentrations in rivers.
- The expected growth in the agri-food industry, as outlined in the Going for Growth report, is vital for the NI economy.
- However, there are significant challenges in achieving this while also realising the current P targets set under the WFD.
- The NI food industry is very reliant on imported P in fertiliser and feed concentrates and therefore vulnerable to changes in the availability and price of RP.

3. Northern Ireland's Phosphorus Substance Flow Analyses

3.1 Phosphorus Substance Flow Findings

Figure 4 presents NI's P SFA for 2017 and shows that:

- NI ***imported*** a total of 18,300 t ± 7% (9.8 kg cap^{-1} yr^{-1}) of P as animal feed (64%), fertiliser (24%), food (6%), fish landings (2%), live animals (2%) and non-food P (3%).
- ***Exports*** of P were 8000 t ± 13% P (4.3 kg cap^{-1} yr^{-1}) primarily as food products (55%), the rest through waste management (25%), animal feed (10%), manure (6%) and live animals (4%),
- This results in a ***system P surplus*** of 10300 t ± 12% which equates to a net national consumption of 5.5 kg P cap^{-1} yr^{1}.
- The ***NI food system produced*** 5700 t of P in food for home consumption and export, 790 t in exported animal feed and 325 t in exported live animals from a total of 17,841 t of P imports
- This results in a ***food system P*** efficiency of 38%.
- The ***low food system P efficiency*** in NI reflects the high prevalence of livestock agriculture, which is inherently less efficient in converting P to food than crop based agriculture (Metson *et al.*, 2012).
- A ***summary of the key data*** for each sector included in the SFA is presented in Table 1. Table 2 provides a further breakdown for the livestock system.

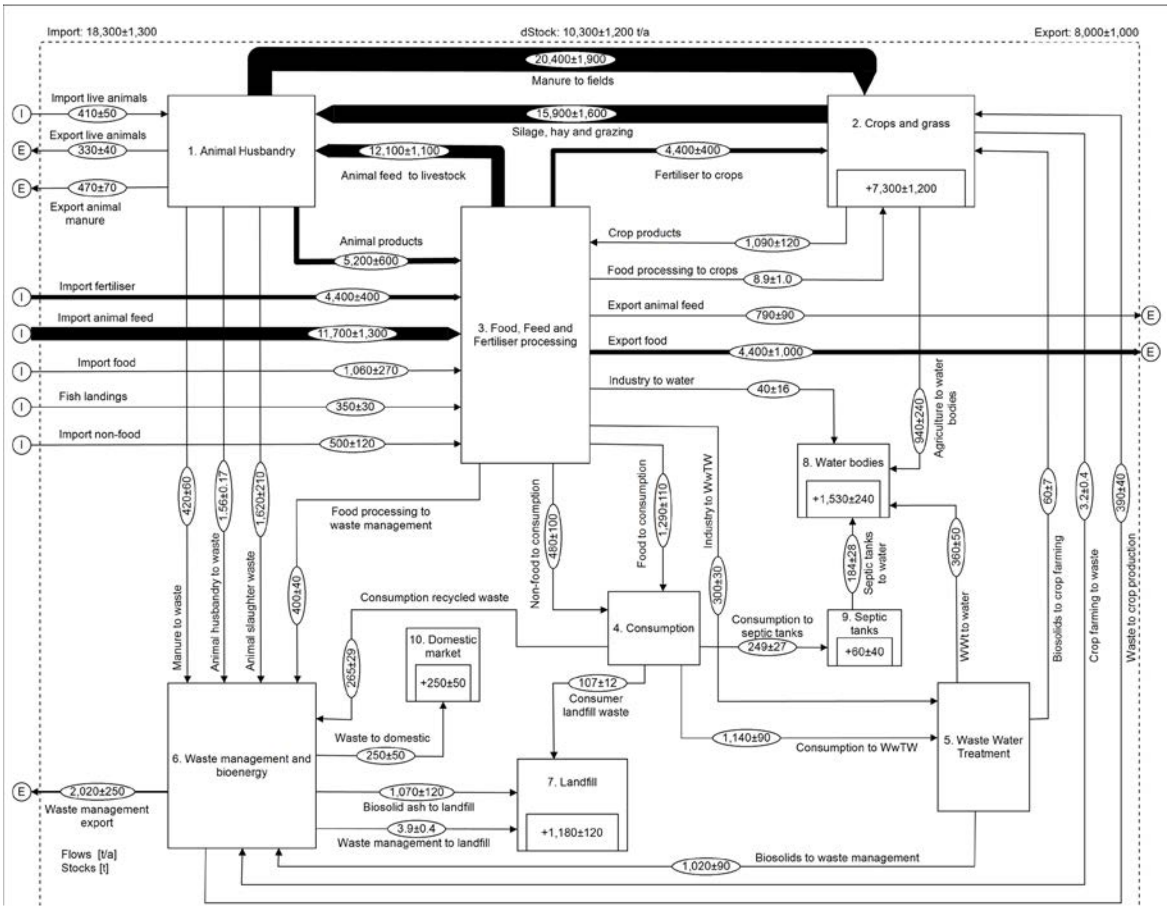

Figure 4: Phosphorus Substance Flow Analysis for the Northern Ireland Food System in 2017

Table 1: Outputs from the Phosphorus Substance Flow Analysis for different sectors with the Northern Ireland Food System in 2017

Sector	Phosphorus			Other Information
	Inputs (tonnes)	Outputs (tonnes)	Efficiency (%)	
Livestock	28,000 57% grass 43% feed	5,200 As meat, dairy & eggs	19	See Table 2 for a breakdown of livestock sectors
Soils	25,200 81% Manure 17% Fertiliser 2% Waster	17,000 As crops & grass	67	7,300 t of P accumulated in the soils 940 t lost to water (i.e 62% of overall load)
Food Processing & Consumption	6,800 77% Livestock products 16% Imported food 5% Fish landings 3% NI crops	5,700 77% Exported 23% Domestic	84	per capita household P consumption is 0.94 kg yr^{-1}
Waste & Wastewater Management	1,440 (WWTW) 51% Population 16% Detergent 12% Plumbosolvency	1,400 71% Incineration 25% Lost to water 4% Recycled to land	n/a	360 t of P lost to water (i.e. 24% of overall load)
	249 (Septic Tanks) 64% Population 21% Detergent 15% Plumbo-solvency	249 74% Lost to water 26% Retained in Septic tanks	n/a	184 t lost to water (i.e. 12% of overall load)

Table 2: Details of phosphorus flows and sector efficiency for different livestock types, all flow values are tonnes P per year for 2017.

