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The economic value and opportunities of nutrient cycling for Finland

Maija Aho, Tiina Pursula, Mari Saario, Tea Miller, Anna Kumpulainen,
Minna Päällysaho, Venla Kontiokari, Miikka Autio, Anna Hillgren,
Laura Descombes, Gaia Consulting

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Enquiries about the publication: publications@sitra.fi

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Foreword

THE CIRCULAR ECONOMY HAS RECENTLY BECOME A KEY ISSUE IN Finland. In many cases, the focus is on waste recycling, despite the greater potential value to be found in sustainable manufacturing, the reuse and remanufacturing of products and materials, and maintenance. In a circular economy, materials and value would circulate within society while, say, services and intelligent solutions added value to products. The objective is to reduce waste and create a system with zero loss of material.

According to the Sitra and McKinsey study "The opportunities of a circular economy for Finland" (2015), conservative estimates put the value creation potential of Finland's circular economy at EUR 1.5–2.5 billion in five investigated sectors: the forest industry, machinery and equipment, the food industry, private consumption, and changing the purpose of real estate. The value potential for the national economy is many times higher.

Nutrients are a crucial resource for society. Major economic value lies in the development of efficient nutrient cycles, as well as the reduction of nutrient loss and of the resulting harmful environmental emissions.

In collaboration with Gaia Consulting Oy, Sitra has performed the first assessment of the economic potential of nutrient cycling for Finland: By 2030, nutrient cycling will have a potential value of EUR 0.5 billion in the studied sectors. This financial added value is based on four business cases: fertiliser leasing, replacing imported soybeans with broad beans, using low-value fish as a source of feed and biogasification to drive the nutrient cycle, and the associated benefits of reduced eutrophication of the Baltic Sea. Other examples of business potential are also described. Drawn up in collaboration with sectoral actors, a roadmap for realising the benefits to the national economy was included in the study. The results were formulated into three key objectives: 1) Primacy of recycled nutrients, 2) Practical trials of nutrient cycling and 3) Collaboration between nutrient cycle builders. This report and the roadmap will create concrete opportunities for companies, consumers and Finland as a whole.

The circular economy is a spearhead project in the strategic programme of Juha Sipilä's government. The government programme also gives clear recognition to the potential of nutrient cycling. Nutrient cycling lies at the core of the circular economy. Around the world and in Finland, key nutrients such as phosphorus and nitrogen are being lost in an unsustainable manner. Fostering the sound ecological status of the Baltic Sea, reducing the leaching of nutrients into water bodies, and enhancing nutrient and energy self-sufficiency in agriculture are focus areas in the government programme.

On the basis of these surveys, Sitra, the Baltic Sea Action Group and Lappeenranta University of Technology propose three goals in boosting Finland's economic growth and the status of the Baltic Sea:

- By 2020, 10% of manure from Finland will be processed into precision fertilisers. Finland will invest in developing nutrient recovery technologies.
- By 2023, 100% of biowaste will be recovered and recycled.
- By 2035, municipal wastewater treatment processes will be modified to recycle and recover nitrogen and carbon in addition to phosphorus.

These goals can be accomplished by creating forerunner markets. The state must create incentives and adjust regulation to steer operators towards recycling rather than importing nutrients. Investments in research and development must be directed at new nutrient recycling technologies and trials. Finland and other Baltic Sea countries should join forces to ensure the creation of an EU nutrient policy and nutrient cycling must become a key part of the European Commission's circular economy strategy, which is currently the responsibility of Jyrki Katainen.

In addition to Sitra and Gaia, the management group in charge of exploring the economic potential of nutrient cycling for Finland included representatives of the Baltic Sea Action Group (BSAG) and Lappeenranta University of Technology. Kari Herlevi, Senior Lead at Sitra, acted as chair of the management group. We would like to extend our warm thanks to Gaia's experts and our partners involved in the project: Ilkka Herlin, Mathias Bergman, Marja Koljonen, Riku Venhola and Pieta Jarva from the Baltic Sea Action Group; Lassi Linnanen and Mirja Mikkilä of Lappeenranta University of Technology, and Hannele Pokka from the Ministry of the Environment.

Helsinki, 1 September 2015

Mari Pantsar
Director, Resource-wise and carbon-neutral society

Kari Herlevi
Senior Lead, Circular Economy

Sitra

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1 Introduction

Phosphorus and nitrogen are key nutrients for every living being. The natural cycle of phosphorus is based on soil erosion. Plants, on the other hand, fix nitrogen from the air into the soil. Nutrients are taken from the soil by plants and re-released into circulation as organic material decomposes.

Human activities can disturb natural nutrient cycles in a number of ways, such as disruption of natural cycles, transfer of nutrients to the wrong places or soil exhaustion. Nutrients are removed by the harvesting of food and feed plants or trees, and replaced using industrially manufactured fertilisers. After their consumption, nutrients are returned to the nutrient cycle by means such as the reuse of nutrient containing waste from food cycle or by recovering nutrients from waste water sludges. Recycled nutrients can be used to replace mineral fertilisers and intensify the use of dwindling nutrient resources. When nutrient cycles are closed, the environmental impacts – such as eutrophication – of runoff due to the loss and accumulation of nutrients will also diminish.

Very little work has been done on the overall economic impact of the nutrient cycle. As a rule, nutrient loss has minimal economic value when viewed solely on the basis of current cost levels – the price per kilogramme of phosphorus and nitrogen. Significant part of the positive economic effects of nutrient cycling would derive from the reduction and reversal of health and environmental problems.

Nitrogen compounds released into the air is an example of health problems. Most nitrogen compounds originate in long-distance sources such as energy production and traffic. Fertiliser users and those handling nutrient-rich masses are another source of environmental loading. It is estimated that health and environmental problems due to atmospheric reactive nitrogen cause over EUR 70 billion in costs in the EU area alone[1].

The economic value of nutrient cycling can be calculated from various perspectives. Inhabitants of the coastal states of the Baltic Sea are prepared to pay up to EUR 3,800 million a year to reduce the eutrophication caused by nutrient runoff[2]. Reaching the water quality targets set by the Baltic Marine Environment Protection Commission would require EUR 2,300 million[3]. The nutrient cycle is thought to account for up to half of the economic

[1] Yale, environment 360. With too much of a good thing, Europe tackles excess nitrogen, 2014.

[2] Ericsdotter, S., Nekoro, M., Scharin, H. 2013 The Baltic Sea - Our Common Treasure. Economics of saving the sea. BalticSTERN Secretariat, Stockholm Resilience Centre, Stockholm University.

[3] Costanza et al. (1997), The value of the world's ecosystem services and natural capital.

value of ecosystem services. On the other hand, in terms of the trade balance annual imports of phosphorus to the EU amount to more than two billion euros per year. It is estimated that replacing this imported phosphorus with recycled nutrients would directly create 66,000 new jobs[4].

In addition, solutions based on recycled nutrients have growing global markets. The export of technologies and service solutions developed and piloted in the home market has a positive impact on the trade balance.

The objective of this project was to identify the economic value of nutrient cycling for Finland and to create a roadmap for realising such value. The study focuses on the value of efficient cycling of phosphorus and nitrogen and the related opportunities for Finland in the food chain, covering primary production (agriculture and livestock), the food industry, households, waste management and final disposal/production of recycled nutrients. This study examines this as a distinct but holistic issue focused on the food chain. However, nutrient cycling has strong synergies with the sustainable bioeconomy, the productivity of agriculture and forestry, waste management and sewerage, air quality, public health, preparation for climate change and food security.

The study was realised by describing a range of practical examples of the promotion of nutrient cycling and evaluating their commercial value using a cash flow-based, regional economic model developed by Gaia. Each of the examples, which were selected in collaboration with the project management group, provides a different perspective on boosting the nutrient cycle. New opportunities for nutrient cycling are described, with a focus on issues such as the potential of business activities and concepts, the potential for raising the added value of nutrient products, the renewal of the nutrient cycle infrastructure, and the application of international good practices. The vision of the nutrient cycle and the added value logic described in Section 2 were drawn up by experts and approved by the management group.

This report calculates **the annual added value of nutrient cycling for Finland as** EUR 510 million euros, or around **half a billion euros**. Finland's overall economic potential is presented as the value of the annual net change between 2030 and the current situation. This potential is based on both the examples calculated using the regional economic model and the benefits resulting from reduced eutrophication of the Baltic Sea. By 2030, the economic value of the calculated examples – including fertiliser leasing, use of broad beans as a replacement for imported soybeans, use of low-value fish as a source of feed, and biogasification as a driver of nutrient cycling – will total EUR 310 million a year for Finland. The corresponding benefit of reduced eutrophication of the Baltic Sea is around EUR 200 million[2].

Other fringe benefits of efficient nutrient cycling include synergies in other sectors, reduced risks, improved security of supply, and reduced health and environmental hazards. The economic value of the last-mentioned benefits was not evaluated by the project.

Actions in both the public and private sectors are needed in order to realise the full economic potential of nutrient cycling. A roadmap for achieving the calculated economic benefits was drawn up as part of the project. Three targets were formulated as the main themes of the roadmap:

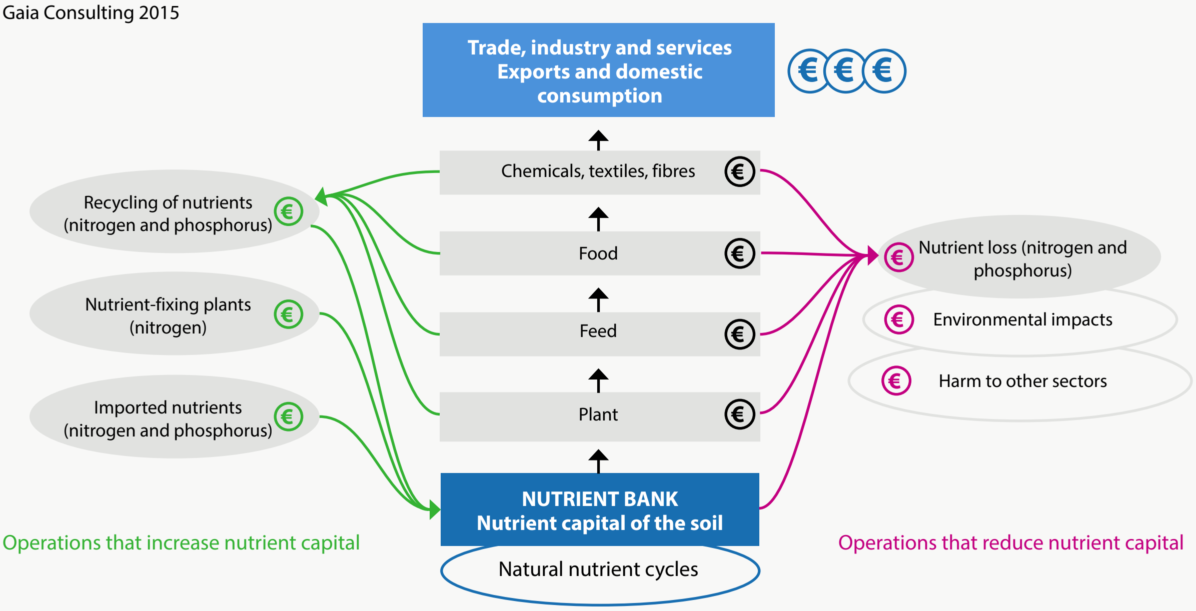
1. **The primacy of recycled nutrients,**
2. **piloting nutrient cycling in practice, and**
3. **collaboration between nutrient cycle builders**.

[4] European Sustainable Phosphorus Platform (ESPC), 2013

2 Nutrient economy

Figure 1. Nutrient economy

Gaia Consulting 2015



2.1 The concepts of the nutrient economy

In a nutrient economy, the soil is the nutrient bank that enables the production of all renewable materials. Within this ban, the available nutrients are considered the capital of the nutrient economy. For example, the food chain and forestry are sectors where the nutrient capital of the soil is used to produce economic value. Such capital can be borrowed to grow plants and the profits can be further processed into goods such as feed, food, fibres, chemicals, textiles and wood products.

However, the bank loses capital every time crops are harvested, or nutrients are removed. To avoid lower profits, withdrawals must be replaced. The balance of various nutrients in the soil may differ; in Finland, for example, we may have more phosphorus and less nitrogen than we need. Nutrients can occur in many forms with varying usability rates.

With respect to phosphorus and nitrogen, in particular, nutrients in soil can be managed through natural processes (such as nitrogen-fixing plants), external contributions (imported fertilisers) or the recycling of nutrients back into the soil. This interaction is presented in Figure 1.

The higher the biomass profits you hope to extract from the soil, the more carefully you need to manage your nutrient capital and its usability. If used nutrients are not recycled, more external contributions are needed. This creates costs that burden the cost structure of the entire processing chain. First of all, if the lost nutrients are not replaced, your operations are not genuinely sustainable and your nutrient capital is gradually diminished. The bill for poor soil management will be paid by future users of the soil, as profits dwindle. On the other hand, if good care is taken of the soil, production can also be increased sustainably.

The better the cycle functions, the more intensively the land can be used. Soil depletion is a global problem[5] causing production to transfer to new areas and, for example, the clearing of forests for new fields. Taking care of nutrient capital enables continuous use of the same soil, reducing the need to take over new natural ecosystems for production.

Phosphorus and nitrogen and their usability are also

[5]FAO fertilizer and plant nutrition bulletin #14, Assessment of soil nutrient balance, 2003

linked to soil properties, such as pH value and carbon fixation capacity. Agricultural land tends to be a source of carbon dioxide, but developing agriculture towards carbon fixation could be economically viable and would have major potential for curbing climate change.[6] When the carbon content of arable land falls, the soil is depleted and field productivity is lowered. At the same time, the flooding and drought tolerance of land deteriorates.[7] Studies have shown that fertile land with a high carbon level is 40–70% better at producing crops than depleted or nutrient-poor soil.[8] Soil pH, on the other hand, affects microfauna and the granular structure, which determine the condition of plant roots and their capacity to use nutrients. In Finland, liming is used to reduce soil acidity.

Nutrients can be recycled back into use from several sources. Side streams from processing chains can be returned to the nutrient cycle. Nutrients from nutrient-rich products, such as food, should be recovered for use through waste management and sewerage. Nutrients do not need to be recycled back into the soil – they can also be circulated higher up the processing chain. In such a case, waste and side streams are processed directly into feed or industrial chemicals, not only into recycled nutrients. Processing enhances the restoration of nutrients. For example, recycled nutrients of stable quality enable more precise fertilisation than manure spreading.

Trapped within products, nutrients are removed from land areas used for agricultural production. Similarly, sustainable use should be made of nutrients remaining in the area after the use of nutrient-rich products. In certain areas, a problem may also be caused by excess accumulation of nutrients in the soil via biowaste, manure and other applied nutrients. In such a case, efficient use is not made of nutrient capital and the amount of loss caused by runoff increases.

Nutrients go to waste during growing and processing. They end up in places from where – due to the high cost of recovery – they no longer return to the cycle. The worst waste streams are caused by the runoff of nutrients into water bodies, where they have adverse environmental effects and a negative impact on several industries, such as fishing and tourism, as well as on the wellbeing of humans

Table 1. Concepts of nutrient economy

Gaia Consulting 2015

Recycled fertiliser	A fertiliser manufactured from recycled nutrients that can be used in the same manner as a corresponding mineral fertiliser.
Recycled nutrient	A product that can be used as a nutrient for various purposes. No standards have been established for this definition and a recycled nutrient may not necessarily be directly equivalent to a fossil mineral product.
Nutrient management	Recycling of nutrients into soil to replace nutrient loss due to harvesting.
Nutrient cycle	The flow of nutrients within the ecosystem, communities and processing chains of products and their return to the ecosystem.
Nutrient bank	The nutrient capital of the soil, or nutrients in the soil that enable the production of renewable materials (biomass).
Nutrient capital	Nutrients available for use in soil for the production of renewable materials (biomass).
Nutrient loss	Nutrients ending up in locations from which they are difficult or impossible to return to the nutrient cycle, such as runoff into water bodies.
Replenishment of nutrients	Recovery of nutrients eliminated or removed from use or lost, and their return as part of the nutrient cycle.

[6] Finnish Environment Institute: Ilmasto-opas, hiilinieluista huolehtiminen. (in Finnish; Climate Guide, taking care of carbon sinks)
[7] Yale, environment 360. Soil as Carbon Storehouse. New Weapon in Climate Fight?
[8] Berazneva et al. (2014), Agricultural productivity and soil carbon dynamics: a bioeconomic model.

and animals. Minimisation of waste streams is an effective way of keeping nutrients and the relevant cash flows in profitable use, since this avoids the need to pay for the impacts and remedying of environmental problems.

2.2 The nutrient economy in Finland

The phosphorus and nitrogen content of the Finnish food chain is worth tens of millions of euros a year. The related flows can be seen in Figure 2, which also shows how the harvesting of food and feed plants depletes these nutrients in the soil. In Finland, nutrients are currently replaced using both industrially produced fertilisers and recycled nutrients. Nutrients contained in plants moving along the food chain are transferred – either directly from primary production or via the food industry – as food for humans and animals in the form of feed, grain, berries, fruit, vegetables and root vegetables.

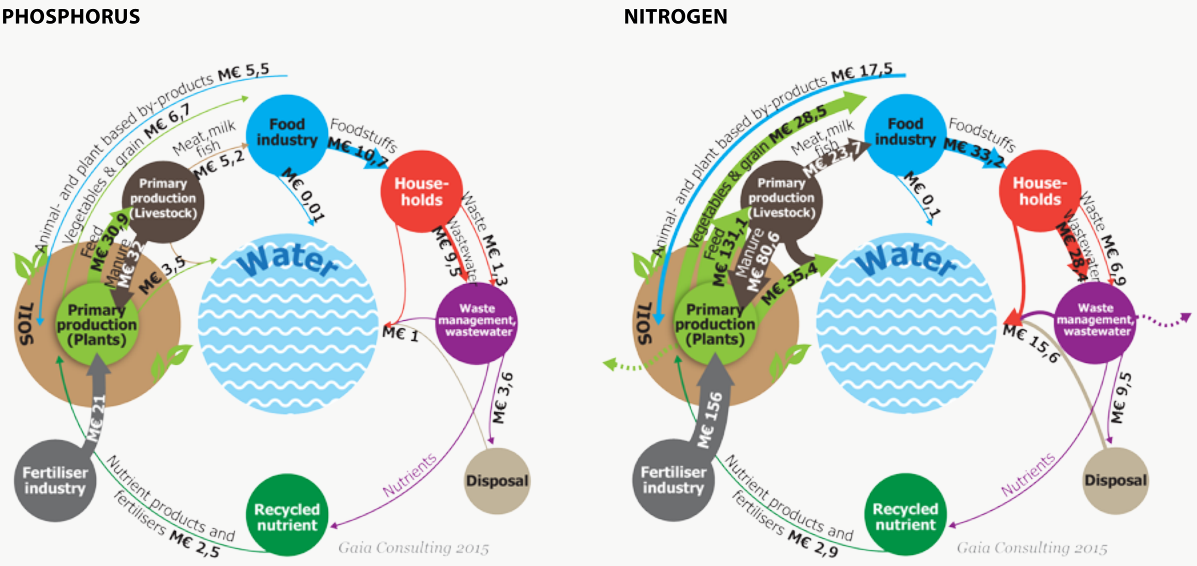
Once the nutrients have been used, they are collected for processing as waste streams, side streams, or wastewater. Some of the nutrients are in a form in which no techno-economic use of them is possible and this biomass is disposed of in places such as landfills. Some side streams are used as fertiliser or in landscaping – through the direct spreading of manure for example. Because of the selected scope (food chain), Figure 2 does not include areas such as the forestry industry or energy production, even though they too produce nutrient-rich side streams.

However, significant quantities of nutrients are lost in the various phases of use, collection and processing, through run off into water bodies. Nitrogen also evaporates or is vaporised into the air. Excess nutrients in the wrong place represent an economic and environmental problem. Because nutrients are lost during the cycle, to guarantee food production they need to be continuously replenished from outside through nutrient management.

The chart in Figure 2 shows that the nutrients travelling through the food chain are still relatively cheap in terms of the material costs of phosphorus and nitrogen only. Costs

Figure 2. The annual value of phosphorus and nitrogen cycling in the food chain, based on raw material prices for 2015. [9]

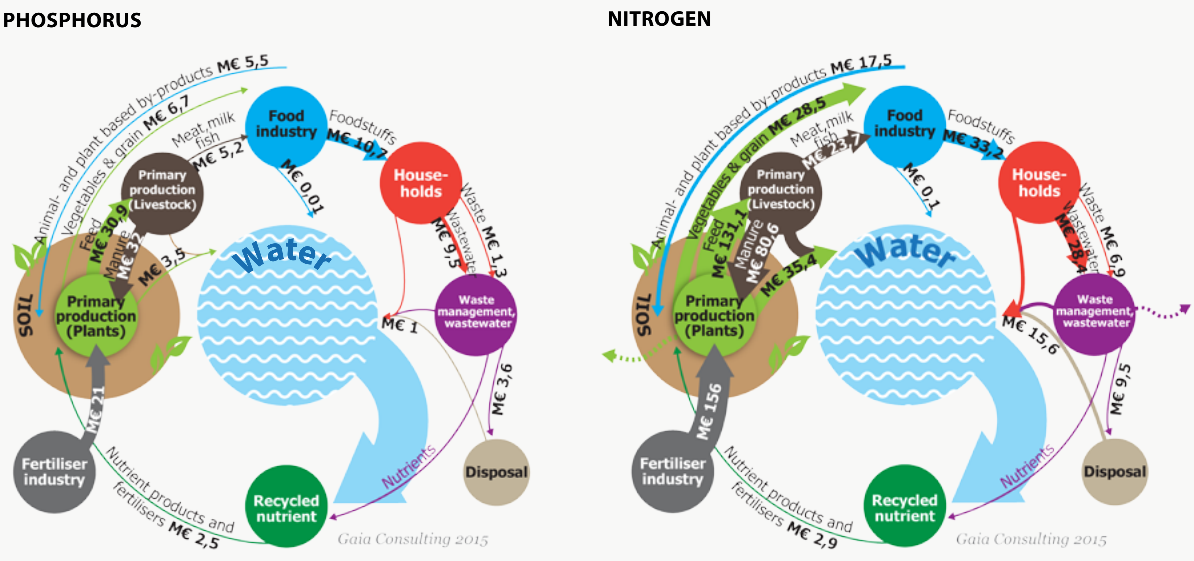
Source and graphics: Gaia Consulting 2015



[9]Source: Gaia Consulting Oy

Figure 3. The cost challenge involved in recovering lost nutrients.

Source and graphics: Gaia Consulting 2015



arising from problems such as the deterioration of water quality due to nutrient emissions or the depletion of the soil's nutrient bank are not shown in the charts.

Figure 3 depicts the same issue, illustrating the potential economic value of nutrient loss. If it were necessary to restore the nutrients lost in water bodies as recycled nutrients suitable for recycling directly from water, the process costs would be higher than any other operation in the economic nutrient cycle. The actual costs of nutrient loss only emerge in the form of environmental problem solving.

The actual costs of nutrient loss manifest themselves through the remedying of environmental problems.

2.3 A vision of a sound nutrient economy

Based on a vision of a sound nutrient economy, Finland would be self-sufficient in the nutrients required for its food chain. The nutrient capital of the soil would be at a high level and well managed. Nutrients leaching into water bodies would have been minimised and nutrient-rich waste and side streams generated in various processes would be recycled. The recycled nutrients used in primary production would eventually be recycled back into the processing chain. A future vision of an efficient circular economy for nutrients is shown in Figure 4.

This chart does not include the forestry and other associated industries that would also benefit from the infrastructure and recycling solutions. In addition, waste and side streams can be processed into products suitable for use, say, as industrial chemicals and producing high added value.

2.4 The logic of the added value of nutrient cycling

Nutrient loss is not just a problem and cost affecting human health and the environment. Solutions related to the efficient use, recycling, restoration and processing of nutrients could provide commercially viable added value for Finland.

Nutrient cycling's added value for the national economy is based on a combination of several perspectives. These perspectives have been drawn up through collaboration between experts and are presented in Table 2 . The economic impacts of the first four perspectives are relatively easy to assess. However, this is not the case for the economic impacts of the last three, which probably have a much greater impact than the first four.

2.5 The sustainability benefits and risks of recycled nutrients

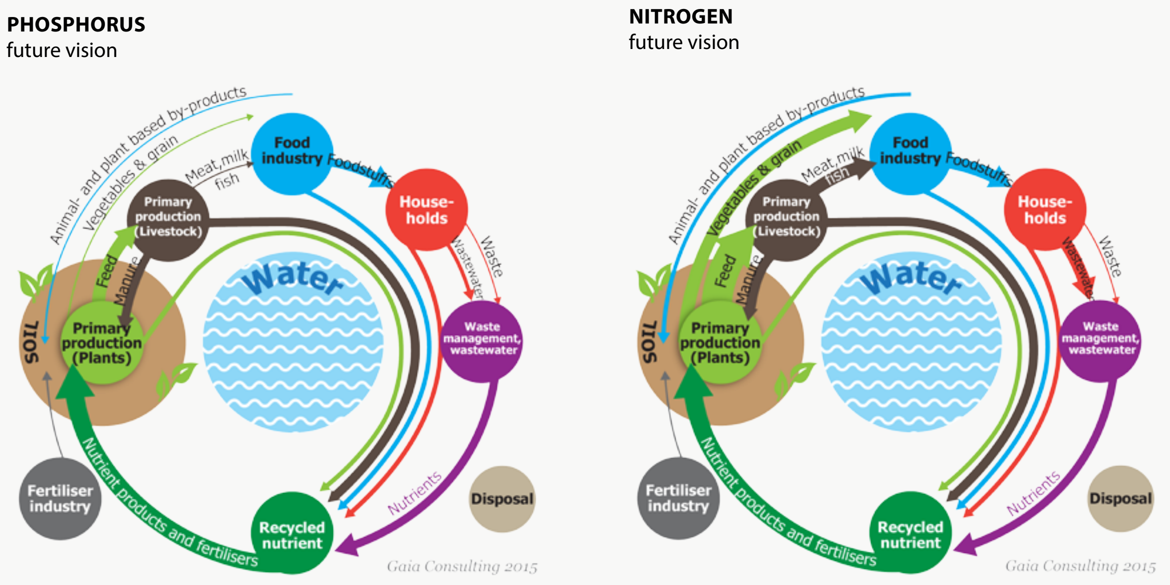
Both nitrogen and phosphorus are essential as nutrients. However, in the wrong place both cause serious sustainability risks to the environment. If recycled nutrients are used to replace traditional industrial fertilisers, recycling will reduce the need to mine new phosphorus or fix nitrogen from the atmosphere.

Recycled nutrients have already been turned into products and can be used as fertiliser in traditional farming and forestry, and as a supplementary fertiliser in organic farming. Nitrogen-rich liquids, on the other hand, could replace products such as the urea used in industrial production. Biogas generated during nutrient recycling is

Production of nitrogen-phosphorus concentrate made from recycled nutrients requires less energy and water.

Figure 4. Circular phosphorus and nitrogen economy [11]

Source and graphics: Gaia Consulting 2015



[11]Source: Gaia Consulting Oy

Table 2. The logic behind nutrient cycling's added value to the national economy

Source: Gaia Consulting 2015

1. Increase in business operations and new business operations	· Production of recycled nutrients · Technology and service solutions in the value chain of efficient nutrient cycling · Increase in the volume of existing business operations through efficient nutrient cycling (e.g. since licensing conditions restrict the growth of operations)
2. Increased profitability of business operations	· Cost savings in the flows of nutrients · Cost savings in the treatment of nutrient-rich waste · Increase in the nutrient capital of soil and improved production potential
3. Improving the trade balance	· Replacing imported nutrients with domestic recycled nutrients or more efficient use of nutrients · Replacing imported protein with domestic protein production · Growth in exports of nutrient cycling solutions
4. More effective capital use	· Shift from centralised, capital-intensive solutions to decentralised, agile solutions · Enhancement and reform of the wastewater treatment infrastructure
5. Synergies	· Professional exploitation of water bodies, such as fishing · Recreational use of water bodies, such as tourism · Improving the operational preconditions of domestic food production
6. Cost savings in risk management	· Improvements in food security and security of supply · Reduced flood risks as a fringe benefit of local management of stormwater
7. Reduced health and environmental hazards	· Reduced eutrophication and contamination of water bodies · Reduction in health and environmental hazards caused by harmful nitrogen compounds · Reduced greenhouse gas emissions outside the emissions trading sector · Prevention of nutrient depletion of soil and reduced contamination · Improved carbon fixation in soil

processed into transport fuel, or can be used as a replacement for butane use in the manufacture of building insulation materials, for example.

Although nutrient cycling causes emissions, as shown in the next example recycled nutrients are more sustainable than mineral nutrients.

Example: Sustainability benefits and risks of recycled nutrients produced in a biogas plant [12]

Gaia analysed the sustainability benefits and risks of recycled nutrients (nitrogen-phosphorus concentrate) produced from the digestate from Biovakka's biogas plant, compared to similar nutrients produced using traditional methods (phosphate rock and atmospheric hydrogen). In this study, the nitrogen-phosphorus concentrate was used in a paper and pulp industry wastewater treatment plant.

The sustainability assessment was performed using the Gaia Biorefiner tool, which enables bechmarking of the sustainability of various products and production chains. The tool consists of indicators which measure the sustainability of various aspects of a product. Such an assessment takes account of global challenges, such as climate change, raw material consumption and the environmental impacts of raw material processing. In addition, the assessment takes account of local factors, such as regional water scarcity and sustainable land use.

The results of the sustainability bechmarking are shown in Figure 5. According to the bechmarking results, the greatest sustainability benefit of recycled nutrients lies in the use of waste as a raw material in a product. The analysis shows that less energy and water is required to produce nitrogen-phosphorus concentrate from recycled nutrients. In addition, the production of energy and water had been implemented in a more sustainable manner than when the nutrient was produced from primary raw materials.

[12] Gaia Biorefiner Biovakka, 2014

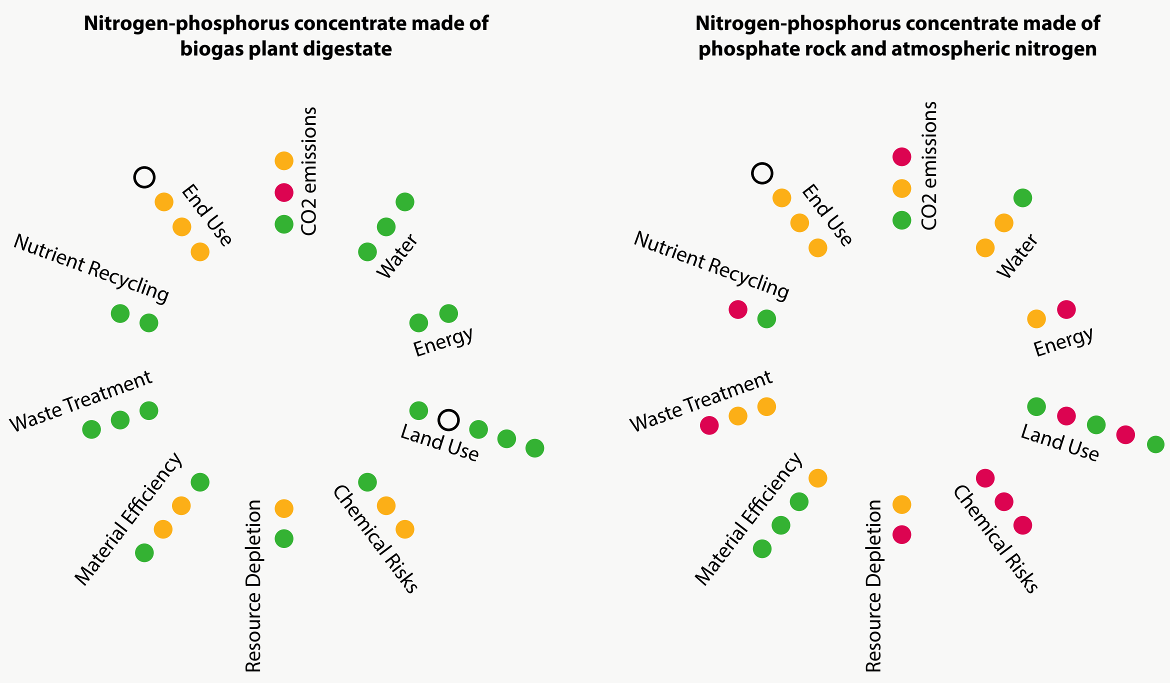
Also, smaller quantities of mineral resources are consumed in the production chain for concentrate made of recycled nutrients. Recycled nutrients pose lower health and environmental risks associated with chemicals and have lower waste management requirements. In terms of land use, waste production and the use of fossil raw materials, both production chains had similar results. As regards land use, the recycled nutrient product had sustainability benefits related to the use of waste streams as a raw material. On the other hand, the product made of primary raw materials benefited from efficient land use in raw material production, although risks were also identified in this regard. These risks included the harmful effects of phosphate rock excavation on biodiversity and the fact that mining operations do not support natural ecosystem services.

Compared to competing nutrients, the use of fossil raw materials was at around medium level in both production chains. With respect to recycled nutrients, this was due to transport fuels whereas, in the case of products made of primary raw materials, it was due to the use of fossil raw materials. Both production chains produced less waste than basic chemical production on average.

In comparison to the competing product, the recycled nutrient product also has sustainability risks associated with material efficiency and climate change. Greenhouse gas emissions from the transportation of the recycled nutrient product were significantly higher than for a similar product manufactured from primary raw materials. This derived from the low dry content of the product, which led to a greater transport capacity requirement. In addition, utilization rate of raw material into product was lower than in its competitor.

Figure 5. Results of a sustainability comparison between nitrogen-phosphorus concentrate made of recycled nutrients (on the left) and of primary materials (on the right).[13]

Source: Gaia Consulting 2015

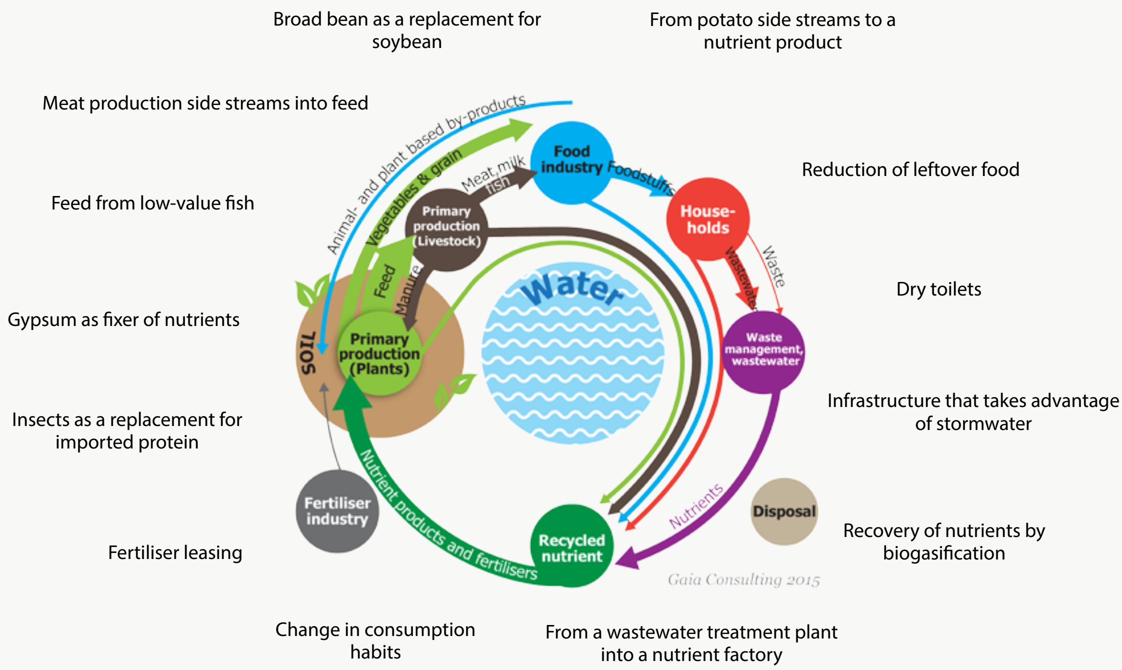


[13]In the figure, each point represents a single indicator, and the colour of each point reveals the result obtained for the indicator. Green means that the assessed product has a sustainability advantage within the product group. Yellow means that there are no actual benefits associated with the product, but no specific risks either. Red, however, means that there is a sustainability risk associated with the product as regards this indicator.

3 The opportunities presented by the nutrient economy

Figure 6. Examples demonstrating the opportunities of nutrient cycling

Source: Gaia Consulting 2015



3.1 Selection of examples

Several examples that promote nutrient cycling were identified during the project. They describe the ways in which the food chain's nutrient cycle can be made efficient or closed: replacing mineral fertilisers with recycled nutrients; reducing nutrient loss and runoff; recycling nutrients into use; and developing new nutrient products. Each example was grouped under one of the following four themes: **Enhancing nutrient cycles in agriculture, new sources of feed, the role of households in promoting nutrient cycling, and the recovery and recycling of nutrients**. In the report, 13 of the examples were selected for closer study in collaboration with the project's management group. The examples selected are shown around the perimeter of the previously presented cyclical image of the vision of an efficient nutrient economy (Figure 6). The figure illustrates the examples' scope in relation to primary production, the food industry, households, waste management, and the processing of recycled nutrients.

The examples were selected to provide the most multifaceted and comprehensive picture possible of the potential of nutrient cycling. In addition to the potential economic value, in the selection criteria the emphasis was placed on aspects of importance to Sitra's circular economy focus area: new business models, export potential, consumer solutions, industrial symbioses, and potential for high added value. When selecting the examples, account was also taken of the perspectives of renewable infrastructure and increasing nutrient capital, as well as the application of international examples. Each of the examples selected offers a different perspective on boosting the nutrient cycle.

The selected examples and the perspectives emphasised in their descriptions are shown in Table 3[14]. In the

[14]The selection of these specific examples does not mean that other business models for or examples of nutrient cycling would not entail opportunities or economic value for Finland.

Table 3. The examples chosen and the perspectives highlighted in the descriptions of the examples.

Source: Gaia Consulting 2015

Theme	Example	National economic value	Export potential	New business model	Consumer solutions	Industrial symbioses	High added value	Renewing infrastructure	Nutrient capital	International example
More effective nutrient cycles in agriculture	Fertiliser leasing	√		√					√	√
	Industrial gypsum waste as a fixer of nutrients	*				√			√	
New sources of feed	Broad bean as a replacement for soybean	√							√	
	Feed from low-value fish	√		√						
	Meat production side streams into feed	**				√				
	Insects as a replacement for imported protein	**								√
	From potato side streams to a nutrient product					√	√			√
Role of households in promoting nutrient cycling	Dry toilet concepts		√		√			√		
	Change in consumption habits	***			√				√	
	Reduction of leftover food	****			√				√	
Recovery and recycling of nutrients	Infrastructure that takes advantage of stormwater							√		√
	From a wastewater treatment plant into a nutrient factory			√			√	√		
	Recovery of nutrients by biogasification	√		√		√		√		

*reduced environmental hazards **replacing imported feed ***impact on the trade balance ****reduces losses

following sections, the chosen perspectives for each example selected for the study have been highlighted with the help of figures, concrete descriptions and examples.

Four of the examples have been included in the calculation of the added value for Finland: fertiliser leasing, use of broad beans as a replacement for imported soybeans, use of low-value fish as a source of feed, and biogasification as a driver of nutrient cycling. All relevant elements in the examples were included in the overall evaluation of the economic value to the national economy, while accounting for the seven perspectives on the added value logic for the national economy, as presented in Table 2. The business logic of the selected examples is described in more detail in the section describing each of the examples, while their economic potential is presented as the value of the annual net change between 2030 and now. The economic value of the four examples mentioned above was evaluated using the cash flow-based regional economic model developed by Gaia[15]. The model evaluates the overall impact of business chains, while converting the related operations into indicators of economic impact. Alongside the examples used in the calculations, the other examples presented also promote nutrient cycling in Finland.

[15]The calculation model used to evaluate the impacts on the national economy was developed by Gaia. Additional information on the model can be found, for example, in the following Sitra publications: "Energiasektorin cleantech-teknologioiden vaikutus ja mahdollisuudet" (in Finnish, "The impact and opportunities of cleantech technologies in the energy sector") and "Energiainvestointien alue- ja kansantaloudellinen kannattavuustarkastelu" (in Finnish with English summary, "Review of the impacts of different energy production investments on regional and national economies").

3.2 Enhancing nutrient cycles in agriculture

In Finland, agriculture is the greatest source of nutrient loading of water bodies. In 2013, phosphorus loading on water bodies due to agriculture totalled 1,800 tonnes a year, accounting for almost 60% of the overall phosphorus loading on Finnish water bodies. Correspondingly, the nitrogen loading caused by agriculture was 30,200 tonnes a year, equalling 50% of the overall phosphorus loading on Finnish water bodies.[16] Nutrients also find their way into water bodies in eroded soil, rainwater and melting snow.

3.2.1 Fertiliser leasing

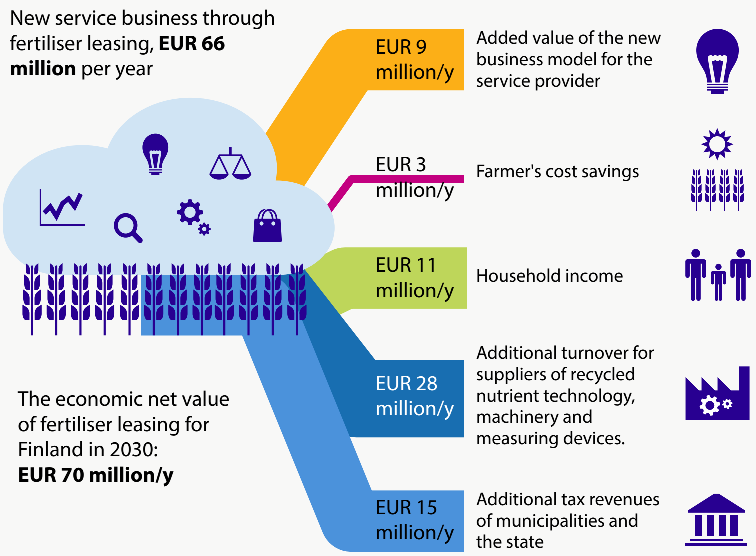
As a business model that promotes resource efficiency, chemical leasing is gaining popularity around the world. In such a case, a seller of chemicals shifts its business model towards business activities based on the impacts of chemical use. The same model can be applied to fertilisers, where the seller sells the nutrient impact on the crops or soil rather than kilogrammes or litres of fertiliser. The purpose is to maintain or improve the quality of land alongside production, in other words to improve the land's nutrient capital.

An operator leasing fertilisers has the opportunity to use the best information, skills and technology available in managing the dosage of fertilisers. This enables the drawing up of precise, fertiliser-specific field maps as a basis for optimising fertiliser quantities. The provider of fertiliser leasing services analyses the nutrient needs, optimises the amount and quality of the fertiliser and its spreading, and monitors the impact of fertilisation. The service provider can also lease measuring technology and its know-how to

Figure 7. Added value of fertiliser leasing.

Source: Gaia Consulting, UNIDO, Finnish Environment Institute, JÄRKI and Agency for Rural Affairs

Fertiliser leasing is a key to the adoption of recycled nutrients



Fertiliser leasing

- **Chemical leasing** is a business model for chemical suppliers which promotes resource efficiency. The related business derives from the impact of chemical use.
- The same model can also be applied to fertilisers where, instead of selling a certain amount of fertilisers the seller **sells the nutrient impact on the crops or the soil.**
- The service provider analyses nutrient needs, optimises amounts, quality and spreading, and monitors impacts. The purpose is to maintain or improve the quality of land alongside production.