Livestock	Feed P	Silage/ grazing P	Manure P to soil	Manure P exported	Manure P to waste manage-ment	Meat P	Milk P	Egg P	% P efficiency
Cattle	5,933	13,992	16,422	n/a	n/a	951	2,174	n/a	16
Pig	1,332	n/a	1,090	n/a	n/a	556	n/a	n/a	42
Poultry	4,238	n/a	951	465	419	1,308	n/a	170	35
Sheep	363	1,749	1,871	n/a	n/a	114	n/a	n/a	5
Other	242	159	44	n/a	n/a	n/a	n/a	n/a	n/a

3.2 Key Messages

- Overall the NI food system has a P use efficiency of 38%, which is comparable to other livestock dominated food systems in Europe.
- 64% of the P imported into NI is in animal feed while inorganic fertiliser accounts for 24%.
- There is net national consumption per person of 5.5 kg P per person which compares to an average net national P consumption of 4.9 kg per person across the EU27, indicating that NI P imports are above average.
- % P use efficiency ranges from 5% in the sheep sector to 42% in the pig sector. However, for cattle, the most dominate livestock sector in NI, % efficiency is at 16%.
- 7,300 t of P accumulated in NI soils in 2017, which equates to a surplus of 8.5 kg ha^{-1} compared to a P surplus of 6.2 kg ha^{-1} for the whole of the UK.
- There is a total loss of 1,530 t of P to waterbodies, 62% of which comes from agriculture.
- Manure P inputs generated by livestock agriculture in NI are 20% higher than the total P demand for NI.
- The waste management industry received 3,740 t of P in 2017, with only 10% of this recycled to land, while 52% and 31% were exported or went to landfill respectively.
- Currently only 420 t of manure P enters the waste management sector for further processing.

3.3 Overview of workshop

Following completion of the SFA, a workshop was held on the 26th February 2020 in AFBI Hillsborough with 29 stakeholders involved the NI food system. Table 3 gives an overview of the sectors involved in the workshop. The aim of the workshop was to;

I. Present the final SFA and obtain stakeholder feedback

II. Explore the usefulness of the SFA to the various sectors

III. Use the SFA as a mechanism to enable a broader conversation on the future of P in NI's food system

IV. Stimulate a conversation on the potential transformative change that may be required in the management of P in NI

Table 3: List of organisations and sectors that participated in the Substance Flow Analysis workshop February 2020

Organisation	Sector	Area
DAERA	Government Agency	Science/Policy
Moypark	Food Company	Poultry
Ulster Wildlife Trust	Conservation Charity (NGO)	Environment
Queen's University Belfast	Academia	Renewable energy/technology
Devenish Nutrition	Nutrition/Animal Feed	Agri-Technology and Sustainable farming
AFBI	Research	Nutrient management
AFBI	Research	Nutrient management
DAERA	Government Agency	Environmental Farming Policy
DAERA	Government Agency	Regulation and Natural Resources Policy
AFBI	Research	Catchment Modelling
DAERA	Government Agency	Emission and land management
NIEA	Government Agency	Industrial Waste and Consents
NIEA	Government Agency	Industry Pollution Regulation
DAERA	Government Agency	Farm regulations
AFBI	Research	Pig and Poultry
NIEA	Government Agency	Environment/Water quality
Stream Bioenergy	Waste Management	Anaerobic Digestion & Energy Production
Queen's University Belfast	Research	Phosphorous Recycling Technology
NIEA	Government Agency	Environment/Water Quality
NIWater	Water Utility	Waste Management
AFBI	Research	Nutrient Management and Anaerobic Digestion
NIEA	Government Agency	Farming & Environment
NIEA	Government Agency	Evidence and Monitoring
UFU	Farming	Farmer Advocacy Group
AgriAD	Waste-Management	Waste Processing
AFBI	Research	Nutrient Management and Renewable Energy
NIWater	Water Utility	Waste & Water Management
WRAP	Waster Management	Environment/resource efficiency

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Organisation	Sector	Area
NIGTA	Animal Feed	Representative Body –Feed Industry
Granville Eco Park	Waste Management	Renewable energy and waste recycling
ISL Waste Management	Waste Management	Waste Disposal
DAERA	Government Agency	Data Management –Resource Efficiency
DAERA	Government Agency	Waste Recycling
DAERA	Government Agency	Slaughter Waste Disposal
DAERA	Government Agency	Economics and Evaluation

Following presentations on the RePhoKUs project and the 2017 P SFA for NI, five future P scenarios were presented at the workshop each representing plausible alternative visions for the NI food system. The purpose of presenting these alternative scenarios was to stimulate a discussion on how the use of P in the NI food system could be transformed. The scenarios are not based on their likelihood or probability but rather on their potential for providing visions for alternative futures that allow stakeholders to reflect on impact, barriers and levers for transformed P use. Key metrics were used to demonstrate the change in the system compared to the 2017 baseline scenario. The metrics selected were P Surplus (kg/ha), Predicted river average soluble reactive P (SRP, ug/l)* concentration across NI, P import (t yr^{-1}), and Food system efficiency (%) (Table 4).

Table 4: Future scenarios for the Phosphorus Substance Flow Analysis Northern Ireland Food System and impact of the changes on metric of sustainability

Scenario label	System change	Key metrics		% change from current
Curent situation (status quo) – 2017	No change.	Soil surplus (kg/ha)	8.5	0
		Predicted river SRP (ug/l)	58	0
		P import (t/yr)	18,337	0
		Food system efficiency (%)	38	0
Scenario 1: Manure export	35% of manure P is 'processed' via waste management and exported.	Soil surplus (kg/ha)	0.16	-98
		Predicted river SRP (ug/l)	31	-46
		P import (t/yr)	18,334	0
		Food system efficiency (%)	38	0
Scenario 2: Legacy P	Fertiliser P application is reduced by 95%. Manure P application is reduced by 40%. Crops/grass draw down existing soil P at a rate of 5.5 kg/ha. Excess manure P is exported.	Surplus (kg/ha)	5.7	-33
		Predicted river SRP (ug/l)	47	-19
		P import (t/yr)	14,403	-22
		Food system efficiency (%)	41	+3
Scenario 3: Diet change	Changing global dietary habits leads to 25% reduction in consumer demand for animal food products. Feed and fertiliser P, grass production P, livestock produce P and food export P all reduced by 25%.	Soil surplus (kg/ha)	57	-33
		Predicted river SRP (ug/l)	47	-19
		P import (t/yr)	14,403	-22
		Food system efficiency (%)	41	+3

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Scenario label	System change	Key metrics		% change from current
Scenario 4: Target 1.5	Fertiliser P use reduced by 75%. Animal feed P concentration reduced to 0.35% with no impact on productivity. Manure P input reduced by 20% due to lower feed P inputs.	Soil surplus (kg/ha)	1.6	-81
		Predicted river SRP (ug/l)	35	-40
		P import (t/yr)	12,269	-33
		Food system efficiency (%)	58	+20
Scenario 5: Balanced System	No P fertiliser is used. All post farm food system waste P is recovered and recycled. Only manure needed to meet crop P demand is used. 30% of manure P is exported.	Soil surplus (kg/ha)	0.22	-97
		Predicted river SRP (ug/l)	31	-46
		P import (t/yr)	13,922	-24
		Food system efficiency (%)	52	+14

Below is a description of each scenario and the rationale behind its development. Of the five scenarios, the participants were asked to vote on which two they wished to discuss during the workshop. Scenario 5 was pre-selected by the RePhoKUs research team because it included aspects potentially relevant to all participating stakeholders, while the other scenarios placed more emphasis on particular sectors. Of the four remaining scenarios, Scenario 2 and 4 received the highest number of stakeholder votes (24 and 17 respectively). Consequently, Scenario 2 and 4, along with Scenario 5, made up the three new agri-food systems to be discussed further during the workshop. A summary of the discussions related to scenarios 2, 4 & 5 are included in Tables 5, 6 & 7 below.

Discussion at the SFA Workshop on the 26th of February 2020

*Note: While NI has variable SRP targets for the WFD, ranging from 20-100 µg L^{-1}, depending on the altitude and alkalinity of a waterbody, 35 µg L^{-1} is used here as an average value for NI. In addition 35 µg l^{-1} is used in the Republic of Ireland as the target P concentration for achieving good status in waterbodies for the WFD.

3.4 Scenario 1-Manure Export

In Scenario 1, 35% of manure P produced in NI is processed and exported. The development of this scenario was based on the fact that there is 7,300 t more P being applied to land than is required by crops and grass. This has resulted in a build of P in soils across NI with 38% of soils currently above the agronomic optimum soil test P level. In addition, due to the high frequency of rainfall and wet soils throughout much of the year, slurry application is an inherently risky practice. Reducing the quantity of slurry being applied to land would therefore also reduce the amount of P lost to water. Manure processing and export provides an opportunity for nutrient recovery and possibly energy production that can help agriculture reduce its dependency on imported fertiliser and fossil fuels. This scenario resulted in a 98% reduction in the P surplus to 0.16kg ha^{-1}, a 46% reduction in SRP to 31µg L^{-1} but no reduction in P imports nor the P use efficiency of the system.

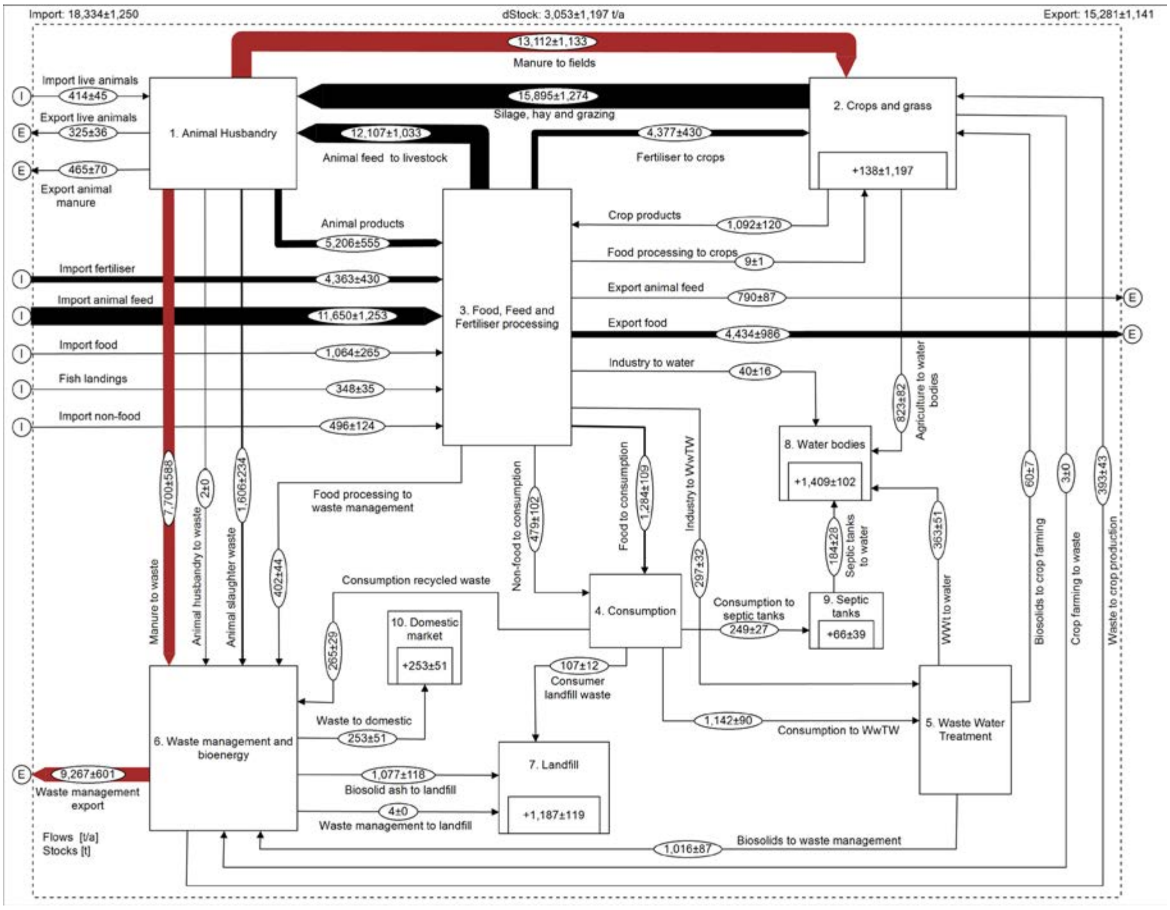


Figure 5: Scenario 1 – Manure Export

3.5 Scenario 2- Legacy P

The main driver behind the development of this scenario was to draw down P in the 38% of soils in NI that are above the agronomic optimum soil P concentration (i.e. 20-25 mg/l Olsen P). High soil P concentrations pose a significant risk to water quality, with evidence showing a rapid increase in P loss to water above Olsen P Index 2 (Cassidy *et al*. 2019).To achieve this, applications to soil of inorganic P fertiliser were reduced by 95%, and 40% of manure P was exported so that the soil system was being managed at a negative P surplus of -5.5 kg P ha^{-1}. This scenario resulted in a 165% reduction in the P surplus to achieve the required negative P surplus, a 65% reduction in SRP to 21µg L^{-1} and the 21% reduction in P imports resulted in a 50% increase in P use efficiency.