Fertiliser leasing is a business model gaining in popularity around the world and already applied in several countries. In Germany, optimisation of nitrogen fertilisation alone has **improved the yield by 6%.**

Key starting points and assumptions:

The economic potential describes the economic value of the annual net change between 2030 and the current situation.

With respect to fertiliser leasing, a shift is under way towards using domestic recycled fertilisers.

[16] The Finnish Environment Institute, Nutrient loading of water bodies in 2013

the farmer. This enables a reduction in the amount of fertilisers used and boosts crop yields. The savings achieved in the use of fertilisers form the basis of the service provider's business. In Finland, the related business model could be used to accelerate the introduction of recycled nutrients.

International examples

UNIDO (United Nations Industrial Development Organization) has been exporting the chemical leasing business model and, through that, the fertiliser leasing concept. In pilots carried out in Sri Lanka, savings achieved via fertiliser leasing in potato farming amounted to as much as 40-50% (EUR 110-160/ha)[17]. The model has also been piloted in Serbia, where the savings achieved in fertilisation costs in wheat farming were 5%, while the yield increased by 2%[17]. In Germany, the optimisation of nitrogen fertilisation alone has improved farmers' yields by 18%[18]. In this case, the improvement lay in both the smaller amount of fertiliser used and the higher yield. The crop was wheat in this pilot as well.

The percentage of savings is always associated with a certain type of product being farmed and is greatly affected by factors such as the grain price and the soil in question. However, the examples provide a measure of the kinds of savings achievable through fertiliser leasing.

The economic value of fertiliser leasing

The starting point for the calculations based on the selected example was use of a fertiliser leasing service for the application of recycled nutrients. In this calculation, the fertiliser producer is not expected to suffer any losses, because the fertiliser markets are global and the use of recycled nutrients is still marginal[19]. In other words, it is assumed that fertiliser producers will maintain the same production level throughout the period under review, until 2030. The service provider's profit margin is assumed to be 15%.

It was also assumed that, by 2030, the fertiliser leasing service model will have been adopted on 50% of the field area used for growing grain. In 2014, Finland had a total of almost 2.3 million hectares of agricultural land. Since grain was grown on almost 1.2 million hectares[20], or on more than half of the total field area – 50% of this corresponds to 600,000 hectares.

In 2014, 95% of the field area in Finland was covered by the former agri-environmental subsidy[21] scheme.[22] For the calculation, it was assumed that the state would pay the same amount of agri-environmental support in 2030 as in 2015, but that future subsidies would be targeted in such a way that 100% of farmers using fertiliser leasing services and recycled nutrients would be granted full agri-environmental support, while the share of recipients would fall among other groups (40% would receive full subsidies).

For Finland, **the economic value of fertiliser leasing** would be EUR 69 million per year. The value of new business for providers of fertiliser leasing services would be EUR 66 million and the economic added value for service providers would total EUR 9 million. The service would also create added value for farmers, who would gain EUR 3 million in added value per year due to reduced use of fertilisers and higher agricultural yield.

The state and municipalities would benefit by approximately EUR 15 million from the increase in tax revenues. Due to higher earned income, the earnings of households would increase by EUR 11 million a year. The turnover of suppliers of nutrient recycling technologies, machinery, equipment and measuring devices would increase by a total of EUR 28 million.

Services and associated technology exports would create additional potential, but this was not included in the calculations. This concept would also provide a good way of preventing nutrient runoff into water bodies.

3.2.2 Using gypsum as a way to fix nutrients

Gypsum is a versatile soil amendment that improves the soil structure and retains soluble phosphorus in soils. Gypsum use on fields can both curb erosion and decrease the runoff of phosphorus into water bodies. While reducing the risk of phosphorus runoff, this method retains phosphorus in a usable form for plants. However, gypsum cannot be used near lakes or in their catchment areas, due to the runoff of sulphate contained in gypsum.

Use of gypsum as a way of fixing nutrients also promotes industrial symbioses, since significant amounts of gypsum waste are generated as a by-product of the fertiliser industry. In Finland, large amounts of gypsum waste are stored at sites such as the Yara fertiliser and phosphoric acid plant at Siilinjärvi. Because gypsum waste can be spread with regular agricultural machinery, no new machine investments are needed.[23]

The concept of using gypsum for nutrient fixation is relatively new and its long-term effects have not yet been studied.

Example: Nurmijärvi

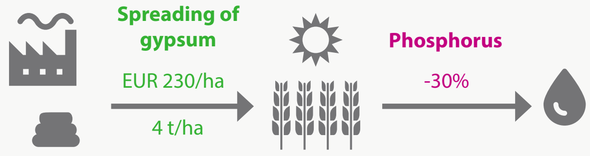
In the TRAP project, use of gypsum was piloted on the clay fields of the village of Nummenpää in Nurmijärvi. Four tonnes of gypsum were spread per field hectare. As a result of the use of gypsum, the runoff of phosphorus bound to soil particles fell by 57%. In addition, the runoff of dissolved phosphorus fell by 33% and the overall phosphorus runoff by 54%.[24]

[17] UNIDO
[18] Yara
[19] Long-term sustainability challenges and business risks related to the use of mineral and fossil products are not covered by this study.
[20] Natural Resources Institute Finland, agricultural statistics, utilised agricultural area, 2015.
[21] Agency for Rural Affairs, From the beginning of 2015 agri-environmental subsidy was changed into an agri-environmental support scheme.
[22] JÄRKI project, Sensible enhancement of water protection and biodiversity in agriculture, agri-environmental support, 2015
[23] Yara: Gypsum-based solutions to reduce the phosphate load of the Baltic Sea
[24] Finnish Environment Institute: Water letter 22 March 2011

Figure 8. Industrial gypsum waste as a fixer of nutrients.

Sources: Gaia Consulting, National Resources Institute of Finland, University of Helsinki, Yara. Graphics: Gaia Consulting

Use of industrial gypsum waste as a fixer of nutrients promotes industrial symbioses



Industrial gypsum in practical use

- Spreading gypsum produced as **a by-product** of the fertiliser industry reduces phosphorus runoff into water bodies.
- Spreading four tonnes of gypsum per field hectare **reduces the phosphorus loading in water bodies by** one third.

Gypsum treatment of fields in Southern Finland would prevent **the runoff of 150,000 tonnes of phosphorus** into the Baltic Sea. This amount corresponds to around half of the target set for Finland by the HELCOM Baltic Sea Action Plan (BSAP) for the reduction of phosphorus emissions.

No other large-scale uses were found for recycled gypsum. Gypsum treatment of fields would cost EUR 55 million and its impacts would last for five years.

Use of gypsum was piloted in the TRAP project in Nurmijärvi. Four tonnes of gypsum were spread per field hectare. As a result of the use of gypsum, the runoff into water bodies of phosphorus fixed by soil particles fell by 57%. In addition, the runoff of dissolved phosphorus reduced by 33% and the overall phosphorus runoff by 54%.

Using gypsum for nutrient fixation is cost-efficient, since the cost of spreading four tonnes of gypsum per hectare of land is around EUR 230. This means that, in the catchment area of the Archipelago Sea and the Gulf of Finland, it would be possible to prevent 150 tonnes of phosphorus runoff with an investment of EUR 55 million. Such an amount corresponds to approximately half of the phosphorus emission reduction target set for Finland by the Baltic Marine Environment.[25]

3.3 New sources of feed

Growth in demand for meat and fish and other foods of animal origin is a global trend, spurred by population growth and increasing wealth. Using fish feed as an example, Figure 9 shows the Food and Agriculture Organization of the United Nations' (FAO) estimate of demand for feed and price trends. Depending on the production animal, animal farming requires 2–30 kg of feed per kilogramme of meat[26].

3.3.1 Domestic broad beans as a replacement for imported soybeans

Finnish broad beans could be used as a replacement for imported soybeans in the high-volume feed industry. The broad bean's other benefits include its ability to bind high amounts of hydrogen during growth (90-150 kg/ha/y[29,30]); it therefore also acts as a natural soil amendment in subsequent growth seasons. Broad bean farming requires hardly any hydrogen fertilisation[31].

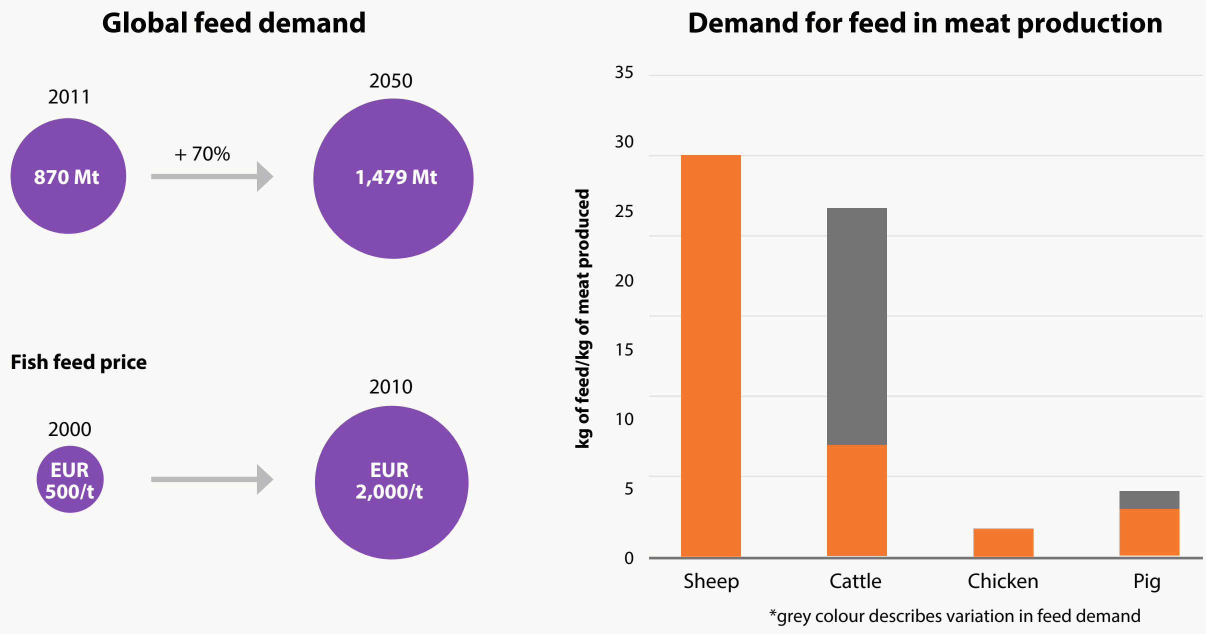
Some 156,000 tonnes of soybean is imported to Finland per year.[32] Most of this, 95%[33], is used as feed for production animals. Because non-GMO soybean is in short supply and its price has risen, the Finnish feed industry's interest in broad beans has increased. Accordingly, broad bean farming increased in Finland in the 2000s; in 2014 production amounted to 21,400 tonnes[34] on a total farming area of 8,700 hectares.

The use of broad beans as animal feed is limited by its content of detrimental elements, such as tannin, which is harmful to the digestion of animals with single-chambered

[25] Juha Nurminen: Vieraskynä column in Helsingin Sanomat, 18 April 2015
[26] J. M. Wilkinson, Re-defining efficiency of feed use by livestock 2011
[27]FAO: Insects for food and feed; FAO: The contribution of insects to food security, livelihoods and the environment; Wageningen UR: Insects as a sustainable feed ingredient in pig and poultry diets; Business Insider UK: This Bill Gates-supported start-up is about to open the world's largest fly farm in South Africa; Agriprotein Technologies, website; FAO: Globefish
[28] J. M. Wilkinson, Re-defining efficiency of feed use by livestock 2011
Finnish Organic Association 2007. Luomutilan valkuaiskasviopas. (In Finnish, Protein crops guidebook for organic farms)
[30] MTT, 2012. Typpi- ja valkuaisomavaraisuuden lisääminen palkokasveja tehokkaasti hyödyntämällä. (In Finnish with English abstract, Improving self-sufficiency in nitrogen and protein by efficient utilisation of legumes) Final report of the MoniPalko project.[31]
In agriculture, the use of artificial nitrogen fertiliser per farmed hectare of land is approximately 74 kg/ha/year. (Statistics Finland 2011.)
[32] Finnish Customs, ULJAS statistics 2014.
[33] FAO, statistics (FAOSTAT)
[34] Natural Resources Institute of Finland, 2014. Crop production statistics.

Figure 9. The development of global feed demand and the fish feed price [27]
Demand for feed in meat production [28]

Source: Gaia Consulting 2015



stomachs[35]. On the other hand, broad beans are ideal for cattle.[36] As a result of cultivation, varieties of broad bean with white flowers contain less tannin, enabling greater use in pig feed in particular. MTT recommends that no more than 10% of broad bean be used in piglet feed, due to lower acceptance[37], but in pig feed its share could be as high as 30%. Due to its amino acid profile, the broad bean is not as ideal for poultry feed.

Broad beans can also form part of the human diet. However, few efforts have been made to productise domestic broad beans. The visine and convisine contained in many broad bean varieties can cause anaemia in some people. To prevent stomach upsets, dry beans need to be soaked for 24 hours, which fits poorly into today's food culture. In Finland, studies have also been performed on the fermentation of beans into food-standard protein, and they have been successfully used in the production of foods, such as yoghurt-type products, similar to those made of fermented oats.

The economic value of broad bean farming

The following calculation is based on the assumption that imported soybeans are totally replaced by broad beans[38]. The feed producer acquires the quantity of broad beans he needs, corresponding to the equivalent amount of soybeans in kilogrammes. 10–30% of piglet and pig feed can consist of broad beans. Since the soybean content of pig feed is no higher than 10%, 100% replaceability is realistic. Some 25% of chicken feed is soybean-based, but broad beans are not suitable for chickens. Broad beans are ideal for cattle, on the other hand, and it is therefore assumed that soybeans have a greater replaceability rate in this case. When feeding cattle, legumes can replace silage made of grass[39], if the entire growth is harvested as whole-crop silage.

In Finland, the yield level of broad beans is approximately 3,000 kg/ha[40,41] which is assumed to fix 30 kg/ha of nitrogen[42]. The nutrient capital of the land is assumed to grow by EUR 25/ha42. The change in land value has been calculated on the basis of the broad bean's ability to fix

[35] Animals with single-chambered stomachs (such as chickens and pigs) mean animals whose digestive system consists of a single stomach. Ruminants, on the other hand, have a multi-compartment stomach and their digestive system consists of more than one stomach.

[36] Lehtinen, Susanna, 2014. Härkäpavun viljely ja käyttö lypsylehmien ruokinnassa (in Finnish with English abstract, Broad beans in farming and dairy cow feed), Bachelor's thesis, HAMK Häme University of Applied Sciences.

[37] Perttilä, Sini, 2014. Toimiva sikala – kotimaisen porsasrehuseoksern raaka-aineet. (In Finnish, A functional piggery – the ingredients of a domestic pig feed mixture)

[38] The amount of imported soybean 156,000 tonnes. Finnish Customs, ULJAS statistics 2014.

[39] Juutinen, E. 2011. Säilörehua herneestä ja härkäpavusta. Nauta 4: 34-35. (In Finnish, Silage from pea and broad bean. Cattle 4)

[40] Pennanen Anna-Maria, 2014. Härkäpapu, herne, virna ja lupiini säilörehussa. (In Finnish with English abstract, Broad bean, pea, vetch and lupine in silage)

[41] Annual crop variations are large in the case of broad beans and the yield per hectare varies from 2,800 to 6,000 kg/ha; the yield is reduced by high dryness stress or water stress in particular.

[42] RaisioAgro

nitrogen from the air into the soil (~25 kg/ha of the nitrogen is retained in the soil[30]), but the added value contributed by rotational cultivation[43] has been ignored.

When modelling the economic added value, it was assumed that otherwise unused agricultural land could be used for growing broad beans[44], in which case the impacts of a lower crop yield could be avoided. It is assumed that, in 2030, the amount of broad beans grown in Finland will correspond to the amount of soybean currently imported for feed. This would make Finland self-sufficient in proteins used for feed production. The farmed area corresponding to assumed production would be approximately 52,000 hectares, i.e. 4% of all agricultural land.

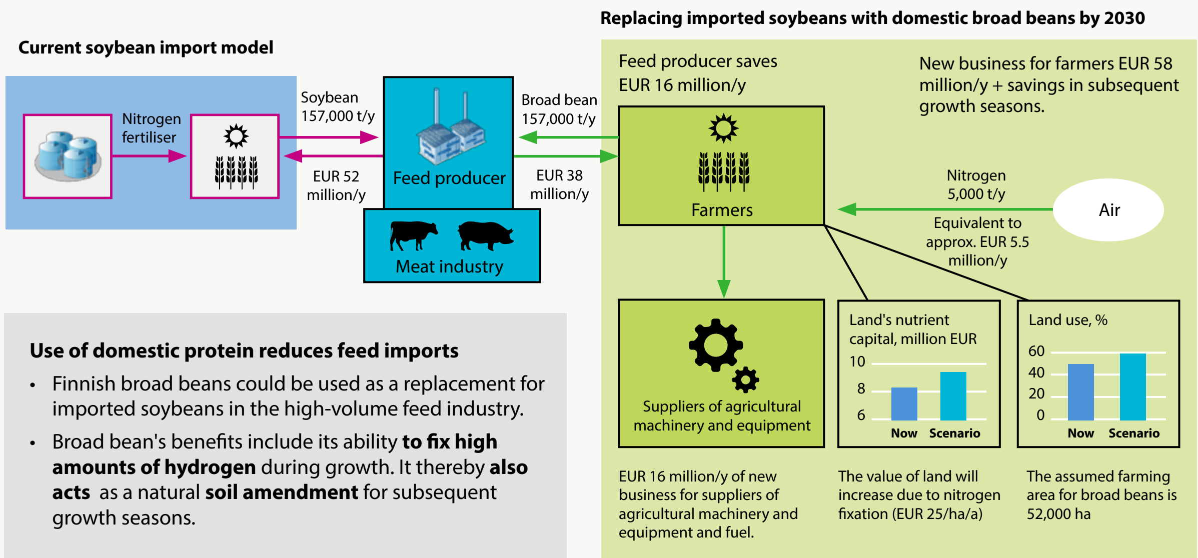
Account was taken of agricultural subsidies – EUR 90/hectare in product-specific subsidies for protein crops would be available as direct EU support when farming broad beans. In addition, the farmer would receive a single farm payment[45], agri-environmental subsidies and aid for farmers in Less Favoured Areas, totalling approx. EUR 518/hectare. The last-mentioned subsides are also available for grain and other crop plants.

Existing feed operators would be affected by **the economic impacts of broad bean farming**. Broad bean farming would bring farmers a turnover of approximately EUR 38 million. By switching from soybeans to broad beans, feed producers would gain savings totalling EUR 16 million in reduced acquisition costs of raw materials. Other companies in the value chain would also gain their share of the increased business, with the highest benefits, approximately EUR 16 million, going to agricultural machinery, equipment and fuel suppliers. The value of agricultural land would change as a result of broad bean farming. On the modelled farming area, this would mean an increase of approximately EUR 1.3 million. The state would lose EUR 29 million in agricultural subsidies paid to farmers. Agricultural subsidies would account for 47% of the farmer's increased turnover. In spite of the losses to the state, Finland's trade balance would grow by EUR 50 million due to the replacement of soybean imports.

Figure 10. The economic value of broad bean farming for Finland in 2030

Source: Gaia Consulting, Ministry of Agriculture and Forestry, Customs, RaisioAgro

Broad beans could replace soybean imports by EUR 52 million/y, reduce the use of nitrogen fertilisers by 5,000 t/y and raise land values by EUR 1.3 million/y



Key starting points and assumptions:

The economic potential describes the economic value of the annual net change between 2030 and the current situation.

The assumption is that broad beans would replace 100% of imported soybeans. The yield level of broad beans in Finland is approximately 3,000 kg/ha. The change in land value has been calculated on the basis of the broad bean's ability to fix nitrogen from the air into soil, but no account has been taken of the value added by rotational cultivation.

[43] Rotational cultivation refers to the rotation of crops over many years, with various plant species grown in rotation. The purpose of rotational cultivation is to improve the soil structure and fertility (Source: Central Union of Agricultural Producers and Forest Owners [MTK])

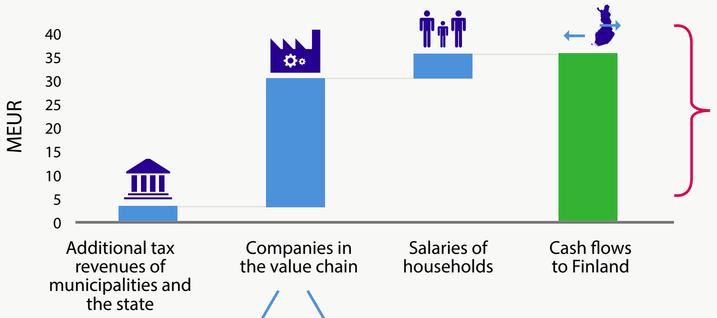
[44] Only 53% of agricultural land is currently used for cultivation.

[45] Known as "the Basic Payment Scheme" from 2015. Ministry of Agriculture and Forestry 2014. Maatalouden muuttuvat tuet. (Changes in agricultural subsidies)

Figure 11. The impacts of domestic low-value fish feed on various operators in 2030.

Source: Gaia Consulting, Finnish Game and Fisheries Research Institute, Natural Resources Institute Finland, Finnish Fish Farmer's Association

Increasing the volume of reduction fishery and the processing of fish feed products in Finland would benefit both water bodies and actors in the product chain.



In 2014, the value of fish feed and fish waste imported by Finland was **EUR 16 million.**

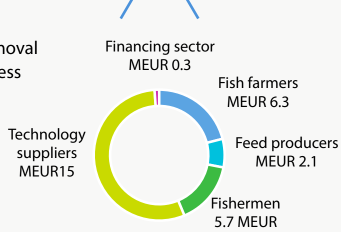
EUR 42 million

Increasing business without increasing the nutrient load

- In Finland, low-value fish could be used to replace some fish feed imports.
- **Using reduction fishery and side streams as sources of fish feed will enable the growth** of the traditional aquaculture **business** within the currently applicable emission limits.
  -> Production volumes of aquaculture could be increased without increasing the nutrient load.

Suppliers of dioxin removal plants gain new business amounting to

EUR 15 million.



Fish farmers and fishermen benefit by more than **EUR 12 million** through increased volumes.

Feed producer will gain EUR 2 million from increased production. Through domestic feed production, it can be ensured that the fish material used is based on sustainable fish stocks.

The fish farming and processing company Salmonfarm is planning a fishmeal plant to be built on Kemiönsaari island in Kasnäs. The investment costs are around EUR 6.5 million and the plant would use some 30–40 million kilogrammes of Baltic herring as raw material each year, representing about one third of Finland's herring fishing quota.

Key starting points and assumptions:

The economic potential refers to the economic value of the annual net change between 2030 and the current situation. Current fish feed consumption can be covered by domestic production. An increase in reduction fishery would boost the number of fishing permits by 2:1.

3.3.2 Feed from low-value fish

Because 90% of European fish stocks are overfished, European fish consumption is dependent on imports. 60% of fish consumed in Europe is imported, and the annual value of imports is approximately EUR 15.5 billion. Aquaculture covers approximately 20% of fish consumption and provides employment for 65,000 people in the EU. The production volume is approximately 2.5 million tonnes a year. Aquaculture is being encouraged due to its lower environmental load. [46]

In 2014, some 31,000 tonnes of fishmeal and fish waste to be used for purposes other than human food were imported to Finland, with a total value of around EUR 16 million.[47] Although the amount of imported feed has decreased during the last ten years, its value has grown significantly. In Finland, low-value fish could be used to replace some feed imports.

Using reduction fishery and side streams as sources of fish feed ("Baltic Sea feed") could also enable the growth of the traditional aquaculture business within the currently applicable emission limits. However, in practice, many questions remain open as regards using compensation to control environmental emissions, particularly in the regional targeting of reduction fishery and nutrient recovery and their relationship to location guidance. A pilot project has been launched in Finland[48], whereby the opportunities and criteria for using compensation in aquaculture are being assessed by the various parties involved.

The Finnish aquaculture strategy [49] also aims to increase Finland's fish self-sufficiency and the use of domestic protein in fish feed. This should also improve Finland's trade balance and food security. In addition, through domestic feed production it should be possible to ensure that any fish material used is based on sustainable fish stocks.

[46] Gaia Consulting Oy: Arvoa ainekierrosta: Teollisten symbioosien globaali markkinakatsaus (in Finnish with English summary, Global market review of industrial symbioses, 2013.

[47] Finnish Game and Fisheries Research Institute: Finnish imports and exports of fish and fish products in 2014.

[48] Natural Resources Institute Finland (Luke) and Finnish Fish Farmer's Association, performed by Gaia Consulting

[49] Vesiviljelystrategia 2022: Kilpailukykyinen, kestävä ja kasvava elinkeino (in Finnish, Aquaculture Strategy 2022: Competitive, sustainable and growing industry). The government's decision-in-principle, 4 December 2013.

Example: Kasnäs

The fish farming and processing company Salmonfarm is planning to build a fishmeal plant as part of its Kasnäs processing plant on Kemiönsaari island. This investment would amount to approximately EUR 6.5 million. The plant would use some 30–40 million kilogrammes of Baltic herring as raw material per year – around one third of Finland's herring fishing quota.[50]

The economic value of domestic feed based on low-value fish

When modelling the economic added value, it was assumed that an increase in reduction fisheries would increase the number of fish farming permits by 50% in relation to growth in the volume of reduction fisheries. Based on this assumption, the nutrient loading of water bodies would remain unchanged. The change in the volume of reduction fisheries corresponds to the annual raw material requirement of a fishmeal plant. The model also assumes that, in 2030, domestic feed will cover the needs of all current fish farming potential. However, any additional fish farming potential would use imports to satisfy its feed requirement. Subsidies for reduction fisheries and investments in fishmeal plants – based on which demand in the Finnish feed industry could be satisfied – would form the preconditions for the changes in question.

The greatest impact on Finland's trade balance would arise from replacing imports with domestic farmed fish, improving the trade balance by EUR 42 million. An increase in reduction fisheries would raise the fish farming potential of Finnish fish farmers in the form of greater numbers of fish farming permits, from which the farmers would reap a benefit of EUR 6.3 million. Even after paying subsidies for reduction fisheries, the state would benefit by EUR 3.2 million and municipalities by EUR 3.7 million a year due to increased tax revenue. For fishermen, reduction fishery would generate EUR 5.7 million in increased business. Increasing the volume of reduction fishery and processing of products in Finland would benefit other actors in addition to those in the direct product chain. The order stock of technology providers would improve with new investments, such as dioxin removal plants and fish farms. Replacing imported fishmeal with a domestic alternative would improve the trade balance by EUR 2 million.

3.3.3 Meat production side streams into feed

Some 253,000 tonnes of animal-based side streams are generated in Finland every year. Use of by-products would reduce the need for imported animal feed and fertilisers and promote nutrient cycling. This would also help to reduce the environmental load of foodstuffs of animal origin. An operating model based on the processing of side streams would also promote industrial symbioses, where one operator's waste is another's raw material.

The use of processed animal protein is currently allowed only in fish, pet and fur animal feeds. EU by-product legislation prevents its use in production animal feeds, but the legislation is already being amended.

Example: Honkajoki

Honkajoki Oy processes protein feed and organic fertilisers for agricultural use, from animal-based food industry side streams. The business is based on the agro-ecological operating model: nutrients are recycled back into the food chain and growth is created through recycling.

Honkajoki currently receives 100,000 tonnes of animal by-products a year. From this, the company produces 30,000 tonnes of various powders, which are divided into three categories. In accordance with EU legislation, Category 1, meat-and-bone meal must be destroyed by incineration. Category 2 meal is suitable for use as fertiliser or for the production of fur animal feed. Category 3 is suitable as fish and pet foods. The protein feeds manufactured by Honkajoki contain nutrients needed by animals. In addition, animal fat can be used to supplement the energy content of feed mixtures. Feeds are subject to strict quality and safety criteria, the implementation of which is supervised by Evira.

EU by-product legislation totally prohibits the use of meat-and-bone meal as animal feed. If legislative barriers were removed, meal from all three categories could be used as animal feed. If all animal by-products generated in Finland could be used as meat-and-bone meal in the feed industry, this would correspond to around 100,000 tonnes of soybean.[51,52]

The fertilisers developed by Honkajoki and its partners are based on the hydrogen and phosphorus contained in meat-and-bone meal. Organic fertilisers release their nutrients slowly, which means that less nutrients leach into water bodies than in the case of mineral fertilisers. Due to their low nitrogen-content, there is no major demand for fertilisers produced via this process. Higher demand for recycled nutrients and feed would enable increased recycling of nutrients.

The process also produces fat as a by-product, which is used as a raw material for biodiesel and in heat generation for the year-round heating needs of local greenhouses. In other words, the related industrial symbiosis functions in

[50] Suomen Kalankasvattaja 2/2015

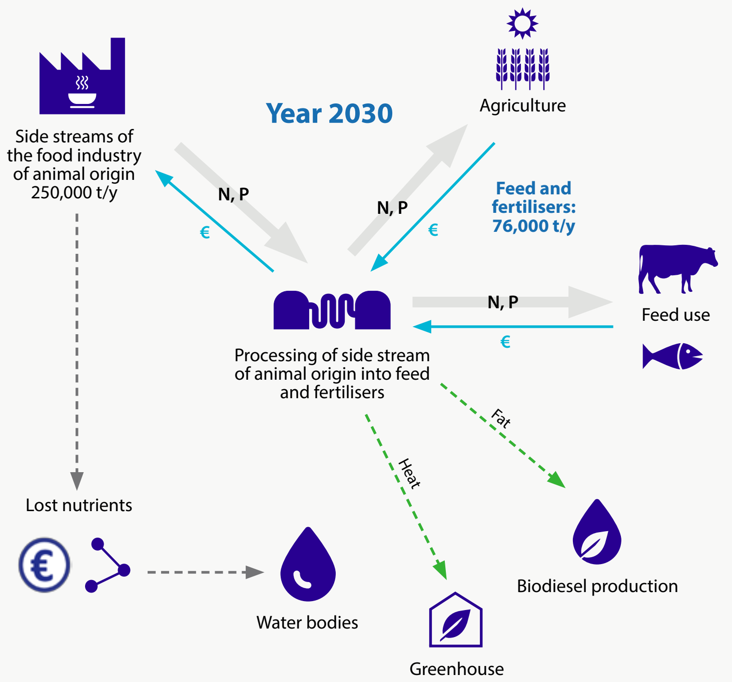
[51] This amount corresponds to 74 per cent of the amount of soybean imported to Finland as animal feed. FAOSTAT 2014.

[52] Honkajoki Oy.

Figure 12. Example of Honkajoki Oy's processing chain for food industry side streams.

Source: Honkajoki Oy, Gaia Consulting

Industrial symbioses would be promoted by an operating model in which meat production side streams are processed into feed.



Nutrients are recycled back into the nutrient chain

Approximately **250,000 tonnes** of animal by-products are generated in Finland **each year**. Some **30%** of these by-products could be processed into feed and fertilisers.

Food industry by-products of animal origin could be used to produce 76,000 tonnes of protein feed. This amount is equivalent to approximately 100,000 tonnes of imported soybean. Some 157,000 tonnes of soybean is imported to Finland as animal feed.

Feed production also generates by-products such as fat (a raw material for biodiesel) and condensing heat for the year-round heating needs of greenhouses in nearby areas.

Processed animal protein can currently be used only in fish, pet and fur animal feeds. EU by-product legislation prevents its use in the production of animal feeds, but an amendment to such legislation is already under way.

more directions than one: Honkajoki obtains its material from the food industry and, besides its primary operations, produces energy for other actors.

3.3.4 Insects as a replacement for imported protein

Insects are a globally significant source of nutrition with growing international markets. Although insects are an alien ingredient in the Finnish and European food culture, two billion people around the world use them as food. Insects are both collected from nature and grown for domestic consumption.

So far, however, the use of insects as human food is new to the EU. We have no legislation enabling the industrial breeding of insects, due to the control of hygiene risks and the status of insects in relation to legislation applied to production animals. Industrial processing technologies are developing globally, with questions remaining with respect to the selection of species, breeding models, input substrates used as food, and the productising of insect biomass.

Insects used as food have traditionally been bred using food-grade sources of nutrition, such as flour. In such a case, the environmental benefit gained primarily lies in higher production efficiency compared to other animal proteins. From the perspective of nutrient cycling, however, a more interesting alternative lies in the use of insects for the recycling of side streams, waste, sludge and manure as feed back into the food chain. This is a potential factor in food security and self-sufficiency, and the building of local nutrient cycles. Insect breeding can be considered a biotechnological process, competing with other, similar microbiological and chemical processes utilising waste materials and side streams.

The FAO is collecting data on the use of insects for animal feed[53]. Much research has been done on this area and the results indicate that insects are suitable as a source of protein for pig, chicken and fish feeds. Depending on the species, 30–70% of an insect's dry weight is protein.

[53] Edible insects – Future prospects for food and feed security, FAO, 2013

The fats and carbohydrates contained in insect food have health benefits, particularly for animals – such as poultry and fish – which naturally eat insects.

Furthermore, it has been observed that the fats and carbohydrates contained in insect-based food have health benefits for animals, such as poultry and fish, which naturally eat insects. For example, there have been indications of a reduced need for antibiotics. Insects could satisfy 20% of the world's demand for feed.

Under circumstances of limited sanitation, in particular, the use of insects in the processing of biodegradable masses, manure and sludges could be important in public health terms. The spread of pest insects could be prevented when beneficial species process the biomass into a form suitable for them and take living space from harmful species.

Example: AgriProtein Technology

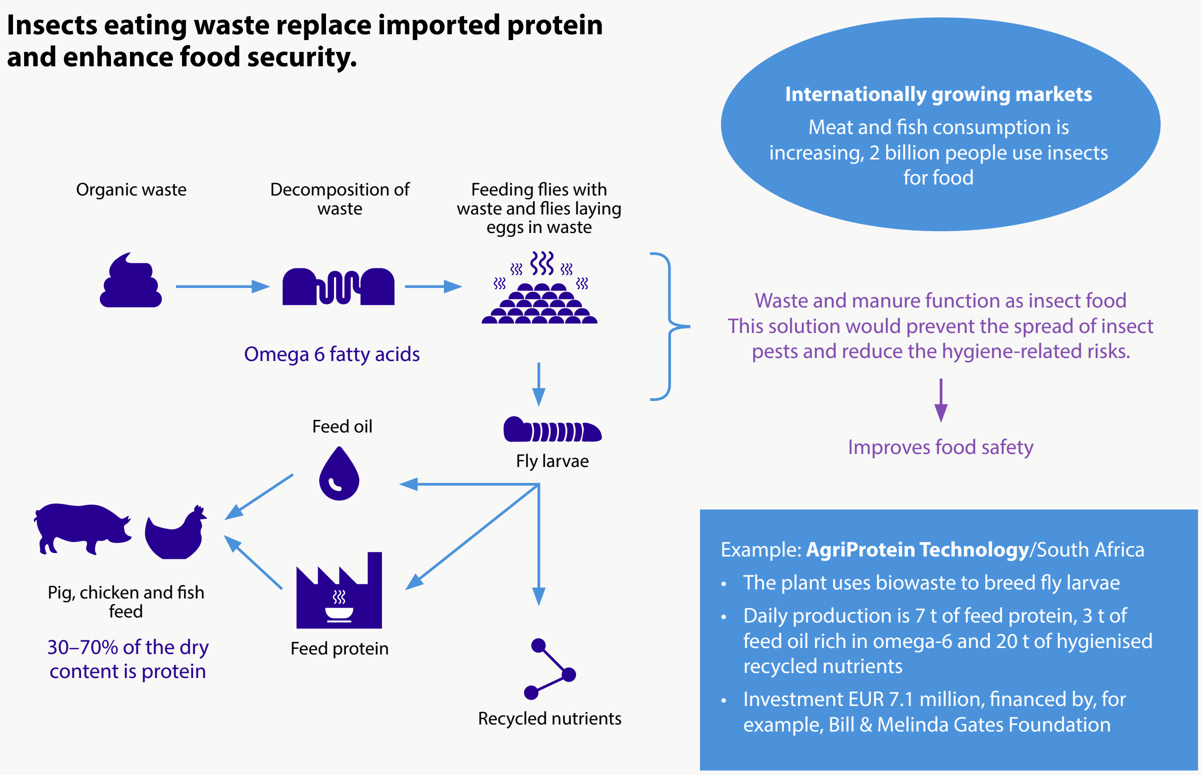
A plant opened in South Africa in 2015 breeds 22 tonnes of larval flies a day. Local biowaste, inedible foods and other biowaste in particular are used as input substrate in production.

The bred larvae are deep-frozen and transferred for production via a sanitation process. In a single day, the plant produces 7 tonnes of feed-grade protein and 3 tonnes of feed-grade oil high in omega-6 fatty acids. These side streams and the processed waste generate 20 tonnes of hygienised and productised recycled nutrients. In addition, whole dried larvae are sold to the pet food industry and as nutrient supplements for organic and small farmers.

EUR 7.2 million has been invested in the plant by donors such as the Bill & Melinda Gates Foundation. The company aims to establish more than 40 similar plants by 2030.

Figure 13. Insects as a replacement for imported protein.

Source: Gaia Consulting 2015



3.3.5 From potato side streams to a nutrient product

The potato starch manufacturing process generates side streams of potato juice, high in protein and nitrogen, which is currently discarded as a hard-to-process waste liquid. Protein-rich potato juice can be used as a nutrient as such.

High in protein, this liquid is of interest as a raw material for industrial processing. Advanced technologies enable the separation of valuable fractions from the liquid, leaving smaller amounts of weaker wastewater.

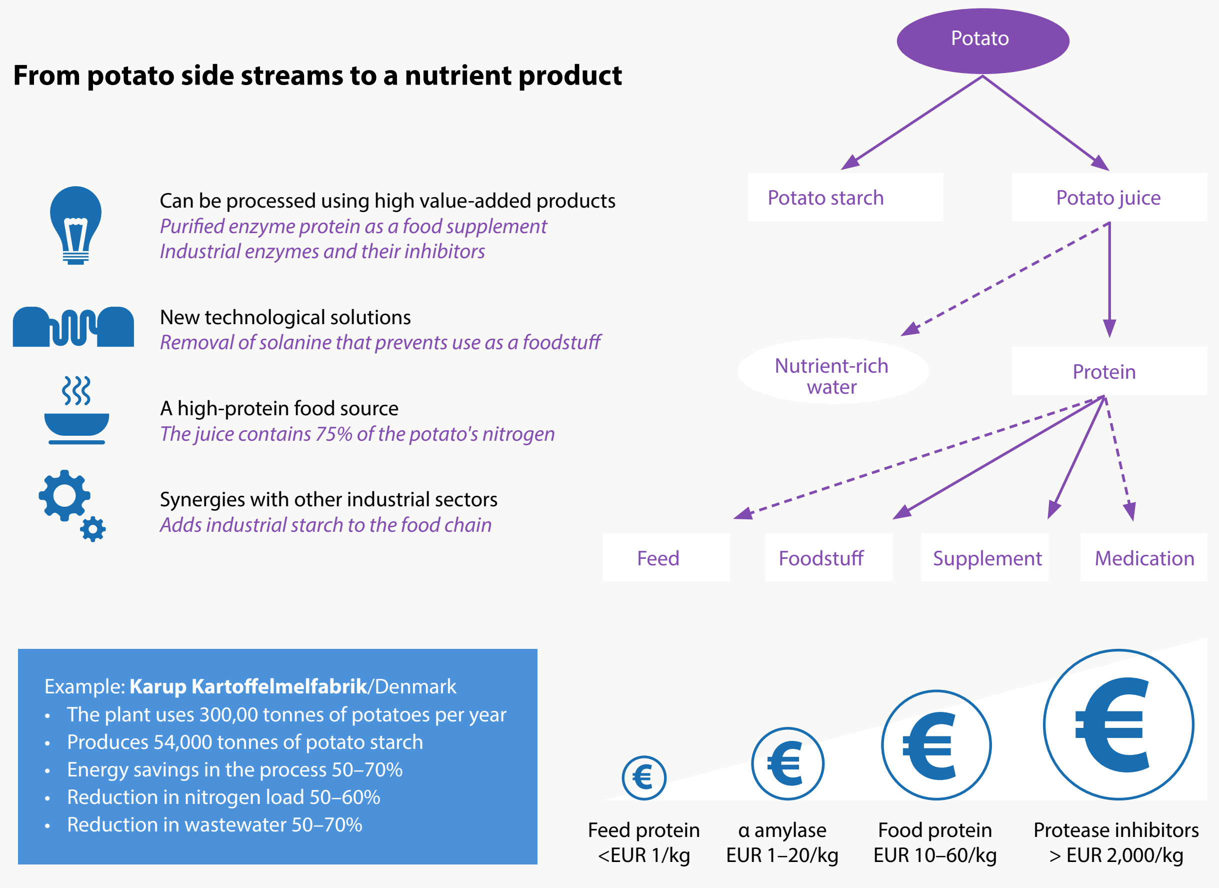
A solution enabling the protein to be purified into a food-grade product has been developed in Denmark. The Finnamyl plant in Finland is also in the process of applying the same technology. This solution would be used to recycle the side stream back into the food chain. Plant-based food protein is 10–60 times more expensive than feed protein.

However, the high added-value products generated through further purification and separation of the proteins constitute the most interesting opportunities for the use of potato juice. The price premium on proteins suitable as nutrient supplements is already high. Through further purification of potato juice, it would also be possible to separate industrial enzymes in large scale use by food and process chemistry companies which depend on biotechnological processes.

Very high-value protease inhibitors could also be separated from potato juice[54]. The uses of protease inhibitors, which are a type of protein, include nutritional applications, as they regulate the operation of digestive hormones and can be used for weight control and the treatment of obesity. They also disrupt the division of cancer cells and thus have potential applications in cancer therapy. MTT (the current Natural Resources Institute of Finland) has estimated that the price per kilogramme of the protease inhibitor separated from potatoes is around EUR 2,000.[55]

Figure 14. High value-added products from potato side streams.

Source: Gaia Consulting 2015



[54] Protease inhibitors are proteins found in potatoes, with potential uses in areas such as cancer therapy. Protease inhibitors disrupt the division of cancer cells, preventing the growth of cancer.

[55] MTT. Perunan ja vihannesten arvokomponenttien hyötykäyttö (in Finnish with English abstract, Utilization of by-products from potatoes and vegetables in value-added products), 2012.

Protease inhibitors derived from potato juice disrupt the division of cancer cells

Example: Karup Kartoffelmelfabrik

As the country's largest manufacturer of potato flour, a plant located in Denmark uses 300,000 tonnes of potatoes and produces 54,000 tonnes of potato starch.

The company has been performing large-scale research and development on the purification and further processing of protein-rich potato juice side streams, based on EU Life funding. It has been studying the liquid as a valuable raw material which could even be turned into food-grade protein via an industrial process. This requires a technological solution used for extracting solanine, which is harmful to humans. The new, efficient process also reduces the oxidation of valuable compounds associated with potato processing, thus improving product quality.

This also has substantial environmental benefits. As a result of the redesign of the process, energy savings in comparison to the primary production of a similar protein amount to 50–70%. Wastewater is reduced by 50% and the nitrogen load falls by 50–60%.

The plant currently has a functional process for manufacturing food-grade protein; markets for higher added-value products are being explored. Alfa Laval Nordic and Carlisle Process Systems A/S are the partners in the development of the process.

3.4 The role of households in promoting nutrient cycling

According to a study conducted by MTT Agrifood Research Finland, households generate 120–160 million kilogrammes of avoidable food waste every year. Using a food category division of food waste, it can be estimated that 0.8–1 million kilogrammes of nitrogen and 0.09–0.11 million kilogrammes of phosphorus are lost each year in discarded food.[56] Households could significantly reduce nutrient loss and promote the recycling of nutrients by changing their dietary habits and reducing food waste, for example.