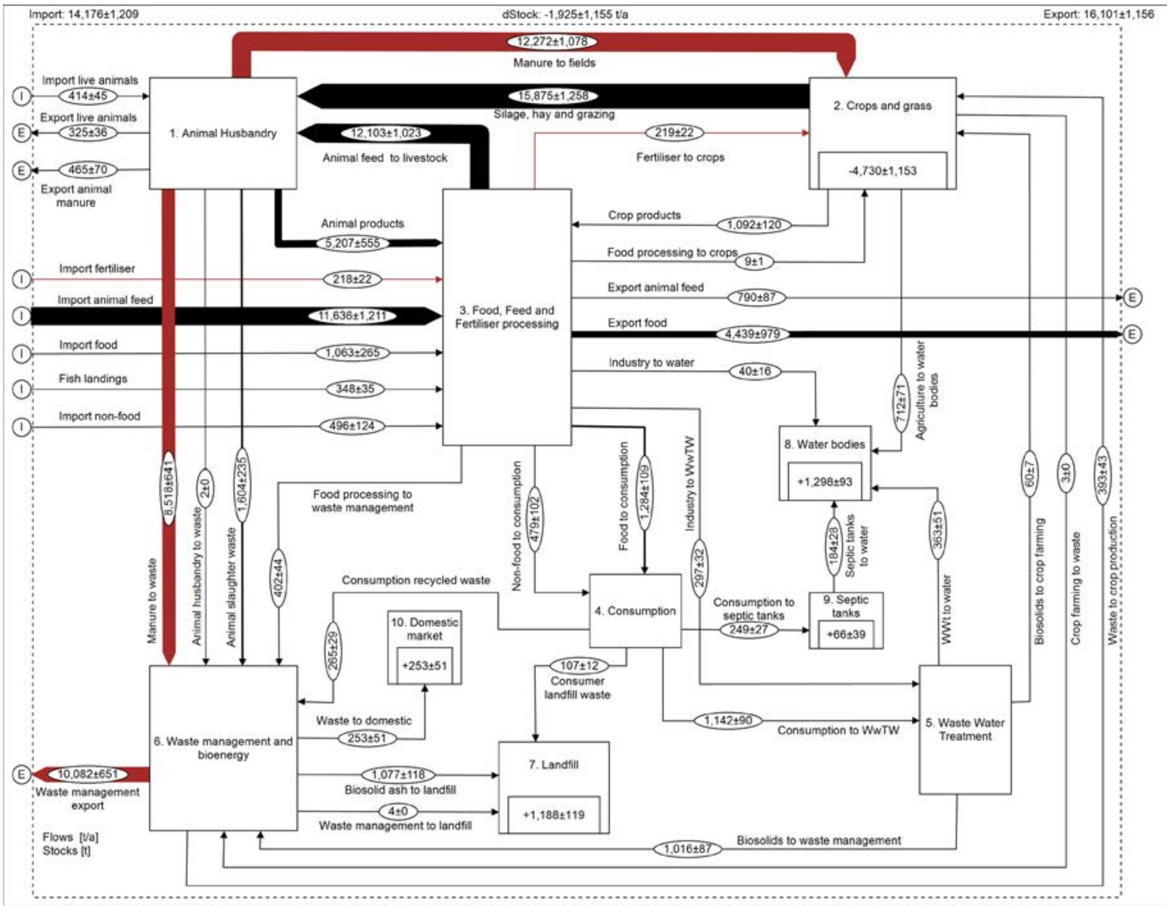


Figure 6: Scenario 2 – Legacy Phosphorus

Table 5 - Summary of the key discussions points for Scenario 2 (Legacy P) arising out of the stakeholder's workshop

Scenario 2 – Legacy P			
Impact	**Response**	**Barrier**	**Lever**
Farm scale and NI scale P deficits, and a reduction in Legacy P A change in future food markets – switch of products to suit new markets Jobs in the energy sector to increase	Adopting best management practices (e.g., making soil testing compulsory and using methods that release higher amounts of organic P) More sustainable stocking (e.g., a reduction in stocking rates) and diversion of manure flows to anaerobic digestors and energy production Diversification to higher value products	Lack of the needed infrastructure and biosecurity of manure movement Lack of market for the new product Costs and challenges associated with attitudinal change Difficult to utilise legacy soil P when and where the farmer needs it.	Change in policy to support new processes, enforce regulations and provide more focussed incentives (funding) – while ensuring more integration. Paying farmers for public goods. Improvements in knowledge transfer and research (including evidence of P in the soil, and cost benefit analysis) – to engage and advise farmers. Technology: to export another way (farm level or centralised approach), to support a circular bioeconomy and for renewable energy e.g. AD, change plant species and/or reseed rotations to identify those that can extract the most P

3.6 Scenario 3 –Diet Change

In scenario 3, a change in global diets away from the current preference for a meat based diet results in a 25% reduction in the demand for meat and dairy products. This causes a knock-on reduction of 25% in livestock numbers and the consequent demand for feed and fertiliser P inputs. This scenario addresses a number of broader international sustainability goals related to climate change and human health and not just those associated with P. This scenario resulted in a 33% reduction in the P surplus to 5.5 kg P ha^{-1}, a 19% reduction in SRP to 47μg L^{-1} and a 22% reduction in P imports while P use efficiency improved by 3%.