Dry toilet concepts that prevent nutrient loss from point sources in Finland constitute an export opportunity for the nation. Insufficient sanitation and separation of fertiliser for use in western countries [57]are global problems that could be addressed with dry toilet solutions.

3.4.1 Dietary habits

Dietary habits and the customary use of food play a key role in efficient nutrient cycling in households. Dietary habits affect the quantities of meat products, fish and vegetables that people choose for the kitchen table. From the viewpoint of nutrient cycling, the most favourable situation would be to choose foods whose production is based on low nutrient intensity, makes efficient use of recycled fertilisers, or promotes nutrient cycling.

Finnish nutrition recommendations, published by the National Nutrition Council in 2014 on the basis of Nordic recommendations, advise Finns to increase their consumption of vegetables, particularly root vegetables, and legumes. An increase in the share of fish, nuts, seeds, berries and fruit in the diet is also recommended. Finns are also advised to reduce their consumption of meat products and red meat. The purpose of the plate model is to support a varied and healthy diet in every meal, where half of the plate constitutes vegetables, a quarter consists of potato, pasta or rice and the other quarter of meat or fish.

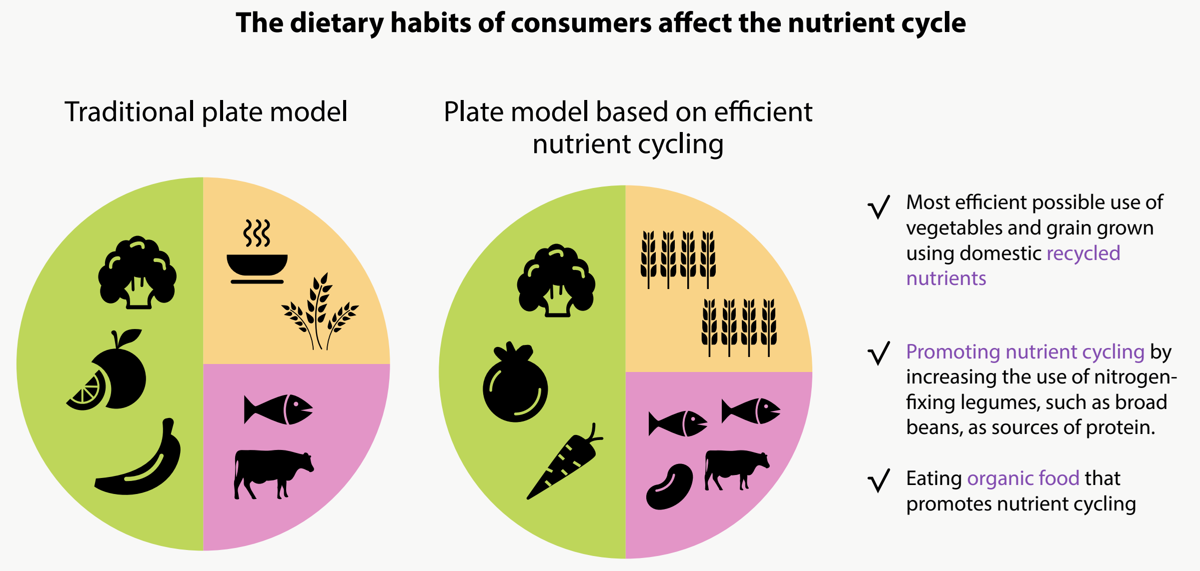
To promote nutrient cycling, the current diet should be replaced with a vegetarian one[58]. Preference should be given to vegetables grown through the efficient recycling of nutrients.

In organic farming, the starting points for fertilisation are improving the organic content of soil and the use of nitrogen-fixing plants, both of which promote nutrient cycles[59]. Improving the organic matter content of soil helps plants to absorb nutrients more effectively, while through crop rotation it is possible to recycle nutrients back into the soil via nitrogen-fixing legumes and clover grass. No artificial fertilisers are used in organic farming, but manure and, under certain conditions, nutrients derived from the biogas process, for example, could be used instead[60]. However, organic farming has also been criticised for causing greater nutrient losses than traditional fertilisation, because the ratio of directly applied nitrogen and phosphorus is sub-optimal and can lead to nitrogen insufficiency or over-fertilisation with phosphorus.[61] Depending on the type of production, the yield in organic farming can be lower per field area than in production with artificial fertilisers. Although demand for organic products is increasing and remains low in Finland compared to countries such as Denmark or Germany, higher margins could be gained from organic products. This study does not take a stand

[56] The food category division of household food waste was used to estimate the amount of nitrogen and phosphorus in households' food waste.
[57] Global partnership on Nutrient Management and International Nitrogen Initiative 2013. Our nutrient world.
[58] Kahiluoto, Kuisma, Kuokkanen, Mikkilä, Linnanen, 2014. Taking planetary nutrient boundaries seriously: Can we feed the people?
[59] Rajala (2012). Ravinnehuollonperusteet luomussa (in Finnish, The basics of nutrient management in organic farming).
[60] Evira, Luomu 2015
[61] Central Union of Agricultural Producers and Forest Owners (MTK): Lannan käytön tehostaminen (in Finnish, Making the use of manure more efficient)

Figure 15. The differences between the traditional plate model and that based on an efficient nutrient cycle.

Source: Gaia Consulting 2015



on the environmental sustainability of organic products in general, but regards organic farming as an opportunity for adopting recycled nutrients.

As in studies on organic farming, comparisons of various meat production methods leave questions of environmental loading open to interpretation, with the results varying from study to study. In Finland, the eutrophying emissions of one serving of rainbow trout have been estimated to be more than double those of a serving of beef or pork[62]. However, studies performed elsewhere suggest that eutrophying emissions from the beef and pork production chains are over seven times higher than for those of rainbow trout. This discrepancy is probably due to the use of nutrients from livestock manure in farming, whereas this is not possible in fish farming. However, the eutrophication impact of fish farming can be reduced by up to 70% through reduction fishery. Climate emissions from fish are also much lower than those of beef, for example.

Factors such as the selection of raw materials for feed, the efficiency of feed use, recycling of manure, recycling of the nutrients from production side streams, reduction of food waste, and the recycling of nutrients back into the soil constitute the nutrient footprint of a meat or fish serving. The sustainability of both chains could be significantly improved. However, in terms of nutrient loading, the most efficient approach is the direct use of plant proteins in foodstuffs.

3.4.2 Reducing food waste

MTT's Foodspill 2010–2012 project revealed that the key reasons for food waste in households were food spoilage (29%) and uncertainty as to whether the food was still usable (28 %). Other reasons cited were the preparation of excessive amounts of food, plate leftovers, and unwillingness to eat food. Edible food is discarded in such cases, which could be avoided through better knowledge of foodstuffs and consumption planning. Using your senses to identify spoiled food is an old but partly forgotten skill that should be taught to households.

Household food waste could be reduced by a range of practical means. Edible food waste in primary production could be reduced by buying malformed vegetables, for example. In home kitchens, food waste could be reduced by buying and using high-quality ingredients and storing food properly (in the correct temperature, humidity and light conditions). People should avoid buying too much food at once and favour package sizes containing amounts of food that they can eat before it spoils. The ingredient

[62] Kirjolohenkasvatuksen ympäristövaikutukset Suomessa (in Finnish with English abstract, The environmental impacts of rainbow trout produced in Finland). Frans Silvenius, Juha Grönroos, Hanna Hartikainen, Helena Hyvärinen, Markus Kankainen, Salla Kaustell, Sirpa Kurppa, Timo Mäkinen, Jari Setälä, Kirsi Silvennoinen, Raija Tahvonen and Jouni Vielma. MTT Report 48 (2012).

Figure 16. Reducing the amount of food waste reduces nutrient loss and enhances nutrient cycling.[63]

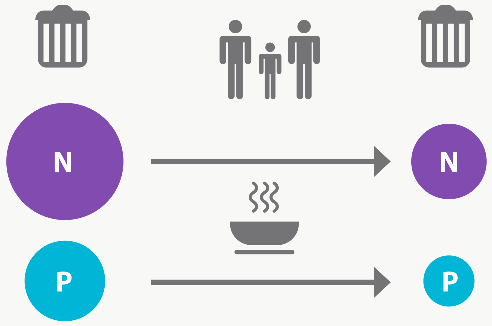
Source: MTT and Gaia Consulting 2015

Reducing food waste reduces nutrient loss and enhances nutrient cycling

Avoidable food waste in households amounts to **an average of 120–160 million kilogrammes** per year. The value of discarded food is approximately EUR 400 million.

In the case of food waste **0.8–1.1 million kilogrammes of nitrogen** and **0.09–0.11 million kilogrammes of phosphorus are lost** per year. The value of lost nutrients is around EUR 1.2 million.

The key reasons for food waste in households are uncertainty about whether the food has spoiled and leaving prepared food uneaten.



Measures required for promoting nutrient cycling:

- Increasing information on foodstuffs
    - food preservability
    - identifying signs of spoilage
- Better planning of consumption
- Proper storage of food
- Preparing and eating smaller portions, so that less food waste is generated, thereby reducing nutrient loss.

Key starting points and assumptions:
Price of phosphorus EUR 1.8/kg
Price of nitrogen EUR 1.1/kg

hierarchy used in institutional catering could be applied to home use: the ingredients bought first should be used first, thereby reducing the spoiling of unused ingredients.

When preparing food, waste could be reduced by the more careful use of ingredients (e.g. jacket potatoes vs. peeled, boiled potatoes) and by planning food for each day according to which ingredients should be used first. Only the amount of food people can actually eat should be produced, with leftover food being frozen immediately if it cannot be used the next day or as an ingredient in the next meal. Waste from food consumption could be reduced by serving tasty, high-quality food in properly sized portions, so that every diner plates his or her own meal. The size of dinner plates also has an impact on the amount of waste: if the plate is too big, people tend to take more food than they can eat.

3.4.3 Dry toilet concepts

Several regions in the world suffer from chronic nutrient shortages[57]. Various outhouse and dry toilet concepts are being used to reduce nutrient loss from point sources and to recycle valuable nutrients. Dry toilets also enable the processing of nutrients when urine is separated from faeces. The produce from dry toilets (urine and faeces separated or together) can be used as fertiliser. Dry toilet concepts are an export opportunity for Finland in particular.

People produce approximately 500 litres of urine and 50 litres of faeces each year, containing some 4 kg of nitrogen and 0.5 kg of phosphorus. If we round the world population to seven billion, the amounts of nitrogen and phosphorus lost in human urine and faeces total around 28 million tonnes of nitrogen and 3.5 million tonnes of phosphorus. Approximately 70% of these nutrients are contained in urine and nutrient cycling can be made more efficient by separating this from faeces. Taking account of country-specific prices of fertilisers, the price of nitrogen and phosphorus is around the same as that of the same nutrients in synthetic fertilisers.

In 2010, the WHO estimated that it would cost around EUR 300 billion to make functional sanitation universally available between 2010 and 2015, in which case the annual investment in sanitation would amount to some EUR 60 billion. Functional sanitation saves time, improves productivity and promotes health care. [64]

[63] MTT Report 41: Final report of the Foodspill 2010-2012 project (in Finnish with English abstract)
[64] WHO: Global costs and benefits of drinking-water supply and sanitation interventions to reach the MDG target and universal coverage. 2012

Figure 17. Increasing exports with dry toilet concepts by 2030.[66]

Source: Gaia Consulting, WHO, Global Dry Toilet Association of Finland

Increasing exports with dry toilet concepts

Due to inefficient sanitation **28 million tonnes of nitrogen** and **3.5 million tonnes of phosphorus** are lost every year.

Based on dry toilet concepts, the value of nutrients that can be recycled amounts to EUR 37 billion.

The greatest export potential for Finland lies in **developing countries and the crisis business**.

In areas affected by conflicts and natural catastrophes, dry toilet concepts are inexpensive and their technical simplicity and hygiene are far superior to those of water-based sewers.

→ The costs of insufficient sanitation amount to EUR 235 billion per year globally

Key starting points and assumptions:
Price of phosphorus EUR 1.8/kg
Price of nitrogen EUR 1.1/kg

Dry toilet concept

- The purpose of the outhouse and dry toilet concept is to reduce nutrient loss from point sources and to recycle nutrients.
- The concept involves the separate collection of urine and the creation of dry toilet compost.
- Produce from dry toilets (urine and faeces separated or together) can be used as fertiliser.

The Biourea project involves testing the use of separately collected urine and composted faeces as fertiliser for Finnish crop plants. The productisation of separately collected urine and composted faeces into fertiliser products. Such productising requires changes in the current legislation. Key objects of study with a view to legislation are the nutrient contents and health risks of urine and composted faeces.

Example: Biourea – innovative fertiliser product based on the realisation of a closed nutrient cycle

The recovery of urine and composted faeces boosts nutrient cycling and significantly reduces the eutrophication of water bodies. The Biourea project involves testing the use of separately collected urine and composted faeces as fertiliser on Finnish crop plant farms. The objectives of the project are a model and practical trials of technical implementation methods for the extensive recovery, processing and utilisation of separately collected urine and composted faeces, and promoting the productisation of such production.

Urine collected from the waterless urinals on petrol stations has not so far been utilised on a large scale.

In the future, large-scale collection of urine and composted faeces could be implemented within centralised sewer networks, by using separating toilets and urinals. Waterless urinals are already becoming more common in locations such as restaurants and petrol stations, but the urine collected from these has not been used on a large scale. Productising urine and composted faeces into fertiliser requires changes in the existing legislation. The purpose of the Biourea project is to generate information in support of this goal. Key objects of study with respect to legislation are the nutrient content and health risks of urine and composted faeces.[65]

The value of dry toilet concepts for Finland.

In Finland, composting toilets have been on the market since the 1980s, but we have only developed an understanding of the nutrient cycling opportunities associated with toilet concepts in recent years. However, the products derived from composting toilets, such as separated urine and faeces, are used as fertiliser on a very limited scale compared to the composting and utilisation of biowaste from households.

[65] Global Dry Toilet Association of Finland: BIOUREA – Innovatiivinen lannoitevalmiste suljetun ravinnekierron toteuttamisessa 2015-2016 (in Finnish, BIOUREA – innovative fertiliser product in the implementation of a closed nutrient cycle)
[66] Image: Worldbank.org 2015, Water and Sanitation Program.

Current exports of the dry toilet concept, amounting to approximately EUR 2.5 million, largely consist of exports by Biolan and Kekkilä to the Nordic Countries, the Baltic Countries and Russia. In export products, functionality and ease of use remain the main sales arguments for the time being – sellers do not yet know how to exploit opportunities for nutrient cycling. Finnish companies engage in R&D by developing local toilet concepts for developing countries both independently and alongside UNICEF as part of the UNIWASH project, for example.

One billion people in the world suffer from lack of clean water and 2.5 billion people lack access to sanitation. In the future, Finland could find that the greatest export potential for dry toilets lies in countries with low sanitation rates and low farming productivity due to scarce or expensive nutrients. The Finnish Biolan already exports dry toilets. Opportunities for home composting and nutrient production are used as key marketing arguments in China, for example.

Account should also be taken of humanitarian needs for the rebuilding of destroyed infrastructure due to conflicts and natural catastrophes. The size of such markets is substantial. Finnish dry toilet know-how could be applied to crisis-based business activities[67], where the affordability, technical simplicity and hygiene of dry toilet concepts can be decisive factors. Water-based sanitation systems are often too expensive in crisis situations and building a functional sewer system is technically challenging. Instead of rebuilding the old waste, sewerage and toilet infrastructure, people could opt for building permanently decentralised solutions that promote nutrient cycling.

3.5 The recovery and recycling of nutrients

3.5.1 Infrastructure that utilises stormwater

Increasing amounts of stormwater are burdening wastewater treatment plants and affecting their operation. Exceptional situations, such as sewer flooding or overflows from treatment plants due to stormwater, are also adding to the environmental nutrient load.

Stormwater can be managed by separating stormwater and waste water into separate sewers, building stormwater detention tanks and creating decentralised infiltration areas. Stormwater management solutions are an essential part of wastewater treatment systems.

Agile, local solutions for treating and using the scarce nutrients in stormwater close to where they are generated offer a cost-efficient way of treating stormwater and reducing the nutrient loading risk from point sources. In the case of decentralised infiltration areas, the scarce nutrients contained in stormwater could be used in landscaping, or recovered from vegetation through processes such as biogasification.

Stormwater solutions include stormwater ponds and wetlands into which stormwater is guided either as surface runoff or through infiltration and filter structures. An infiltration pit or trench is a fairly large pit or trench filled with material of high soil pore volume (such as rock material); this stores stormwater guided into it, which gradually drains into the surrounding soil. An infiltration drain field, on the other hand, is a larger area built for infiltration purposes. A bioretention area is a small-scale depression in the ground – these are covered by vegetation in order to retain and clean stormwater and filtrate it through soil layers. Bioretention areas are suitable for residential yards, parks, parking areas and traffic areas.[68]

Green roofs are built areas of low-lying vegetation that filtrate and evaporate water and reduce the quantity of water drained through gutters by 50–100%[69,70,71]. In addition, green roofs reduce the need for heating and cooling, control noise and improve the microclimate. Due to their higher cost, green roofs are best suited for densely built urban areas.

Investments in landscaping also bring other benefits. An increase in the number of green areas makes living environments more pleasant and raises property values. It has been estimated that landscaping reduces the number of untimely deaths and asthma attacks due to air pollution and excessive heat.[72]

Example: Germany

Changes were made to German national legislation in 2010 to prohibit German states, municipalities and cities from combining stormwater with waste water. As a rule, properties are obliged to retain, filtrate or recycle stormwater. Because sewage fees are separately collected for stormwater directed into sewers, properties can save money by adopting property-specific stormwater treatment solutions. The fee depends on the amount of roof area and impervious yard surface area of each property.[73]

In Germany, property-specific stormwater systems can be used to collect water and, after filtration, to use it for watering gardens, flushing toilets, laundering, washing-up and washing cars. This is beneficial because rainwater in Germany is much softer than tap water and therefore better suited for the aforementioned purposes. Companies

[67] Gaia: Preliminary assessment of the market potential of the metal and marine industry in the disaster response and recovery market. 2012

[68] Association of Finnish Local and Regional Authorities , 2012. Hulevesiopas (in Finnish, Stormwater guidebook)

[69] Berndtsson 2010. Green roof performance towards management of runoff water quantity and quality.

[70] Carter 2006. Hydrologic behaviour of vegetated roofs.

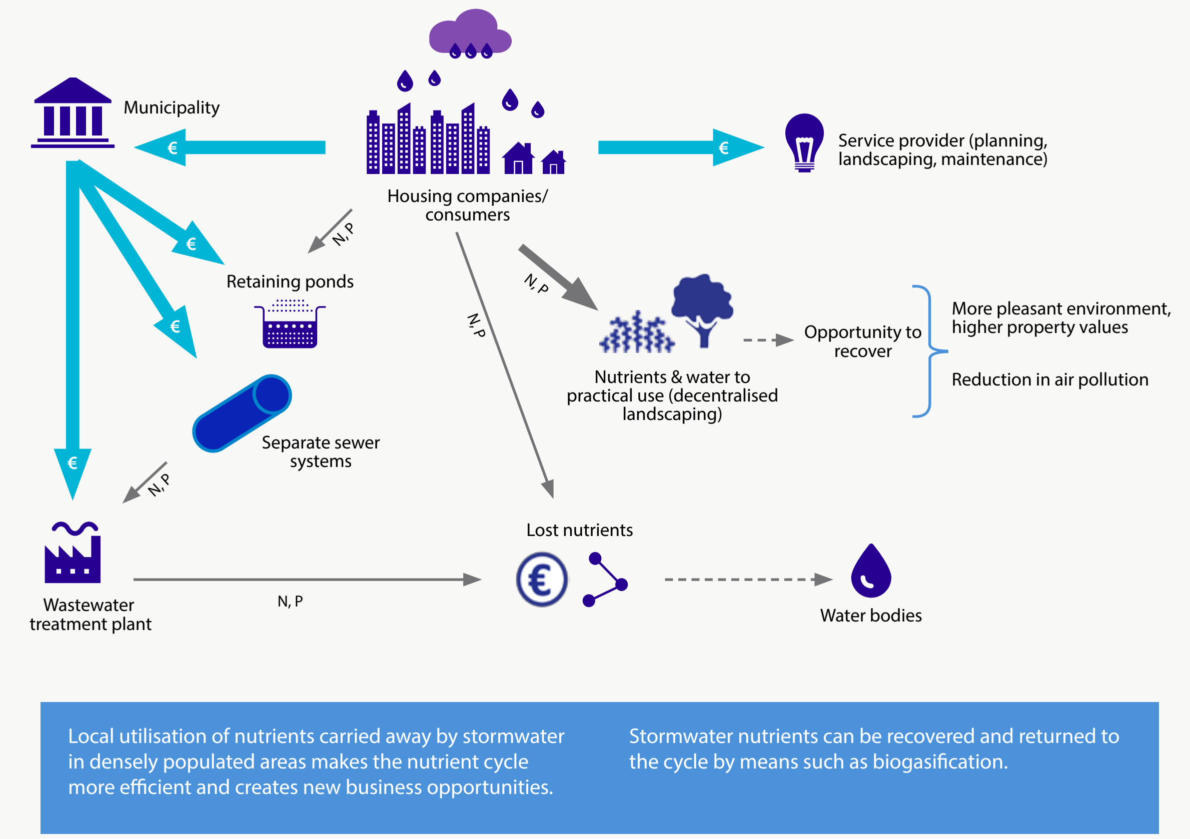
[71] Villarreal 2005. Response of a Sedum green-roof to individual rail events.

[72] NRDC: Financing Stormwater retrofits in Philadelphia and Beyond (2012)

[73] Neue Pflichten für Grundstücksbesitzer: Regenwasser-Rückhaltung und –Versickerung http://www.baulinks.de/webplugin/2011/1210.php4

Figure 18. Infrastructure that utilises stormwater in 2030.