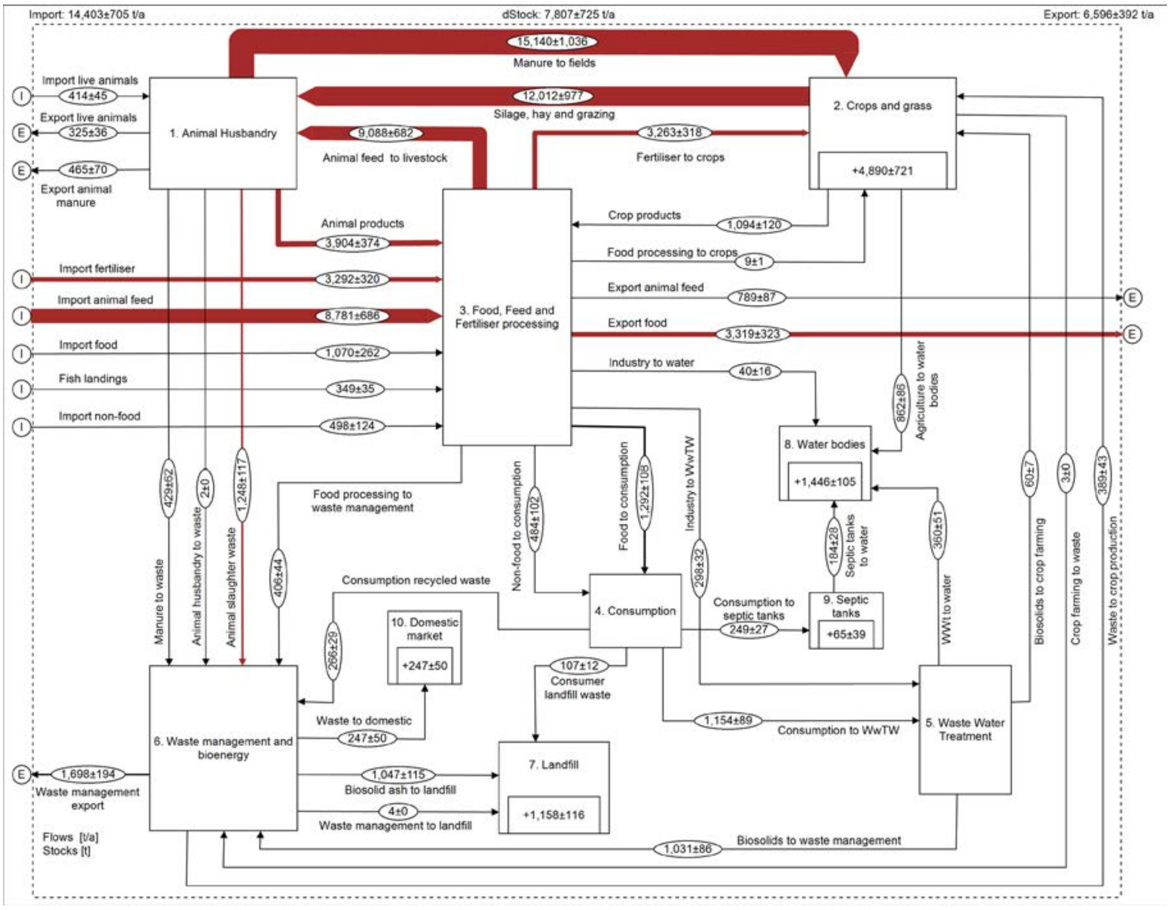


Figure 7: Scenario 3 – Diet Change

3.7 Scenario 4 –Target 1.5 kg P ha^{-1} surplus

In scenario 4, the P surplus of the system is reduced to 1.5 kg P ha^{-1} in order to achieve a water quality target of 35 μg L^{-1} soluble reactive P in waterbodies. The target of 1.5 kg P ha^{-1} was achieved by reducing fertiliser P use by 75% and reducing the P content in animal feed to 0.35% which resulted in a 20% reduction in manure P fluxes. The main driver for the development of this scenario is that only 39% of NI's waterbodies are below the targets required for good status under the WFD due to elevated P levels. While the overall P load entering waterbodies from agriculture is relatively low (940 tonnes), it is sufficient to cause eutrophication in lakes and rivers across NI. This scenario resulted in a 81% reduction in the surplus to achieve 1.5 kg P ha^{-1}, a reduction of 40% in SRP concentrations to 35 μg L^{-1}, while P import and P use efficiency change by -33% and +20% respectively.

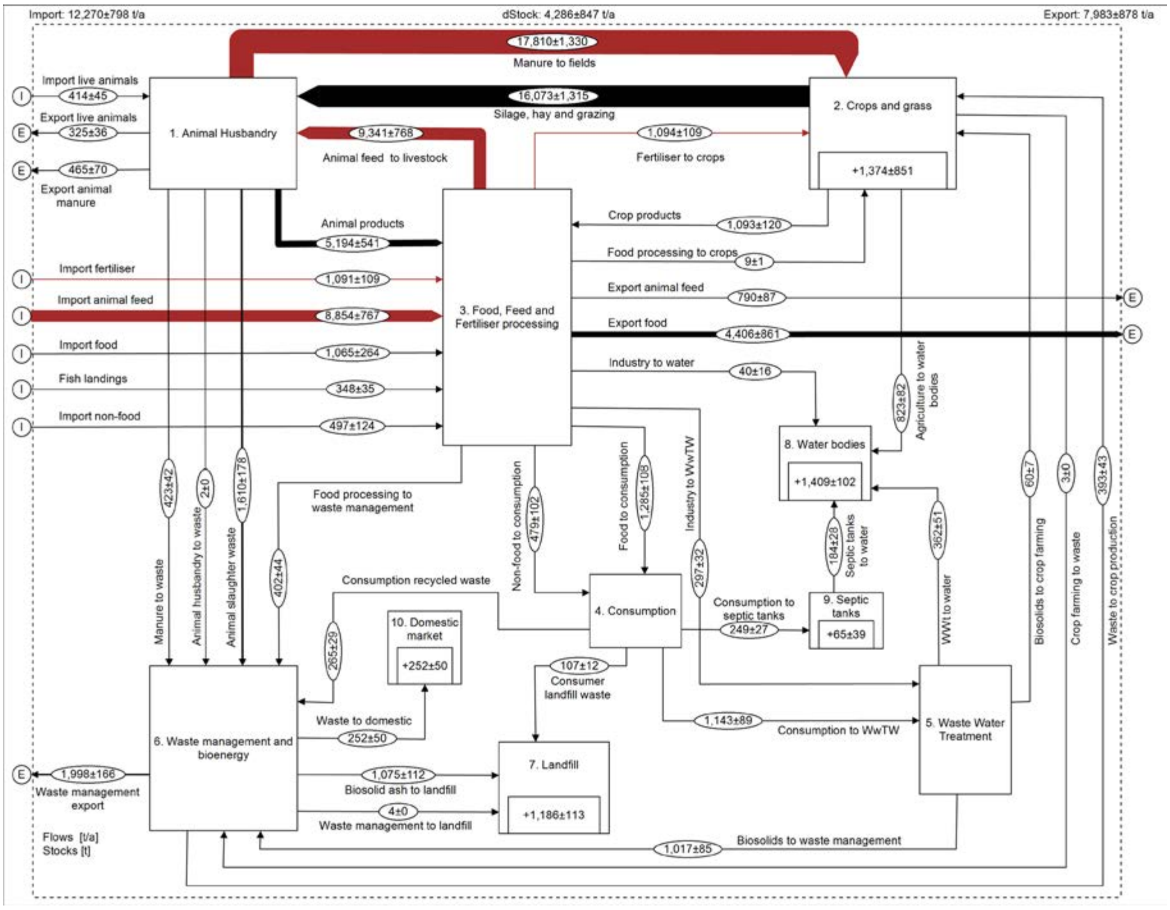


Figure 8: Scenario 4 - Target 1.5 kg ha-1 Surplus

Table 6: Summary of the key discussions points for Scenario 4 (Target 1.5 kg Ha) arising out of the stakeholder's workshop

Scenario 4- Target 1.5 kg/ha			
Impact	**Response**	**Barrier**	**Lever**
Impact will vary across sectors: Biggest impact on intensive dairy, followed by pig sector, with less impact on the beef sector Negative impact on cost in farming and feed sectors, but farmers could also benefit economically from using less fertiliser. Impact on the use of other nutrients	New P recovery methods and manure processing utilised Potential change to bio-energetic crops, replacing grassland e.g. hemp to drawdown more P Source low P ingredients	Cost e.g., manure transport issues, economies of scale (small farms) Mind set of slurry as a source vs waste, as well as willingness to change Lack of knowledge and integration of information sources	Research and knowledge transfer on e.g., forage, grazing, precision diet nutrition Technology to support a mobile or centralised manure system Policy changes needed to accommodate these; policy to provide incentives (public good for public money)

3.8 Scenario 5 Fully Balanced System

Scenario 5 is a fully P balanced system where inorganic fertiliser use is reduced by 88% and is instead replaced by P from all post-farm food processing waste. P is only applied based on crop requirements, so 30% of manure P has to be exported from the NI food system. This scenario represents a future system operating a P circular economy with maximum P recycling, a zero P surplus and minimal P losses to water. This scenario resulted in a 97% reduction in the P surplus, to just above 0 kg P ha^{-1}, a 46% reduction is SRP to 31 μg L^{-1}, a reduction in P import of 24% and an increase in the P use efficiency by 14%.