Source: Gaia Consulting, Association of Finnish Local and Regional Authorities, NRDC.



that use large amounts of water for washing purposes or water-based cooling can also cut costs by using stormwater systems. On its website, Speidel, which provides property-specific stormwater systems, states that households can cut their daily water consumption by up to 50% by using its systems. The saving per household is approximately 90,000 litres and EUR 200–400 a year. In Germany, stormwater collection systems helped households to save around 100 million cubic litres of water and some EUR 447 million in 2011.[74]

However, Germany also has combined sewerage systems which cause runoff when they flood. A good example of this is Berlin, whose densely built central area has a combined sewerage system. A large construction project to modernise Berlin's sewerage system is under way. By 2020, the retention capacity of the sewerage system will have been increased by 300,000 cubic metres. Bottlenecks will be installed to slow down the flow of water, evening out the amount of water entering wastewater treatment plants during downpours. The project is expensive: the 17-metre bottlenecks cost one million euros each. One bottleneck can manage 900,000 cubic litres of water.[75]

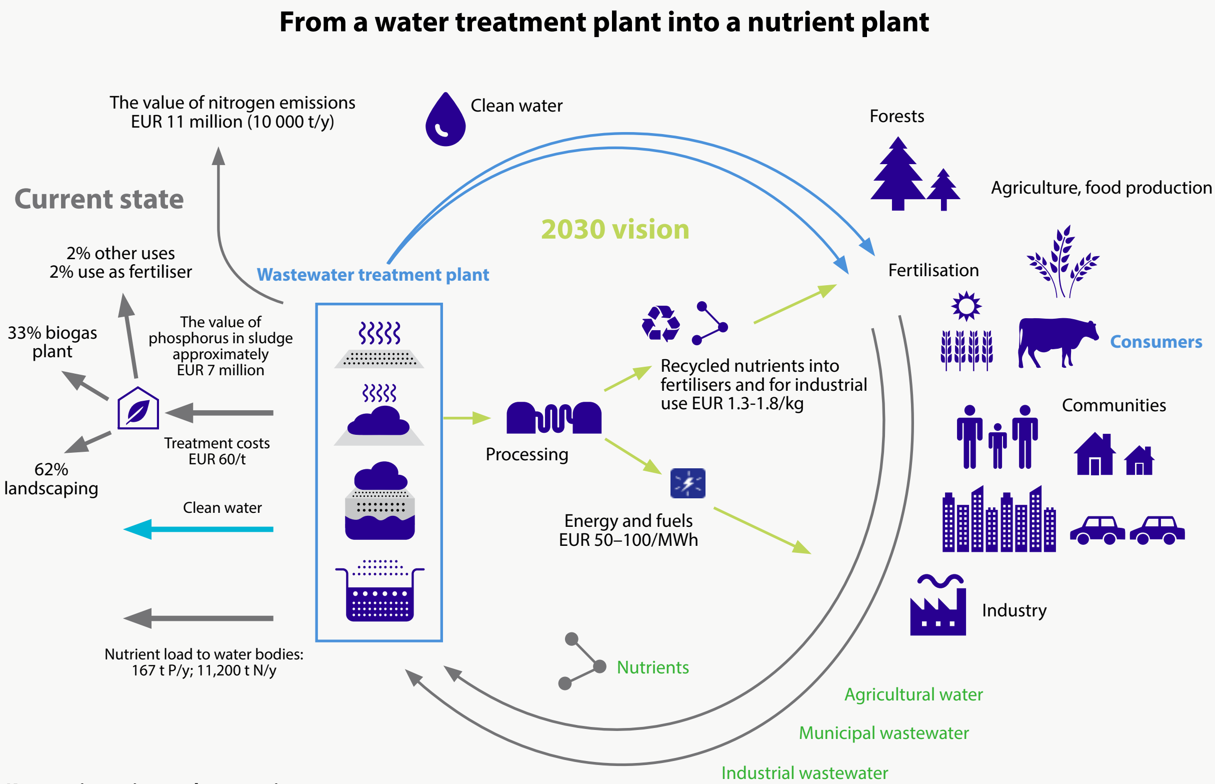
The economic value of the use of stormwater in Finland

Using filtration systems to make use of stormwater in densely populated areas could create an entirely new sector in Finland. Most of this business value would be based on labour force used in planning, maintenance and construction. On the other hand, this could also have an employment reduction effect as extremely heavy infrastructure solutions are replaced by lighter technologies. Housing companies would benefit, provided that stormwater payments were adopted on a large scale. The key impact of new business generation would be a lighter public sector balance sheet. The construction of some heavy

[74] Speidel website, accessed in May 2015, http://www.speidel-regenwasser.de/
[75] Der Tagesspiegel 17.12.2014. Wasserbetriebe: Stau unter der Warschauer Straße http://www.tagesspiegel.de/berlin/damit-das-abwasser-nicht-in-spree-und-havel-fliesst-wasserbetriebe-stau-unter-der-warschauer-strasse/11129600.html

Figure 19. Water treatment plant as a nutrient plant in 2030.

Source: Gaia Consulting, VVY



Key starting points and assumptions:
Price of phosphorus EUR 1.8/kg, nitrogen EUR 1.1/kg.
Biogas price in heating use EUR 50/MWh, as transport fuel EUR 100/MWh.

sewerage infrastructures could be avoided altogether, tying up less capital in infrastructure. Potential for additional economic value lies in the possibility of exporting know-how and technologies in the future.

3.5.2 From a wastewater treatment plant to a nutrient plant

A central wastewater treatment plant is an example of a centralised system which uses transfer pipelines to collect wastewater nutrients into a single place from dozens of square kilometres. The infrastructure required for these is expensive, but economies of scale can enable investments in efficient water treatment technology. With a view to nutrient cycling, the key issue is how the nutrients recovered by the plant are recycled into use.

Finland produces around 140,000 tonnes of treatment plant sludge from municipal wastewater each year.[76] Some 62% of this is used for the landscaping and reforming of landfill sites, 33% at biogas production plants, and around 2% is used for agricultural soil amendment. The remaining 2% is used in other ways or placed in landfills for final disposal.[77]

In other words, sludge from wastewater treatment is mainly used without processing into actual recycled nutrient products. Furthermore, existing wastewater treatment plants do not recover nitrogen, which evaporates into the air during the denitrification process. Around 10,000 tonnes of nitrogen is lost in this way each year. In addition, the microplastics (fine plastic particles) and potential harmful substances contained in sludges set limitations on their practical use. Nutrient cycling could be further improved by enhancing the recovery of nutrients (incl. nitrogen), and by productising and processing sludges.

In the future, new wastewater treatment systems that support nutrient cycling could be a combination of processes such as the minimisation of stormwater and

[76] Finnish Environment Institute, Monitoring of the National Waste Plan.
[77] ELSU, Waste plans for Southern and Western Finland – progress towards targets.

decentralised treatment at source, dry toilets and composting equipment in suburban areas, and central treatment plants functioning as producers of nutrient products, effectively exploiting both the phosphorus and nitrogen contained in wastewater. Totally new business activities could be created by shifting the business logic of wastewater treatment plants from water purification to nutrient production.

Recovery of phosphorus from wastewater has been studied and various technological solutions have been developed for this purpose. In a technology review by the Fraunhofer Institute, the costs of phosphorus recovery technologies ranged from EUR 2 to 14 per recovered kilogramme. Differences in technologies and the treatment capacity of wastewater treatment plants affect costs. According to the Fraunhofer Institute, the most promising phosphorus recovery technologies in economic terms involve its recovery from the wastewater sludge using the enhanced biological phosphorus recovery method (EBPR) and recovery from the ashes of incinerated wastewater sludge.

However, so far no recovery technology has achieved the price level of phosphate fertilisers made of virgin raw materials (approximately EUR 1.8/kg). On the other hand, the continuous rise forecast in the price of virgin phosphorus and the expected fall in the marginal costs of phosphorus recovery technologies will promote the commercial breakthrough of such technologies. The Fraunhofer Institute estimates that phosphorus recovery from wastewater will become an established part of wastewater treatment by 2030 in industrial countries. Germany has estimated that, by 2030, it will benefit by EUR 64 million from business activities associated with recovery technologies.[78]

Kemira has developed a chemical sludge conditioning process, KemiCond. One KemiCond plant is capable of treating some 12,000 tonnes sludge dry solids per year, but plants can also be designed for larger volumes than this. The cost of the chemicals required for such treatment is around EUR 35–80/t of treated sludge dry solids.[79]

In Finland, the KemiCond method is being used in two locations, in Oulu and Pori. In Oulu, the KemiCond method is used for treating sewage sludge from the Oulu Waterworks and treated sludge is forwarded for further processing by composting. The Finnish Food Safety Authority Evira has approved KemiCond sludge as a soil amendment complying with Finnish fertiliser legislation, which means that the sludge can be used on fields as such.[80] In Pori, the KemiCond method is used in the hygienisation of unpurified dewatered sludge, after which Kemira ships the treated final product for recycling.[81] In both Finnish examples, Kemira handles the further processing of the treatment plant sludge and its delivery for recycling under a service agreement.

The Finnish technology supplier, Outotec, also has existing technology for the treatment of wastewater sludge. In the ASH DEC process, ashes from the incineration of wastewater sludge are pelleted, after which they undergo a thermal decontamination process. Other nutrients and, if necessary, additional phosphorus can be added to the nutrient product prior to final processing into a fertiliser. This technology is profitable only at high input rates and is therefore mainly intended for export markets.[82]

The situation is more challenging in the case of nitrogen, since no technically and economically feasible recovery solutions have become available so far. VTT is studying a novel method of treating organic waste flows based on which nutrients can be recycled. In this process, filtration would be effected using novel soil-repellent membranes, after which nitrogen, phosphorus and carbon could be separated as pure products with resale value. VTT believes that a wastewater recovery plant in a municipality of 2,000 inhabitants could produce 50 t of ammonium nitrate per year, with an annual value of EUR 15,000. While it may be technically possible to build such a recovery plant, this would not yet be cost-efficient.[83]

Envor has developed nitrogen recovery from the reject water of biogas production plants. Based on this technology, nitrogen contained in reject water is separated by

When waste becomes a competed raw material, the revenue generation model for the biogas sector will change. Revenue will consist of own products and energy and service concepts that enhance the sustainability of symbiosis partners.

[78] Sartorius, Christian et al., 2011. Phosphorus recovery from Wastewater – State of art and Future Potential.
[79] The Kemicond – Kemira sludge conditioning technology for reduction of sludge volume, brochure.
[80] Oulu Waterworks customer bulletin, 2011.
[81] Pori Waterworks, annual review 2011.
[82] Outotec Oy
[83] VTT: Resource recovery demonstration for organic streams, 2014.

gasification and refining the resulting nitrogen gas into liquid ammonium sulphate. Envor claims that it has solved an earlier processing challenge caused by the blockage of the degassing column's inlet filters. Envor will pilot the technology in its own production processes in autumn 2015.[84]

It will be years before technically and economically viable comprehensive solutions revolutionising water treatment and enabling efficient nutrient recovery and the manufacture of nutrient products in wastewater become available. Lappeenranta University of Technology estimates that no nitrogen recovery solutions will be in use before 2035.[85]

3.5.3 Biogasification as a driver of nutrient cycling

Anaerobic fermentation of biodegradable waste enables nutrient recovery in addition to the exploitation of biogas. Rather than biogas plants, we might refer to these as biorefineries that promote nutrient cycling. Finland has strong know-how and several companies in biogas production. Each year, the Finnish Biogas Association publishes information on biogas production plants operating in Finland and their gas production, but no data has been collected on nutrient cycling.

A fundamental issue with regard to the circular economy is that biogas production plants tend to exploit waste and side streams i.e. they do not compete for virgin raw materials with products higher up the value chain. Biogas production improves the sustainability of operators involved in the same type of industrial symbiosis; partners can include actors from the sewerage, waste management, energy supply, primary production, fish processing, food, feed, forestry and chemical sectors.

For the time being, some revenue from biogas production is based on waste mass intake. This puts a price on waste that has environmental impacts and creates incentives for its reduction. When competition develops for waste as a raw material, the biogas sector's revenue generation model will shift from its own products and energy to service concepts that enhance the sustainability of symbiosis partners. For example, Gasum offers Biogas Certificates to partners that use biogas. The customer can use these in the marketing of its own products and services and marketing communications. The benefits reaped by the customer's clients could also lie at the core of service provision by future nutrient recyclers.

Biogas plants can specialise by accepting only certain input substrates. In Finland, biogas operators specialising in wet processes include Biovakka, Envor Biotech, Sybimar and Biotehdas. Dry fermentation is an alternative process based on which biogas plants use dry manure and underutilised field biomass. Dry fermentation methods have been developed by companies such as Metener and BioGTS.

The properties of the input substrates used for biogasification vary according to the technology and process selected. In Finland, potential input substrates for biogasification include manure and field biomass from agriculture, municipal treatment plant sludges, biowaste, garden waste, industrial waste sludges, and biowaste from the food industry. A total of 833,257 tonnes of techno-economically usable cow manure is produced[86] per year. It has been estimated that Finland generates around 2,148,816 tonnes of field biomass suitable for biogasification each year.[90] In 2010, some 140,000 tonnes of wastewater sludges were produced.[87] Production of municipal biowaste and garden waste, on the other hand, amounted to 283,245 tonnes in 2012.[88] In 2007, the Finnish pulp and paper industry produced 504,000 tonnes of waste liquors that are techno-economically suitable for biogas production. The food industry produced 59,353 tonnes of waste usable using biogas production plants.[89],[90]

The economic value of biogas plants for Finland

The review took account of large fermentation plants capable of using varying biomasses as input substrate. It focused on the fermentation of rapidly degrading biomasses (biowaste, sludge and field biomass). The moisture content of the raw materials used for fermentation tends to be very high. This increases transport costs and restricts fermentation to local biogas plants in general.

For the purposes of the review, it was assumed that, by 2030, biogas plants would use all techno-economically available sludges from municipal wastewater treatment plants [91], biowaste and garden waste. In addition, the utilisation rate of industrial waste liquors and biowaste from the food industry would reach 50 per cent of its full technical and economic potential[89]. The use of manure and field biomass as a raw material would increase to 10 per cent[91] from the current one per cent. In such a case, 13 million tonnes of raw materials would be usable in biogas plants, 160 of which would be required for their treatment. Investments in biogas plants would amount to two billion euros by 2030[92]. These are only rough and indicative estimates and the investment costs have been scaled on the basis of a single sample plant. In reality, a range of biogas plants would

[84] Envorilta ratkaisu typen talteenottoon jätevedestä (in Finnish only, Solution for nitrogen recovery from Envor), 2015

[85] SITRA, Suomelle talouskasvua ravinteiden kierrätyksestä (in Finnish only, Economic growth for Finland from nutrient cycling)

[86] Amounts in dry weight.

[87] Finnish Environment Institute, Monitoring of the National Waste Plan, 2nd interim report, appendix: indicators

[88] Finnish Environment Institute, Foresight on amount of waste by 2030 (unpublished).

[89] In the quantities, account was taken of the fact that more than half of municipal waste is used as animal feed or processed into other products.

[90] Tähti and Rintala, 2010. Biometaanin ja –vedyn tuotantopotentiaali Suomessa (in Finnish, Production potential of biomethane and bionitrogen in Finland).

[91] Based on the goals set for Finland by Sitra, BSAG and LUT (SITRA: Suomelle talouskasvua ravinteiden kierrätyksestä; in Finnish, Economic growth for Finland from nutrient cycling)

[92] Based on raw material amounts. (Gaia estimated in the Sitra report "Energiasektorin Cleantech-teknologioiden vaikutukset ja mahdollisuudet, 2015" [in Finnish, "The impact and opportunities of cleantech technologies in the energy sector"]) the basic potential for biogas plants to be EUR 1,500 million by 2030 and, the optimistic scenario EUR 2,400 million by 2030.)

emerge whose input substrates and costs would differ from those assumed for this study.

The nutrient products of the biogas plant used in the calculation consist of fertiliser products meeting the requirements of the Decree of the Ministry of Agriculture and Forestry: liquid nitrogen and digestate. Liquid nitrogen consists of 9% nitrogen and some sulphur. It is ideal for oil plants, grass and grain. The proposed sales price of liquid nitrogen is EUR 12 per cubic litre, corresponding to around EUR 1.3/kg of nitrogen[93]. The digestate currently generated by biogas plants[94] can be used as a soil amendment for fields, as such[95], in the case of grain crops and energy plants, for example. On the basis of the digestate's phosphorus content, its economic value has been estimated at EUR 1.8/kg of phosphorus.

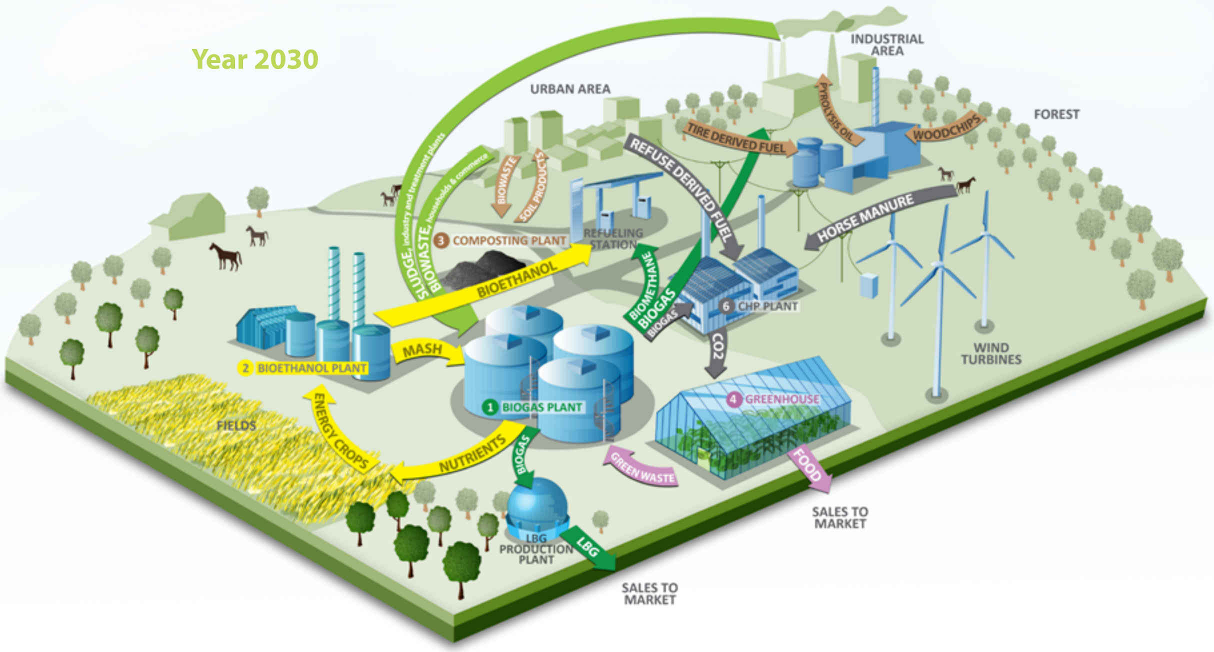
Based on these assumptions, new business generated by the increase in biogas plant capacity would be worth EUR 190 million and its impact on Finland's trade balance would total EUR 150 million. Biogas plants and their value chains would provide employment for 3,500 people per year, to whom the monetary value of the capacity increase would be about EUR 130 million. In addition, the state would benefit by around EUR 200 million from increased tax revenue due to the growth of the bi-

Figure 20. Biogas plants as a driver of nutrient cycling in 2030.

Source: Gaia Consulting, Envor, Forssa Biorefinery

Using biogas plants as a driver of nutrient cycling will generate new business operations for Finland amounting to EUR 190 million per year.

- 9,000 t of phosphorus and 22,000 t of nitrogen are recovered from biogas plants every year.
- The annual value of these nutrients is approximately **EUR 45 million**
- In 2030, the annual impact of biogasification on Finland's trade balance will be **EUR 150 million**
- Biogas plants and the relevant value chains will provide employment for **3,500 people per year**



Key starting points and assumptions:
The economic potential describes the economic value of the annual net change between 2030 and the current situation. Price of recycled phosphorus EUR 1.8/kg, price of recycled nitrogen EUR 1.3/kg.

[93] The total amount of nitrogen in the liquid is 90 kg/m3. Source: Envor – product description and price list of nitrogen liquid

[94] The product meets the requirements set by the Ministry of Agriculture and Forestry for fertiliser products, but there are certain restrictions in its use. For example, it has not been approved for use for fresh vegetables or seedling production (Source: Envor Oy).

[95] When used as a soil amendment, the digestate also improves the soil structure, which improves the field's water economy, enables earlier spring sowing, evens out yields, and enables earlier harvesting.

ogas plant business. Other parties, such as the financial sector, municipalities and gas suppliers, would also benefit from the change. Gas suppliers would mainly benefit from higher production of domestic biogas, which would reduce the share of imported natural gas. This would also result in the reduction of cash flows to foreign countries. Furthermore, the production of recycled nutrients by biogas plants would replace imported fertilisers. Such recycled nutrients would be worth around EUR 45 million a year.

3.6 The opportunities of nutrient cycling for Finland

3.6.1 Summary of computational examples

Improving nutrient cycling and preventing nutrient runoff is not only a matter of environmental concern and cost savings. It could also lead to the creation of new business operations, achieve savings and significantly improve the state of water bodies and various associated sectors in turn. The economic value of the four examples calculated for this study (fertiliser leasing, use of broad beans as a replacement for imported soybeans, use of low-value fish as a source of feed, and biogasification as a driver of nutrient cycling) would amount to EUR 310 million per year for Finland by 2030.

The synergy gains for the operations and profitability of the related sectors, the impacts on risk management and the impact of nutrient cycling on ecosystem services are separately addressed in the following sections.