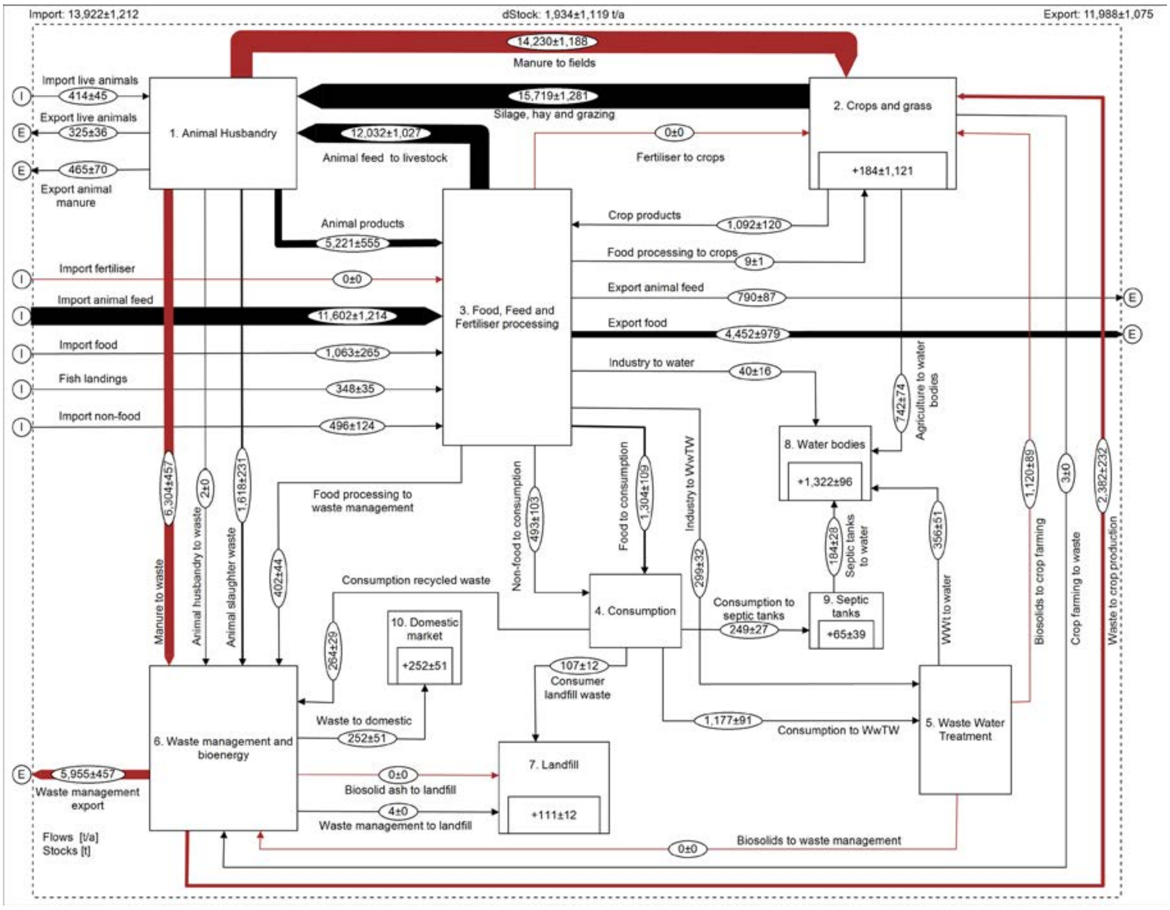


Figure 9: Scenario 5 – Fully Balanced System

Table 7: Summary of the key discussions points for Scenario 5 (Balanced System) arising out of the stakeholder's workshop

Scenario 5- Balanced System			
Impact	**Response**	**Barrier**	**Lever**
Impact on the ag-industry, increasing investment More available recycled P for agriculture Economic impact and push for product mixes Capital intensive manure management	Finding improved monitoring, measuring and management techniques in the farming and water sectors e.g. soil testing across soil types Land use change – hydroponic change of the ag/food system A change in waste-water treatment (incinerating sludge process, economically viable P recovery and redesign) Change to food and crop waste processing and develop new markets - potentially new products (from WWT and bio products)	Cost e.g., exporting slurry, cost of going arable. Mindset e.g., farmers don't like being told what to do, others feel some farmers get preferential treatment (e.g., with payments), and consumer mindset to recycle P Bio-solid to grassland vs crop	Policy (e.g., development of a land management strategy) and new regulations to allow for new markets Research and knowledge transfer to change people's perception; radical thinking needed; working groups/discussions on an EU scale; diversity into other areas through advisory services Concentrating on the public good (recovered P) and its value Destocking and integrated solutions for C, P and N

4. Improving P sustainability in Northern Ireland

Table 5, 6 & 7 highlight some of the key discussion points arising from the workshop in relation to the three SFA scenarios discussed by the participants. Within the workshop Scenario 4 was regarded as most achievable in terms of current knowledge, technology and stakeholder's ability and willingness to adapt. The key issues that arose during the workshop and development of the SFA are discussed in the following sections which address a number cross cutting themes

4.1 Reducing P losses to Water

At the workshop the discussion around sustainable P management in NI was mainly focused on the impact on water quality and how the targets of the WFD can be achieved in the context of an increase in agricultural intensity. Between 2015 and 2018, SRP was the cause of decline in status for 100 waterbodies across NI. In 2015 SRP accounted for 20% of cases where waterbodies failed due to one WFD metric. In 2018 this had increased to 40%. On average across NI, flow weighted mean concentrations of SRP concentration in rivers has increased from a low of 47μg l^{-1} in 2012 to 68 μg l^{-1} in 2018.

While there is evidence to support the value of the Nitrate Action Programme (NAP) regulations and other initiatives in reducing losses of P to waterbodies in NI (Barry and Foy, 2016), 62% of the P entering waterbodies still comes from agricultural land. This was reflected in the discussions at the workshop, which largely focused on reducing agricultural P losses to water. Agricultural sources of P discussed include losses from freshly applied manures and fertilisers, and soil accumulated P from historic over-application (Doody *et al*., 2012, Cassidy *et al*., 2016). Along with the recorded increase in the national P surplus since 2008 (Figure 1), the recent Significant Water Management Issues Report IN 2019 highlighted the close correlation between the increase in cattle numbers and the increase in SRP in rivers in NI. While no cause and effect relationship is confirmed by this analysis, participants felt that reducing P losses from agriculture, to the extent required to achieve the targets of the WFD, will require some significant changes to be made within the agri-food sector. However, there were diverging views on how this should be done and the extent to which water quality targets should be prioritised over farm profitability.

While agriculture is the biggest contributor of P to waterbodies, currently 24% of the national P load comes from WWTP with a further 12% coming from septic tanks. Approximately 34% of P received by WTTP and septic tanks is discharged highlighting the need for improvement in these treatment processes. Although over half of received P is treated by advanced P stripping technology, around two thirds of P lost in wastewater treatment comes from facilities with poor P removal efficiency, particularly those with secondary treatment and septic tanks typical of small and rural communities. There was an acknowledgement within the workshop that solutions had to be identified to address this problem, and in common with other rural populations (e.g. Yates *et al*., 2019), opportunities for using advanced P removal technologies in small waste water treatment are limited. The potential of different nature based technologies such as constructed wetlands (Vymazal, 2011) or short rotation coppice willow plantations grown for bio-resources (McCracken and Johnston, 2015) were highlighted in the workshop as sustainable cost effective opportunities for reducing P loss to water in these situations. Investment in these options has to date been relatively low.

4.2. P Inefficiency in the System

The NI food system has high P inputs relative to productive output which is typical of regions with high animal densities (Withers *et al*., 2020). The predominance of ruminant livestock has led to a regional food system with a very low P efficiency (38%). As highlighted in Table 2, P efficiency in the ruminant sector is lower than in the non-ruminant sector, and this has been reflected in other SFA studies; for example (based on 2005 data of van Dijk *et al*. (2016)), system P efficiency in the Republic of Ireland was only 22% compared to Belgium (59%), The Netherlands (66%) and Denmark (44%) with much larger non-ruminant livestock industries.

The low P efficiency in NI leads to a large amount of unused P that either accumulates in the soil as a P surplus (7,300 t yr^{-1}), is lost to fresh and coastal waters (1,530 t yr^{-1}), accumulates in landfill (1,180 t yr^{-1}) or is exported outside the region as waste (2,020 t yr^{-1}). Based on the methods of Foy *et al*. (2002), surplus P accumulation in NI soils has been ongoing since at least 1925 when the national balance for agriculture was estimated to be 3.5 kg P ha^{-1}, rising to a high of 24 kg P ha^{-1} in 1962 before gradually declining to a surplus of 8.7 kg P ha^{-1} recorded in 2008. This accumulated 'legacy' soil P from past inputs is reflected in the high percentage of soils with excessive P in NI (Higgins *et al*., 2020), which have been a long-term and increasingly significant source of P loss to water (Foy *et al*., 1995, Foy *et al*., 2003, Cassidy *et al*., 2019).

Addressing this legacy soil P now is a significant challenge for agriculture. Estimates for the length of time it would take for high P soil to return to the agronomic optimum vary from 1-15 years depending on soil type, current soil P concentrations and management (Cassidy *et al* 2016). However, for some soils the agronomic optimum may not equate to an environmental soil P optimum, meaning losses to water may still be unsustainable (Cassidy *et al* 2016). Therefore, it is imperative that options are explored for managing soils below the current soil P agronomic optimum while maintaining farm profitability. To this end AFBI are carrying out an agronomic trial on a number of beef farms in NI to explore whether some farms can operate at Index 1 Olsen soil P without impacting on productivity.

Reducing the soil P concentration to the agronomic optimum level will require careful management of these soils and the correct strategies for doing this, so as to balance agronomic and environmental targets, have yet to be identified for NI farming systems. An important recommendation arising out of the Agri-Food industry's SALMS report is that increasing grass utilisation and quality will increase farm profitability and reduce farm and soil P surpluses. In some cases this may require managing soil at a P deficit, with less or no fertiliser or manure applied over an extended period. While some stakeholders at the workshop advocate for the need to address this issue, it was generally acknowledged that unless carefully managed, there could be a significant negative impact on farm outputs, either through the cost of exporting manure or the potential impact on grass yields and/or quality and knock-on impact on stocking densities. One of the key uncertainties for stakeholders in implementing scenario 2, was how long legacy soil P would supply sufficient plant available P to maintain herbage yield and quality in different farming systems.

4.3. Increasing P circularity

Livestock manure is the largest P flow in the NI food system, and most of this is already recycled back to agricultural soil. Opportunities for increased P circularity therefore rest with the waste management sector. On mass balance, if the 3,740 t of P currently received by the waste management sector was effectively recycled, it could meet 22% of the crop and grass P demand for NI, directly replacing 88% of fertiliser imports. At the workshop, stakeholders felt that for this to occur there would need to be investment in the 'right' technology and the development of markets for these new products. The focus on the 'right' technology stemmed from a general consensus that while recovery and recycling technology existed, there was a limited understanding of which were the best technologies for use within NI and at what scale these could be applied.

The relative agronomic efficiency (RAE) of recycled P products compared to conventional P fertilisers is important when considering fertiliser replacement potential (Hamilton *et al*., 2017) and this was also highlighted as a knowledge gap by stakeholders. Novel waste processing technologies, for example for animal slaughter waste (Darch *et al*., 2019) and struvite from human waste (Talboys *et al*., 2016), can equal conventional P fertiliser performance suggesting potential full fertiliser replacement from different waste streams is feasible (Huygens and Saveyn, 2018). However, stakeholders felt that there was a need to demonstrate the effectiveness of these products within NI to strengthen the likelihood of their use in replacement of inorganic fertiliser. While some stakeholders felt there would be significant opposition to this in the fertiliser industry, others felt that the industry would quickly adapt to develop new novel products to replace inorganic fertiliser.

In practice, other barriers to increased waste recycling including public perception concerns ranging from odour when stored or spread and regulatory, licensing and food safety requirements can compromise acceptability were also raised. These can limit the land area available to spread and will often inflate the cost and management requirements when using such materials as fertilisers. For example, the majority of wastewater sludge (biosolids) in NI are incinerated rather than spread largely because of the regulatory restrictions on their application to pasture, and land application of aerobic and anaerobic sludges from agri-food processing waste treatment must be licensed under regional legislation (Waste Management Licensing Regulations (Northern Ireland), 2003), which increases the management cost.