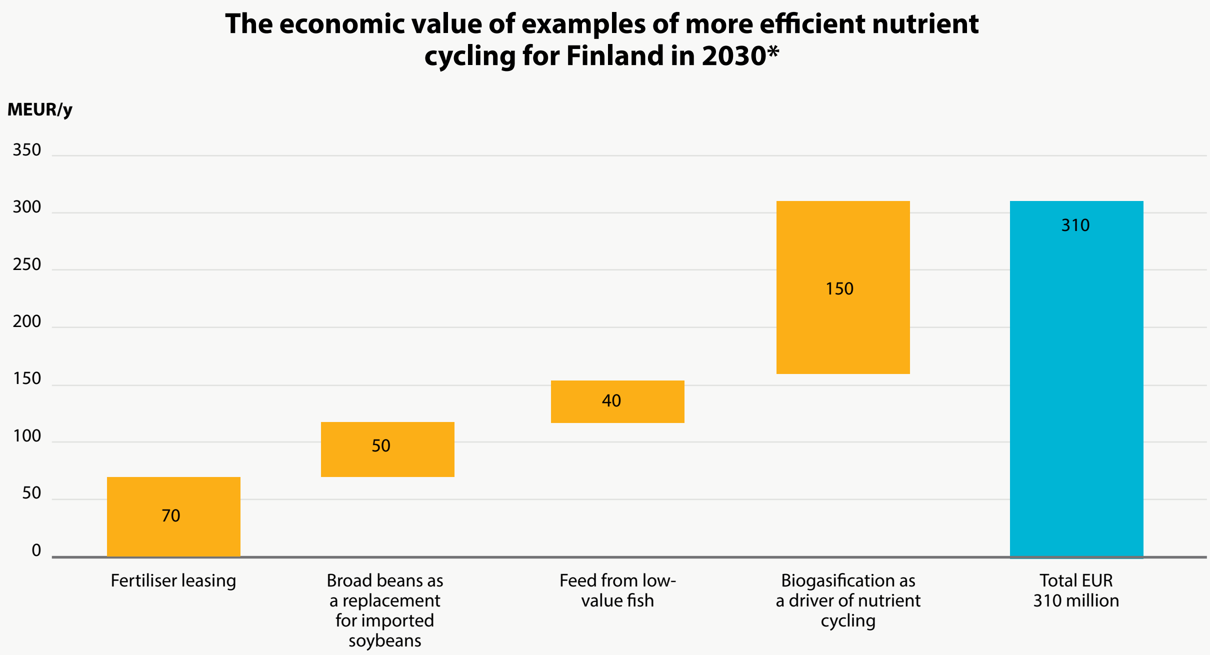
3.6.2 Synergy gains in the operations and profitability of the related sectors

Water ecosystems offer various services that enhance human wellbeing. Some of these take the form of direct benefits, such as food production through fishing, and recreational use of waters. Others, such as improving the operational preconditions of Finnish food production, are indirect. When nutrients are lost in water bodies, the operations and profitability of these associated sectors is also affected.

The 2012 assessment of the current state of the Finnish marine environment, which forms part of the preparation

Figure 21. The economic value of the calculated examples for Finland in 2030.

Source: Gaia Consulting



*Based on the selected examples and describes the annual net change in 2030.

of Finland's sea management plan, assesses the key sectors commercially based on or affecting the Baltic Sea area. Economic sectors covering direct production services include transport and traffic, the fishing industry and hunting, tourism, energy production and the industrial use of water, submarine pipelines and cables, use of natural resources on the seabed, and national defence. Sectors directly linked to cultural services include those related to recreational use, environmental protection and cultural heritage. Indirect utility value includes agriculture, forestry and water bodies.[96]

In 2006, the combined turnover of maritime sector operations in the Finnish maritime cluster was around EUR 13.2 billion, providing direct employment to 44,000 people. The overall turnover of maritime cluster companies was EUR 107 billion, employing 340,000 people.[97]

3.6.3 Impacts on risk management

Some nutrient-based solutions could also have impacts on risk management. This study highlights food security and flood risks as examples of these. The project did not include the evaluation of cost savings related to risk management.

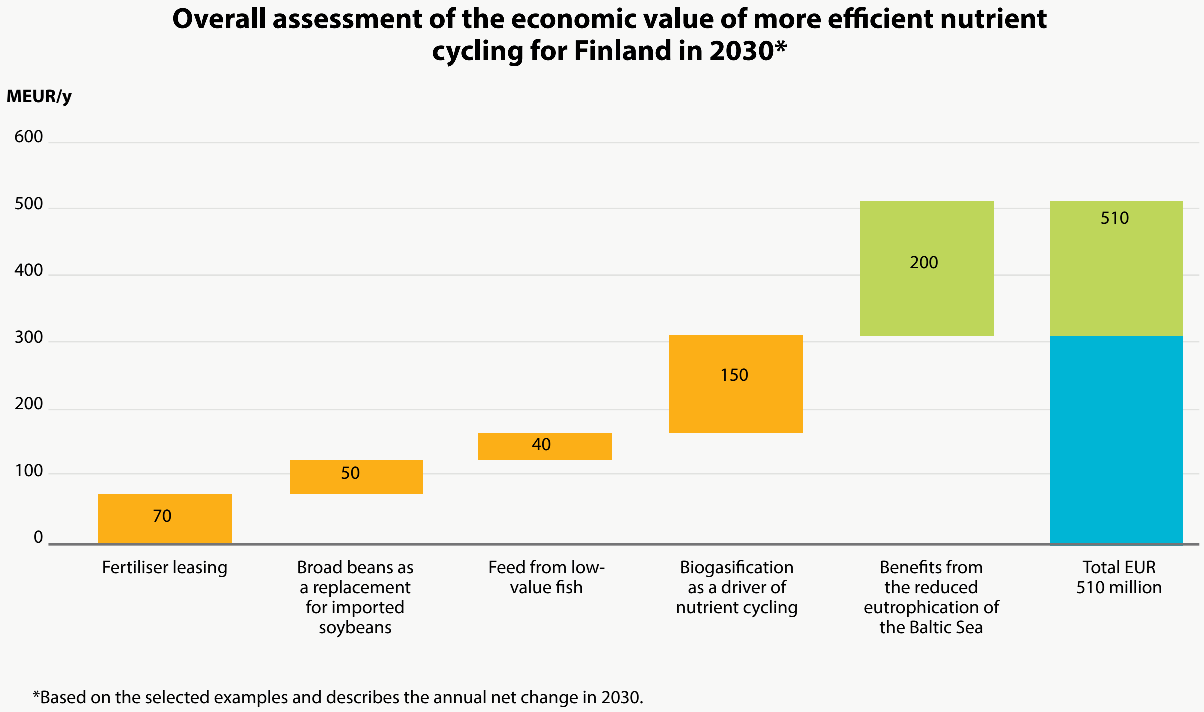
Example: Food security

Finland's food security consists of agricultural self-sufficiency and the export inputs – such as fertilisers, fuels, feed protein and machinery and equipment – required for agriculture. When combined, energy products form the largest import product group. Chemicals are an important export input for the food industry, since plant protection agents are primarily manufactured abroad. Finland is not self-sufficient in oil plants, which provide cooking oil and feed protein. In addition to oil plants, the largest import groups among agricultural products are coffee and cocoa ingredients. However, these are not critical with respect to food security.[98]

In Finland, the National Emergency Supply Agency is responsible for security of supply. 80 per cent of the National Emergency Supply Agency's stockpiles consist of liquid fuels. Other large product groups that need to be stockpiled include grain and seed grain, medical supplies, and various materials needed by industry. Detailed information on these stockpiles is confidential. The agency's operations are covered by the emergency supply contribution collected as part of energy taxes, which amount to around

Figure 22. The economic value of nutrient cycling for Finland in 2030.

Source: Gaia Consulting 2015



[96] Leppänen, Rantajärvi, Bruun & Salojärvi 2012. Meriympäristön nykytilan arvio. Sosioekonominen analyysi. (In Finnish only, The assessment of the current state of the Finnish sea environment. Socioeconomic analysis.)
[97] Karvonen et al. 2008. Suomen meriklusteri 2008. (In Finnish only, The Finnish Maritime Cluster 2008)
[98] Suomen ruokaturvan ja elintarvikehuollon nykytila ja tulevaisuuden näkymät. (In Finnish with English abstract, Finland's food security and maintenance and supply security: The current situation and future prospects) Jyrki Niemi, Marja Knuuttila, Petri Liesivaara and Eero Vatanen. MTT 2013.

50 million euros per year. The current balance of the National Emergency Supply Fund is 1.2 billion euros, most of which is tied up in reserve stocks.[99]

Factors that would improve Finland's food security include the more efficient use of phosphorus, biofuels, use of biological protection methods, and stepping up oil plant and protein crop production. In the case of grain cultivation, almost half of the energy consumed per hectare is due to artificial fertilisers – nitrogen fertiliser availability is strongly dependent on fossil energy resources[30]. Growing nitrogen-fixing legumes would promote nutrient cycling.

Due to the lack of substitutes for phosphorus in food production, dependency on unevenly distributed global phosphorus supplies poses a risk to Finland's food security and security of supply. An article published by Cordell and White[100] suggests that this risk could be reduced by using less imported phosphorus and shifting towards recycled nutrients processed from food industry side streams. Other methods include more-efficient phosphorus use, which would reduce the overall phosphorus requirement by making the same amount go further in terms of the share of the population it feeds. Phosphorus use can be made more efficient by diminishing phosphorus loss across the chain – from phosphate mine to field and the consumer's plate – and then back to the field.

Example: Flood risks

Local stormwater solutions for preventing nutrient emissions from point sources also effectively reduce flood risks. Between 2002 and 2013, there were 11 floods in Finland, with direct costs amounting to EUR 170 million[101]. This sum is equivalent to EUR 15.5 million per actual flood. Flood costs also amounted to an average of EUR 15.5 million per year.

3.6.4 The nutrient cycle's impact on ecosystem services

Few studies have been performed on the nutrient cycle's impact on ecosystem services. A U.S. study[102] estimated that the nutrient cycle's share of the annual aggregate value of global ecosystem services was around half, or some EUR 15 billion.

In Finland, it has been estimated that the value of recreational use of the Baltic Sea is around EUR 436 million per year[103]. Finns would benefit from a reduction in the eutrophication of the Baltic Sea by around EUR 201 million per year, at a cost of around EUR 105 million in order to achieve such a benefit[104]. We used this estimate when calculating the over potential for Finland.

3.6.5 The overall potential of nutrient cycling for Finland in 2030

This report suggests that nutrient cycling has an overall annual potential of around EUR 510 million euros, i.e. half a billion euros, for Finland. Finland's overall economic potential is presented as the value of the annual net change between 2030 and the current situation. This potential is based both on the examples calculated for the project using the regional economic model[105] and the benefits resulting from reduced eutrophication of the Baltic Sea.[104]

Other fringe benefits of efficient nutrient cycling include synergies achieved in other sectors, the impacts on risk management, reduced risks, improved security of supply, and reduced health and environmental impacts. The economic value of these was not evaluated by the project. The estimated added value of half a billion euros eclipses the overall value of fertilisers imported to Finland in 2014 (approximately 150 million[108]). The Sitra report "The opportunities of a circular economy for Finland", estimated the economic value of the circular economy to be EUR 1,5-2,5 billion[109].

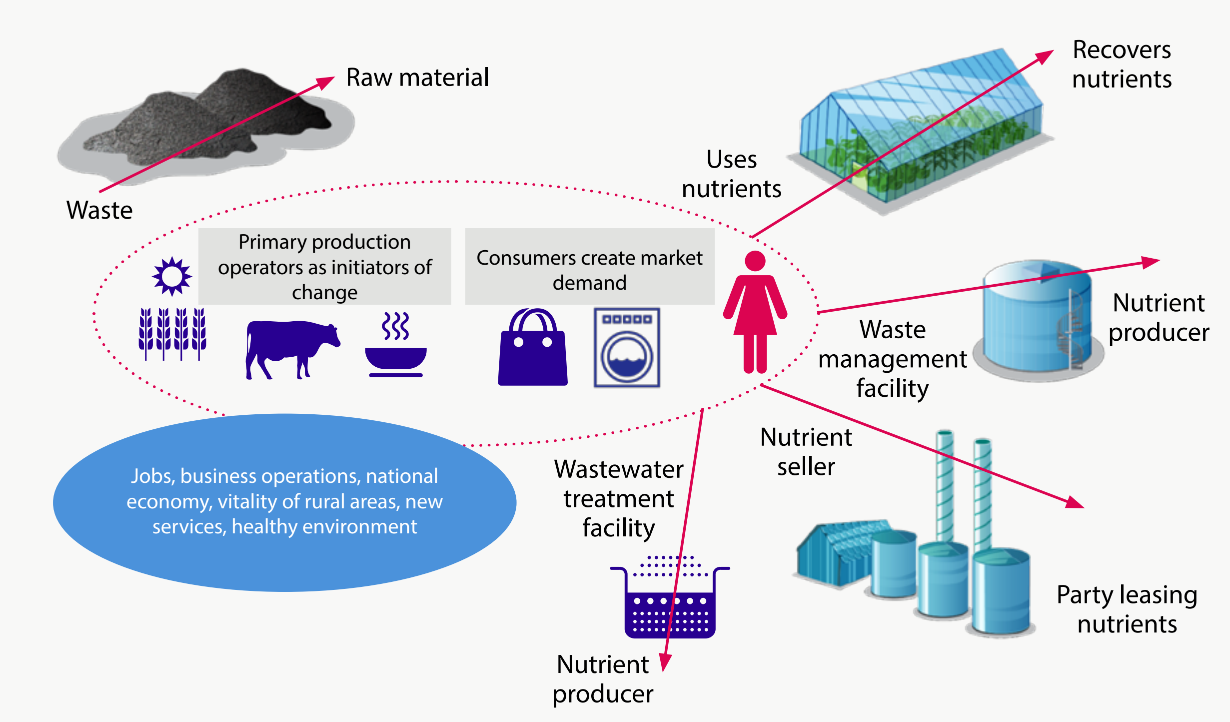
The benefits reaped by Finns from the reduced eutrophication of the Baltic Sea amount to EUR 201 million per year.

[99] National Emergency Supply Agency
[100] Life's Bottleneck: Sustaining the World's Phosphorus for a Food Secure Future. Dana Cordell and Stuart White. Annu. Rev. Environ. Resourc. 2014.39:161-188.
[101] European Commission (2014), Study on Economic and Social Benefits of Environmental Protection and Resource Efficiency Related to the European Semester.
[102] Costanza et al. (1997), The value of the world's ecosystem services and natural capital.
[103] Hyytiäinen et al 2012.
[104] BalticSTERN: The Baltic Sea – Our Common Treasure. Economics of Saving the Sea, 2013.
[105] Additional information in Section 3 of the report.
[108] Finnish Customs, Uljas database
[109] Sitra Studies 84. The opportunities of a circular economy for Finland. 2014

4 From consumption of nutrients to nutrient economy

Figure 23. Paradigm shift – from consumption of nutrients to a nutrient economy.

Source: Gaia Consulting , Sitra, Kari Herlevi, 2015



4.1 Paradigm shift

Figure 23 describes the paradigm shift required by the transfer to a nutrient economy. As a result of such a change, waste, for example, becomes raw material, waste managers become nutrient producers, or nutrient sellers become nutrient leasers. In addition to the markets, the pace of change depends on factors such as regulation and technological development and, most of all, attitudes.

Those searching for future success are already developing and piloting various closed cycles. However, for the reasons described in earlier sections, open cycles remain more profitable in the short term. As an analogy, we can examine renewable energy sources in whose case the growth of renewables has evoked two kinds of reaction. On one hand, the shift to low-carbon and renewable solutions has gained support, while structural change has created the need to support fossil fuels.

Primary production and consumers play key roles with respect to this change. Primary production should challenge habitual and traditional consumption habits and test new feed plants, for example. Consumption habits will change if, in the future, the costs of the consumption and replenishment of nutrients and environmental damage are priced into products and services. In such a case, some consumers may still be prepared to pay for flush toilets and meat-based diets, whereas some may shift to alternative sources of protein, self-sufficiency farming, and dry toilets.

As regards energy, we are familiar with the concept of energy poverty, where people on low incomes cannot afford to invest in energy efficiency or use new energy solutions. As energy prices rise, an increasing share of income is spent on energy, which further reduces people's prospects of improving their wellbeing. We should also avoid creating a situation where nutrient cycling would raise the price of the most affordable foodstuffs in particular. If we really want to change, products manufactured using closed cycles should be mainstream, not luxuries.

It also matters how the need for change is presented to the public. This will gain wider acceptance if described in terms of issues such as local food, employment, rural vitality, recreational maritime use and the state of the environment.

Regulation will also affect the shift towards a nutrient economy in particular. As a result of unfavourable regulation, it may not be possible to implement all of these changes, but change could also be promoted via taxation, regulation, investments, innovation support and public procurement.

4.2 Bottlenecks in nutrient cycling

Bottlenecks in nutrient cycling can partly be found in the overall promotion of the circular economy, business operations and the promotion of investments, and in specific themes related to nutrient cycling.

The issues underlying key bottlenecks can be summarised in the form of three questions:

1. Do the nutrients return to circulation?
2. Is it possible to recycle nutrients?
3. Is it profitable to recycle nutrients?

The views presented below on bottlenecks are based on studies performed as part of the EU circular economy package and the End-of-Waste consultation on digestates, earlier studies performed by Gaia on making the circular economy possible in Finland, Minister Tarasti's survey of the development of environmental regulation, presentations at Sitra's circular economy seminar, the RAKI project seminar on nutrient cycling, interviews with various experts, and the electronic survey performed in preparation for the roadmap workshop as part of this study.

A shift from the consumption of nutrients to nutrient cycling will require the support of the business environment. No national strategy yet exists for a circular economy and nutrient cycling as an element of such an economy. The forthcoming EU circular economy package will define recycling targets and the Finnish Ministry of the Environment has launched an update of the National Waste Plan involving the specification of national targets from 2017 onwards.

As regards the profitability of nutrient cycling, low nutrient prices still constitute a key bottleneck.

Lack of basic information is also a factor preventing the achievement of targets and monitoring. The savings pressures targeted at Statistics Finland and other producers of public information are hardly likely to promote the development of national indicators for nutrient cycling. Information on circular economy streams and the related economic sectors is scarce, the amount of publicly produced and freely available information is even smaller and geospatial information on biomasses is not yet openly available in support of investment decisions, contracting or planning[110], although projects are under way. Public, freely available data combined with geospatial data has yielded good results in terms of its innovation impact. The production of such public data could help to boost nutrient cycling, since the raw materials required cannot be profitably transported across long distances.

The current steering systems were not built to optimise the nutrient cycle. For example, there is a complex relationship between agricultural subsidies and regulation and nutrient cycling. Farm sizes have grown and crop farming and animal husbandry have diverged both regionally and operationally[111]. New technologies and steering are needed for the efficient, growth-oriented use of manure. Otherwise, phosphorus in particular may accumulate in livestock areas.

Primacy of use as a material rather than energy (as in waste management) is crucial in the case of nutrients, because nitrogen evaporates in the incineration process used during energy recycling. Current wastewater treatment methods also vaporise nitrogen. The current wastewater treatment system does not favour the nutrient cycling of nitrogen, despite the fact that nitrogen is in particularly short supply[112].

Since nutrients still represent an expense rather than income, the profitability of nutrient recovery must be based on gate fees, or compensation for waste treatment. A waste producer may be unwilling to pay the premiums for nutrient cycling, and will seek the cheapest alternative. The landfill ban to be introduced for organic waste in Finnish legislation will transform the sector in 2016.

[110] Natural Resources Institute Finland, Background study for the Biomass Atlas project, 2014

[111] Research programme for finding alternatives for the utilisation of manure and other organic waste and by-products (HYÖTYLANTA), MTT 2008-2010 and expert interviews

[112] Source: survey performed as a background study for the roadmap

Processing systems and logistics constitute the main challenges in waste mass recycling. In the case of nutrients, we need to resolve the issue of the national balance sheet and the balance between the regions, in a way that returns logistics to the heart of the matter. If no bans or restrictions are imposed on waste and open cycles, change will be left up to the markets.

The low price of nutrients still constitutes a key bottleneck in making nutrient recycling profitable[113]. Mineral fertiliser and fossil fuel prices have remained relatively low. In addition, nutrient recycling technologies are relatively expensive. For example, the biogas sector has been subsidised with feed-in tariffs for energy and small-scale investment support, but no subsidies have been granted for the production of recycled nutrients.

Energy subsidies have been limited to large production plants[114] and the operations of small biogas plants are not necessarily profitable, even though this would better enable decentralised nutrient cycling.

A producer testing innovative solutions cannot be sure of meeting official requirements; in practice, many policies governing practices are defined by market supervision. Because the financing of development projects is fragmented and limited, its impacts on business operations remain negligible. For example, the RAKI project for the development of nutrient cycling has a budget of EUR 6 million. On the other hand, the new EU financing instrument, the Life Integrated Programme (LifeIP), promotes the circular economy. This and the Horizon programme make financing available – even for investments of a type not covered by many traditional Finnish project instruments[115].

Agricultural and other business activities are being hampered by uncertainty among operators about the regulatory environment. Environmental legislation is viewed as an obstacle to nutrient cycling. Strict requirements have been imposed on the use of nutrient-rich masses as fertiliser in order to ensure safety. While risk assessments are justified, scrutiny is often targeted at only a specific part of the value chain. Although recycled nutrients are more sustainable in terms of the entire production chain, an industrial nutrient of even quality may be less risky to use. Users do not assess the environmental impacts of fertiliser production. Similarly, only the local impacts of plants producing recycled nutrients are visible – when granting licences, no consideration is taken of factors such as the net benefits of products[116]. This creates a system in which environmental legislation favours the licensing of fuel oil and artificial fertilisers and their use in the food chain over fuels and nutrients made of waste masses. Registration and approval procedures are already in place for traditional solutions, whereas new operators need separate approval for pioneering solutions.

Administrative bureaucracy is heavier in relation to waste than ready-made products. The EU's technical paper of 2014, on the significance and potential of the end-of-waste criteria for digestate, will play an important role in the future[117]. The paper discusses the significance of nutrient cycling, alongside the need to set coherent criteria for the productisation of nutrient-rich masses. The objective is to remove obstacles related to waste classification and rationalise the operational environment in order to allow Europe's nutrient cycling markets to grow. End-of-waste criteria are expected to raise the standard of environmental protection and generate benefits for the economy and the environment. For example, the report estimates that 40% of Central Europeans would benefit from a system enabling the transfer of recycled nutrients across borders.