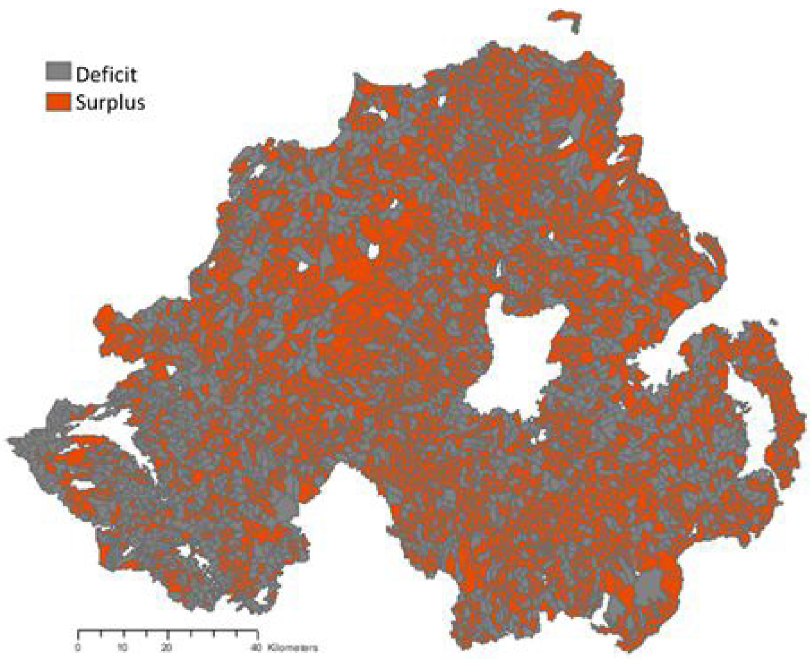
4.4 Achieving a Sustainable P Balance

While increasing P circularity would reduce the need for imported fertilisers, a more fundamental problem for the region's P sustainability is that recovery and further recycling of P from the waste management sector will only add to the animal manure P burden within the food system (Withers *et al*., 2018). Balanced manure P application to agricultural land is also constrained by the available area as a large proportion (ca. 68%) of the NI agricultural area is classed as a 'Less Favourable Area' with agricultural activity constrained by high soil moisture, frequent rainfall and slope. Figure 3 demonstrates that even if there were no logistical constraints on the movement of cattle manure around NI, 54% of townland areas would remain in surplus, even before recycled P from other sectors is factored in.

Since the P supplied by animal manures alone already exceeds total crop P demand by nearly 20%, to achieve a zero P balance, inputs of manure P would need to be reduced by 3,390 t P yr-1 (20%), or 8,220 t P yr^{1} (48%), depending on whether current fertiliser and recycled P usage rates dropped to zero or remained the same. An additional constraint to the land area is that many lowland catchments have significant proportions of critical source areas of runoff P loss where repeated manure applications would not be advised (Cassidy *et al*., 2019).

One option discussed at the workshop for reducing the P surplus was to reduce livestock numbers, with stakeholders pointing to the impact of the national manure P ceiling implemented in the Netherlands in 2016. This was a contentious issue, with some stakeholders feeling it was necessary to achieve sustainability, while others highlighted the impact this would have on rural livelihoods and the economy. However, with the agri-food industries ambition to expand (Agri-Food Strategy Board, 2013) and the importance of agriculture to the NI economy, it was generally agreed that reductions in livestock numbers are unlikely to occur except through regulation.

Figure 10: Map of Townland that have a phosphorus surplus or deficit when P in livestock manure is fully redistributed throughout Northern Ireland based on crop requirements (note: no logistic constraint were considered in this analysis)



One of the preferred options for addressing this issue was by reducing the P content of the manure produced thereby reducing the national P surplus and the potential loss of P to waterbodies. O'Rourke *et al*. (2010) observed that a 43% reduction in the P content of the diet of dairy cows resulted in a 61% reduction in manure water soluble P and consequently a 58, 74, and 48% reduction in dissolved reactive P in overland flow, in summer, winter and spring, respectively. The average supplementary feed P content (excluding grass and silage) calculated in this SFA was 0.46%. (Note: the estimates of P in feed used in this SFA are lower than measured values from a recent farm survey of feed samples taken from 40 dairy farms across NI, where feed P content of 0.60% DW or 0.53% FW were recorded (Bailey *et al* 2019). While a survey in the Upper Bann catchment found that the average feed P concentration for Beef and Sheep farms was 0.55% DW or 0.49% FW).

To achieve a 20% reduction in manure P content, taking account of the fact that over half of manure P comes from grass and silage consumption with an assumed P concentration of 0.33%, average supplementary feed P concentrations would have to drop to 0.25%. (Note: Based on information from the Upper Bann, in Beef and Sheep systems, it is likely that >75% of manure P comes from grass and forage, whereas in intensive dairy systems it could be < 50%). Given that minimum adequate dietary P levels in dairy cattle are around 0.35 to 0.42% (Ferris *et al*., 2010), and opportunities to further reduce feed P in pigs and poultry beyond current phytase supplementation without welfare issues are limited (Liu *et al*., 2019), such reductions in feed P content would not be sustainable. As such, a reduction in fertiliser use and increase in manure export are therefore required to achieve a sustainable national P surplus. When scenario 4 was presented to the stakeholders it focused on achieving the 1.5kg ha^{-1} target surplus by reducing the P content of feed and inorganic P fertilser use. However, in the discussions on this scenario, stakeholders felt that export of manure would also have to play a role if 1.5 kg ha^{-1} target was to be achieved.

Exporting slurries and manures outside of the NI food system could resolve the P surplus problem, especially as the P demand in arable areas of the UK is high (Bateman *et al*., 2011). Within the workshop there were conflicting opinions of the feasibility of processing and exporting manures. Some stakeholders cited concerns over biosecurity, capital and transport costs and the relatively small scale of farms, while others felt investment in the 'right' technology, coordination between farms and accounting for the nutrient & energy value of manures would help to overcome these barriers. Some (ca. 25%) of the poultry manure produced in NI is exported directly, reflecting its relatively low moisture content and high nutrient value compared to other livestock manures. A further quarter of NI poultry manure is processed via a unique AD technology, the dry fraction of which captures 95% of the P, can be easily transported and is currently exported outside NI in horticultural products after further processing (Anon, pers. comm). Though this currently only represents around 2% of total manure P production, it demonstrates the potential for new processing technologies to manage manure P.

New processing technologies that allow physical and chemical separation of the nutritional components of slurry and AD products (e.g. dewatering, filtration, thermochemical conversion) could make future transport and export of manures more viable (e.g. Porterfield *et al.*, 2020). Stakeholders highlighted how processing manure for both nutrients and energy provided "waste to wealth opportunities" through the development of jobs and value-added products.

5. Summary of Key Findings

- P use within the food system is very inefficient and needs to be improved in order to achieve the water quality targets while also maintaining agricultural production.
- Of the three scenarios discussed, the national P surplus to 1.5kg ha^{-1} seem to draw interest in terms of feasibility. This could be achieved by a combination of reducing P fertilser use and P content of animal feed, but would also require manure P export from NI.
- However, there are significant challenges to implemen ting P export on farms, related to biosecuity, identifying the right equipment, right scale, infrastructure/logistic and economic viability.
- In order to improve the economic viability of export, a holistic approach to the management of manures needs to be taken, that accounts for its value for carbon sequestration and energy production and the trade-offs/synergies with the management of nitrogen and carbon.
- There are also important knowledge gaps in how best to manage legacy soil P so as to reduce the impact on water quality without a significant impa ct on agricultural outputs. There are uncertain ties related to how long existing soil P pools can supply plant available P.
- Increased circularity of P within the food system (P other than in livestock manures) may in the short term increase the P loading to land, but in the long term it could provide a strategic P reserve to buffer against stresses or shocks related to the availability or price of RP.
- To achieve this there is a need to better understand the relative agronomic efficiency (RAE) of recycled P products compared to conventional P fertilisers.
- Stakeholders felt that while knowledge gaps exist, technology and expertise are available to make significant progress towards sustainable P management. The biggest barrier to achieving this was related to governance and cross sectoral collaboration.

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