An important future policy will concern the inputs allowed for hygienised and stabilised compost and digestate, in order to make them eligible for an end-of-waste procedure enabling productisation. Based on the EU technical proposal, the materials included in the procedure would be separately collected biowaste, manure, the mechanically or manually separated elements of organisms, biodegradable packaging materials, and previously composted or digested biomasses. On the other hand, biodegradable fractions mechanically separated from unsorted municipal waste, wastewater sludges, paper industry liquors, and contaminated materials would be excluded from the procedure. The final restrictions will have an impact on the kinds of inputs processing plants can accept if they want to produce nutrient products.

4.3 Roadmap to a circular nutrient economy

4.3.1 Drawing up a roadmap

The purpose of the roadmap work was to formulate the measures and objectives through which an operating environment that promotes a circular nutrient economy might be created in Finland. The roadmap was drawn up based on the results of the stakeholder workshop organised on 19 August 2015. The workshop participants represented companies, authorities and researchers.

Before the event, an online survey was conducted to gather various actors' perspectives on the subject. Several new examples were gathered of business activities

[113] Source: survey performed as a background study for the roadmap
[114] Motiva: Investment subsidies for renewable energy
[115] Source: survey performed as a background study for the roadmap
[116] Towards a circular economy – Finland's recipe for success, joint statement workshops and recipes, Gaia Consulting, 2014
[117] End-of-waste criteria for biodegradable waste subjected to biological treatment (compost & digestate) Technical proposals (EUR Number: 26425 EN, 2014)

based on nutrient cycling. These are shown in Figure 24, which is based on the original examples shown in Figure 6.

The change required in the operating environment was examined from the following four perspectives: regulation as an enabler of change; technology as an enabler of change; market demand as an initiator of change; and service and concept development as a generator of innovations. A few sample themes were highlighted in advance within each of the perspective areas, as shown in Figure 25.

4.3.2 Roadmap

The purpose of the roadmap is to generate market demand to simulate nutrient cycling and to create new nutrient cycling services and concepts that satisfy such demand. Regulation and technology that promotes nutrient cycling will be needed in support of this.

In every case, target implementation will involve the common requirements which emerged as overarching themes of the roadmap. The nutrient value chains bring together biological and technical materials, the private and the public sector, and urban and rural areas. Administrative borders ending at a certain shore, edge of a field or business sector can easily become obstacles. Co-operation and a common purpose crossing sectoral boundaries were therefore considered a key issue. This will help to put recycled nutrients in a favourable position and to create opportunities for new, various kinds of experiments.

The following three, key roadmap targets were formulated on this basis:

1. **The primacy of recycled nutrients**
2. **Piloting nutrient cycling in practice**
3. **Collaboration between nutrient cycle builders**

The first target concerns the raw materials used in various processing chains, where recycled nutrients should be prioritised. The second is aimed at the creation and application of innovations, learning among various actors, and the sharing of new information. The third target emphasises the

Figure 24. Ideas for nutrient cycling from the roadmap work participants

Source: Gaia Consulting 2015

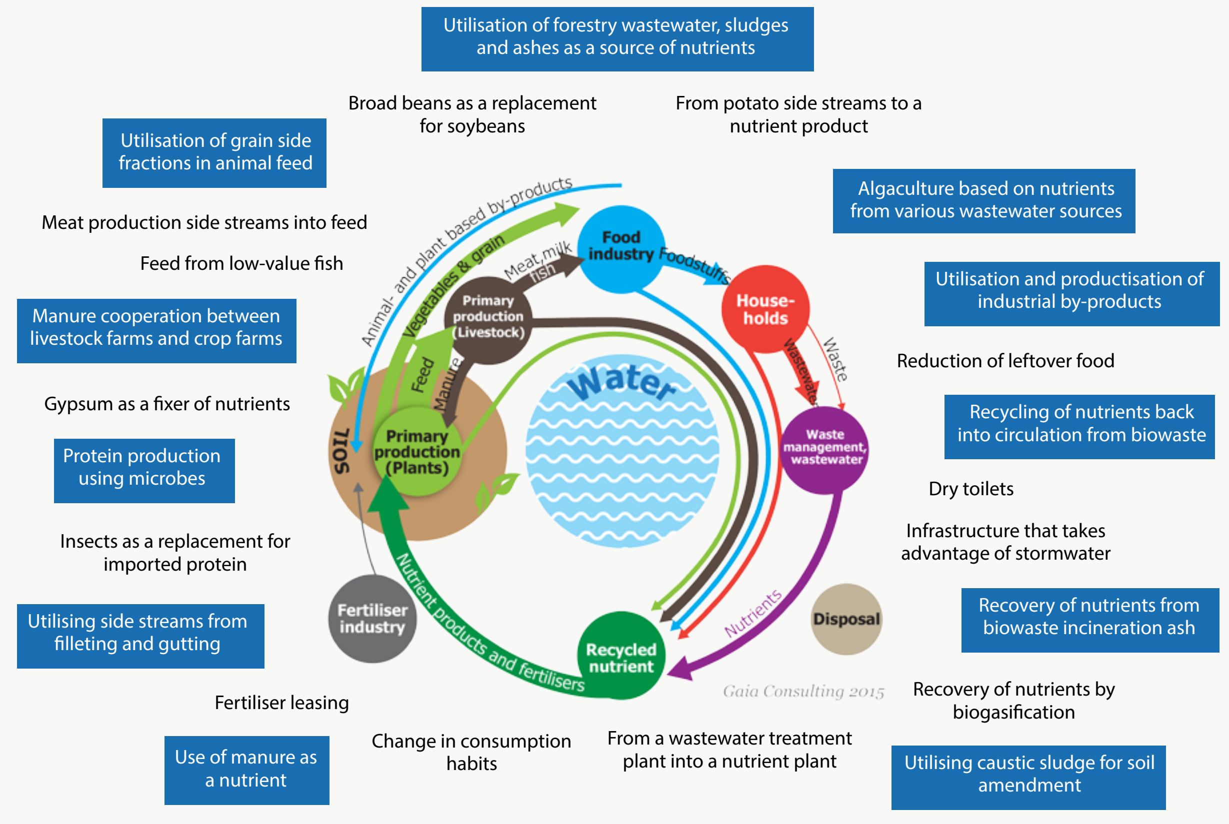
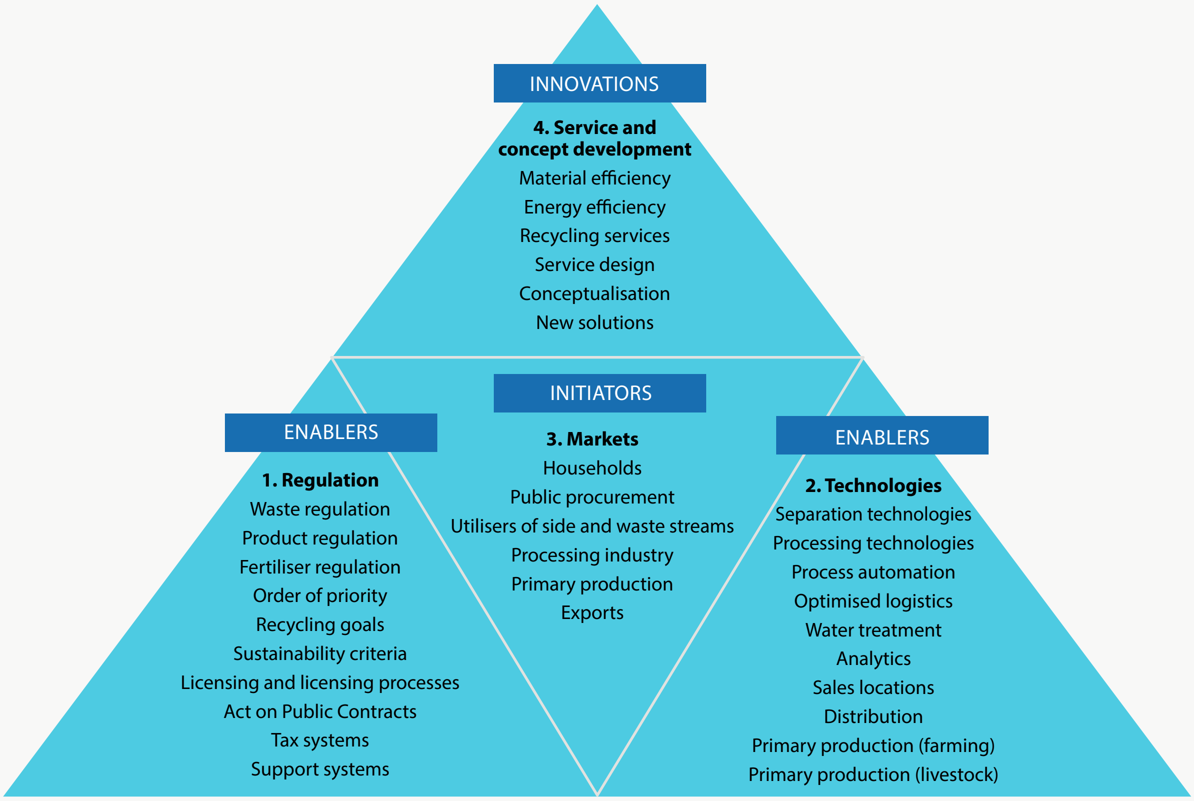


Figure 25. Perspectives on change promoting nutrient cycling.

Source and graphics: Gaia Consulting 2015



identification and removal of obstacles, the role of business intelligence, and benefiting from system flexibility.

The order of priority applied in waste management could be used as a model when considering the primacy of recycled nutrients[118]. As in waste management, recycled nutrients should be favoured when techno-economically feasible. The threshold could be lowered through technological development and the markets; demand could be created on the same basis by consumers, commerce and public procurement, as well as industrial manufacturers and developers. The acquisition criteria of various parties and thereby the markets could be shaped by regulation and taxation, as well as softer methods such as awareness raising and communications.

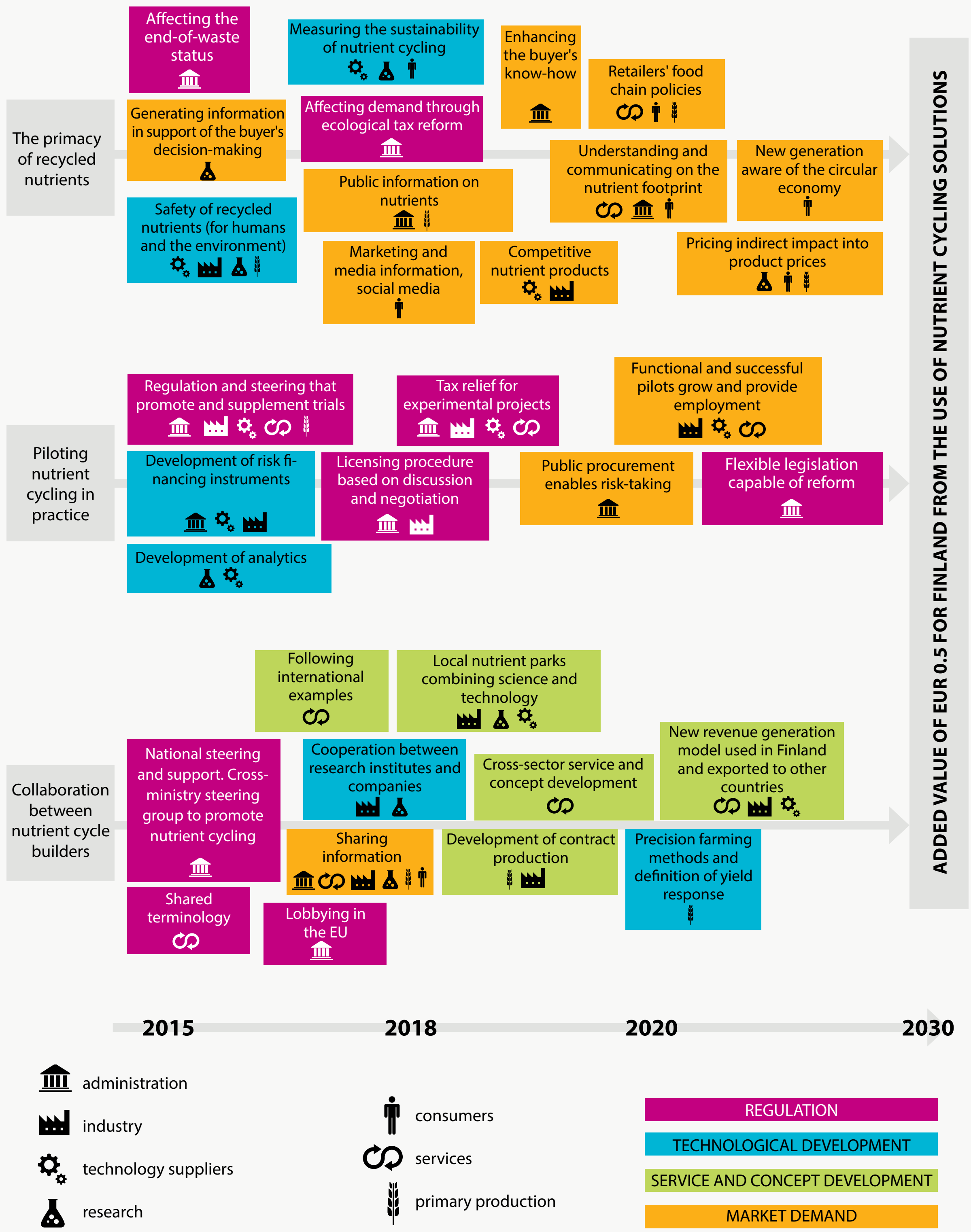
Many nutrient cycling solutions are dependent on logistics and the processing of physical, concrete masses. The second roadmap target proposes the measures and preconditions required to create better opportunities for a culture of practical experimentation. Entailing several practical measures, this target is probably the most concrete of the three. Regulation must enable experimental activities and testing on various scales. Safe experimentation areas can be created in different parts of the country by combining location with efficient monitoring, inter-authority cooperation and measurement enabled by improved technologies. Operations would be transferred from such areas to pilot plants, where demonstrable safe processes would be broadened to industrial scale.

The construction of pilot plants based on new technologies would pose a challenge to current funding systems; the licensing of pioneers may well constitute a shared learning process for authorities and operators alike. The funding of pilots should allow more risk-taking and licensing procedures should be advisory and phased, for example. Financing mechanisms should also support the application of existing technologies; the requirement for novelty and export potential is ill-suited to the funding of everyday consumer trials. The atmosphere must be one in which failure is permitted and lessons are learned. Access to public information and the sharing of knowledge on

[118] The order of priority defined in the Waste Act serves as the basic principle for waste management. 1) Primary effort should be directed at avoiding waste generation. 2) If, however, waste is generated, the waste holder should prepare the waste for re-use, or, secondarily, recycle it. 3) If recycling is not possible, the waste should be utilised primarily as material and, only secondarily, as energy. 4) Waste should be placed in a landfill only if its re-use is economically or technically impossible. Departure from this order of priority should only be possible if another alternative would be more environmentally sound. When selecting a waste management measure in accordance with these priorities, account should be taken of the life-cycle impacts of waste, environmental protection issues, and the technical and economic capabilities of the operator responsible for waste management to comply with the priorities. (Source: The Ministry of the Environment website)

Figure 26. Roadmap to a circular nutrient economy

Source and graphics: Gaia Consulting



failures will provide the basis for new experiments.

The third target addresses common intent and networking between nutrient cycle builders. A great deal of knowledge and communication on the circular nutrient economy as well as a shared set of concepts for use by researchers, civil servants and operators are needed. Cooperation across sectoral boundaries, including research and education, were highlighted as key prerequisites. Sector-specific financing tools, targeted solely at, say, water-body protection, agriculture, or technological development, are ill-suited to the development of overall concepts and cycles. After all, as well as consumers the same cycle may include people involved in fish farming, fishery management, animal husbandry, meadow management or commerce.

4.3.3 Regulation

Many operators regarded regulation as one of the key factors shaping the operating environment. Nutrient cycling is not about a single trade or sector, but requires the simultaneous application of multiple legislation. Regulation should not overlap, but be mutually complementary. Most policies on the issue are formulated at EU level, but it is still possible to provide counselling, wield influence and take advantage of the principle of subsidiarity. In addition, Finland must lobby to enable the creation of sound Finnish solutions and their promotion within the EU.

Since the recycled nutrient industry will develop in Finland through regional trials, fairness and consistency must be maintained in licensing and steering. However, advisory steering authorities can enable trials in which operators must take the special features of each region into account. All parties must take a common approach to reconciling fairness, predictability and flexibility. While not all of these issues are specifically related to nutrient cycling, they are linked to the development of the Finnish regulatory environment in general. In addition, due to the speed of technical development, more attention must be paid to the quality and flexibility of existing licenses.

The productisation of recycled nutrients is a concrete example of the development of nutrient cycling. Because end-of-waste status is an essential interim phase for various use purposes, the fulfilment and verification of product safety requirements must also be addressed. A joint effort should be made to define where further information on promoting the use of recycled nutrients is needed and public resources should be directed at filling this information gap. For example, more information and research references are need on the recyclability of various ashes and manure- and sludge-based phosphorus, and their use in plant cultivation. Based on the knowledge made available in this way, regulation could be refined and, say, consistent agri-environmental support schemes could be developed for various fertiliser products.

Taxation is also related to regulation. Taxation should be reformed to incentivise experimental projects and sustainable processes. Taxation could be used to raise the price of mineral nutrients or lower the manufacturing costs or prices of recycled nutrients. However, the multiplier effects should be examined – for example, if the result were to be a rise in the costs of domestic food production, this could increase food and feed imports from abroad. An impact assessment is required in this respect. A more visionary alternative would be to promote the growth of the recycled nutrient industry through employment by means such as using tax breaks and lower employer contributions to create sustainable jobs.

4.3.4 Technological development

Technology plays a key role in ensuring the safety of recycled nutrients. Ensuring safety refers to the ability to remove any harmful substances, such as drugs, heavy metals, hormones, antibiotics and nanoparticles from recycled nutrients, for example through regeneration techniques or other technical solutions. It also means that the use of recycled nutrients do not pose greater risks to the environment than mineral fertilisers due to factors such as their different composition. The quality assurance of nutrients must be clear and transparent.

Analytical methods can be used to promote nutrient cycling solutions if the right issues are measured and monitored. More advanced analytical methods are still needed to understand issues such as the above-mentioned cycles of harmful materials and the detection of even the smallest traces of substances. Real-time understanding of how different types of fertiliser function (usability and dissolution) and of yield response is also regarded as necessary. When developing analytics, consideration should be given to the kind of information needed by end users and to answering their questions in order to steer them towards more sustainable choices.

Risk financing instruments should be developed to support pilot projects for technological solutions of various scales. According to the respondent companies, although funding is available for R&D there is a lack of new types of instruments aimed at investment in start-ups. Ready-made, technical legislative procedures for risk division and IPR are needed for pilots that cover the entire value chain.

Cooperation across sectoral boundaries is also crucial to technological development. Cooperation between

Construction of pilot plants based on new technologies is a challenge for the current funding systems. Licensing of pioneers may be a shared learning process for authorities and operators alike.

a farmer and an engineer in defining the yield response, the development of precision farming, and the design of spreading equipment for fertilisers and field infrastructure would be an example of this.

The need for technological development exists in areas such as water analytics solutions and cost-efficient separation, filtering and concentration technologies.

4.3.5 Market demand

The low price of mineral fertilisers is restricting market demand for mineral fertilisers. Nutrient cycling solutions could be made more competitive by developing them further and gaining a broader understanding of the large-scale impacts of various solutions, for example at the macroeconomic level in Finland. Demand for various solutions promoting the nutrient cycle should be boosted by producing reliable information on their impacts on ecological, economic and social sustainability. For example, information could be produced in the form of a "nutrient footprint" to help buyers and users of nutrients and nutrient products to make decisions.

Other factors impeding the development of nutrient cycling solutions include quality and safety issues related to waste-based nutrients. Alongside the development of analytical methods in order to answer the above questions, demand for fertiliser products based on treatment plant sludge could be promoted through systematic quality control and open communication.

Pilots of various nutrient solutions and products would create opportunities for winning over operators and, in particular, raising awareness among buyers and consumers. The development and use of contract production models would also promote the simultaneous development of demand and supply.

4.3.6 Concept and service development

As business operations develop, a new sector – the recycled nutrient industry combining various traditional sectors – will develop in Finland. A successful and profitable sector will be based on novel nutrient cycle services and business concepts, none of which yet exist. Although the roadmap participants considered concept and service development essential, there is little concrete evidence of this in practice. This is typical of a young sector.

Various actors were also of the opinion that concept development expertise is weak in Finland. They suggested public investment and the creation of new collaboration networks as a solution to this. A comprehensive approach will require a new kind of leadership and use of networks.

Concept and service development is based on understanding the client's needs and foresight and is strongly linked with experimentation. Novel revenue generation models and cooperation are tested with potential clients. With a view to business development in nutrient cycling, activities must be deeper, more systematic and longer-term than before. Trials can be implemented as individual projects, but must also have a clear business focus. Even in cases where trials involve public sector actors, someone with an eye on the business issues must be involved from the outset.

In Finland, several companies are already promoting nutrient cycling, but service provision varies between regions. As well as direct service development for local needs, functional trials should be duplicated both in Finland and abroad. Correspondingly, good service solutions from abroad – such as the business model for fertiliser leasing presented in this project – could be duplicated in Finland.

Nutrients are a crucial resource for society. Developing nutrient cycles and reducing nutrient loss and the resulting emissions that damage the environment would generate major new economic value. In collaboration with Gaia Consulting, Sitra has performed the first assessment of the economic potential of nutrient cycling for Finland. This report reveals that nutrient cycling would have an annual added value for Finland of 510 million – or around half a billion – euros.

In a circular economy, materials and value circulate within society. Added value is created for products through services and a smart approach. The objective is to reduce the amount of waste and create a system with zero material waste. The Sitra and McKinsey report "The opportunities of a circular economy for Finland" calculated that, based on conservative estimates, the circular economy will have value creation potential of EUR 1.5–2.5 billion for Finland by 2030.

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