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Towards a breakthrough in nutrient recycling

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Abstract

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This report describes the state-of-the-art in phosphorus and nitrogen recycling in Finland and looks at basic data on the volumes and geographical distribution of biomasses and their nutrients. Based on this data, the report makes proposals for measures aiming to promote nutrient recycling. This report was prepared collaboratively by experts at the institutions making up the Finnish Partnership for Research on Natural Resources and the Environment (LYNET) to underpin a national action plan on nutrient recycling.

Of all sectors in Finland, agriculture is the largest user and recycler of phosphorus and nitrogen. Different biomasses contain an annual total of approximately 26,000 t of recyclable phosphorus, which exceeds the fertilisation needs of grasslands and cereal crops in the entire area of Finland. The volume of nitrogen contained in biomasses is approximately 95,000 t. Still, approx. 11,000 t of phosphorus and 152,000 t of nitrogen are annually used in Finland as conventional inorganic fertilisers.

There is a regional imbalance between manure production and crop nutrient requirements. The breakthrough in nutrient recycling means increased implementation of manure processing, thus making manure nutrients easier to transport and reducing the use of conventional inorganic fertilisers. At minimum 20% of the entire volume of manure generated in Finland will require advanced processing to enable long-distance transport of the manure phosphorus to areas in need of it. This requires separation of water. The highest demand for advanced processing is experienced in the regions of Ostrobothnia (approx. 60% at minimum), South Ostrobothnia and Satakunta (approx. 30 %) and Southwest Finland (13%).

In the agricultural sector, fertilisation is currently guided by a wide array of different policy instruments, which make up an incoherent and unstructured whole. The instruments cause considerable amounts of regulatory burden, but appear to do little to promote sustainable nutrient recycling.

This report proposes a total reform of the policy instruments to boost the recycling of nutrients. All legal standards related to fertilisation should be merged into a single statute, for example by developing the Nitrate Decree. At the same time, the current policy that controls nutrient use via the EU agri-environmental scheme should be abandoned, and the role of the environmental permit for livestock installations and its relationship with general regulatory instruments be clarified. A field plot specific nutrient database should be created to support guidance.

The knowledge base of nutrient recycling should be developed by creating and maintaining a comprehensive data system on the quantities, properties and locations of nutrient-rich biomasses and ashes and their current processing methods. The report also proposes setting regional processing targets for livestock manure. Key objectives should include reducing excessive fertilisation in crop production. The goal of normative guidance should be nutrient use according to the crop needs.

Keywords: phosphorus, nitrogen, nutrients, recycling, biomass, ash, fertilisation, processing, policy instruments

Contents

1. Introduction

Through various industrial and agricultural activities, humans have altered the natural biogeochemical cycles of substances. For example, phosphorus is excavated from phosphorus rock deposits and nitrogen is captured from the atmosphere to produce inorganic fertilisers. As the phosphorus and nitrogen inputs in the cycle exceed the volumes bound in production, nutrients remain in soil and are vulnerable for leaching to water bodies and air in different forms. This has had a negative effect on the status of water systems in many places, including Finland.

Phosphorus rock reserves are diminishing natural resource (estimated sufficiency 300–1,500 years) and the occurrence of these resources in a handful of deposits may affect the availability of phosphorus in the near future and lead to unpredictable price fluctuations (European Commission 2014). Many phosphorus rock deposits also contain impurities, especially cadmium, which may increase production costs when producing fertilisers with lower Cd content.

Of all sectors, agriculture is the largest user and also the greatest recycler of phosphorus and nitrogen. The largest quantity of nutrients is used in fertilisers for plant production. Through feeds and food, they are carried to livestock manure as well as to municipal sewage sludge and municipal biowaste. Agriculture is also the greatest source of phosphorus and nitrogen emissions into water bodies in Finland.

Efficient nutrient recycling will reduce the need for conventional inorganic fertilisers and improve both the ecological sustainability of nutrient use and the security of Finnish food production. Recyclable nutrient-rich materials often also contain organic matter that improves the growth condition of soil (Heikkinen et al. 2013). In addition to agriculture, nutrients circulate within and between other sectors, and it is thus important to improve the efficiency of nutrient recycling in other sectors as well.

Nutrient recycling has been highlighted as a key development area in Prime Minister Sipilä's Government Programme as part of the objectives related to the breakthrough of circular economy and getting waters into good condition. The specific target is to increase the recovery of nutrients especially in areas that are sensitive with regard to water systems so that at least 50 percent of the manure and municipal sewage sludge will be directed to advanced processing by the year 2025 (Government Programme 2015). While processing alone is not enough to keep nutrients in circulation, it often is a precondition for nutrient recycling.

According to a vision for nutrient recycling in 2030 prepared by Raki, a monitoring group that follows up on the progress made in nutrient recycling in Finland, *"A breakthrough will have been made in nutrient recycling, environmental emissions are low, and nutrients are recycled efficiently. Nutrients that have leaked into water systems are returned to the cycle, and the volume of imported nutrients is low. Nutrient recycling has generated new business."*

To translate these objectives into concrete actions, a long-term action plan will be drafted; the purpose of the present report is to provide background information for this action plan. The report was prepared collaboratively by experts at the institutions that are part of the Finnish Partnership for Research on Natural Resources and the Environment (LYNET) and funded by the Ministry of the Environment and the government key project implemented by the Ministry of Agriculture and Forestry. The report describes the state-of-the-art in nutrient recycling in Finland, explains concepts associated with the theme, provides basic data on the volumes and geographical distribution of biomasses and the recyclable nutrients- particularly nitrogen and phosphorus - contained in them, gives proposals for measures aiming to promote nutrient recycling on the basis of this data, and assesses the impacts of the proposed measures. The report is a synthesis of prior studies, interviews with experts and the results of a workshop organised as part of the work on this report.

2. Terms

Nutrient recycling

Nutrient recycling refers to measures by which the nutrients contained in nutrient-rich materials generated in production and consumption are reused sustainably and safely as recycled nutrients. Nutrient recycling reduces the use of non-renewable natural resources and may reduce nutrient emissions into the environment.

Advanced processing

In this report, advanced processing refers to the technological processing of organic, nutrient-rich materials, making them easier to transport and enabling their division into different fractions, thus improving the possibilities for nutrient recovery. In all types of processing, the associated logistics and material use, the harmful impacts of the entire chain of operation on human health and the environment should be minimised, recovery of nutrients should be maximised, and any by-products generated during the process should be used or treated appropriately. In order to achieve overall sustainability, the processing methods should be not only environmentally friendly but also economically feasible and socially acceptable.

Areas sensitive with regard to water systems

In this report, areas sensitive with regard to water systems mean areas where the ecological status of surface waters as referred to in the Water Framework Directive is less favourable than good (Putkuri et al. 2013) and areas with high livestock densities (Ylivainio et al. 2014). In the latter areas, the content of highly soluble phosphorus in arable land (the so-called phosphorus level) is also high (Ylivainio et al. 2014). These include the areas of Uusimaa, Southwest Finland, Satakunta, South Ostrobothnia, Ostrobothnia and North Ostrobothnia as well as North Savo, and most of them have high livestock density (Figure 1). While nutrient recycling should be addressed in all parts of Finland, due to the status of water bodies, elevated phosphorus levels in arable fields and high livestock densities, these areas are the primary targets for intensified nutrient recycling and advanced processing

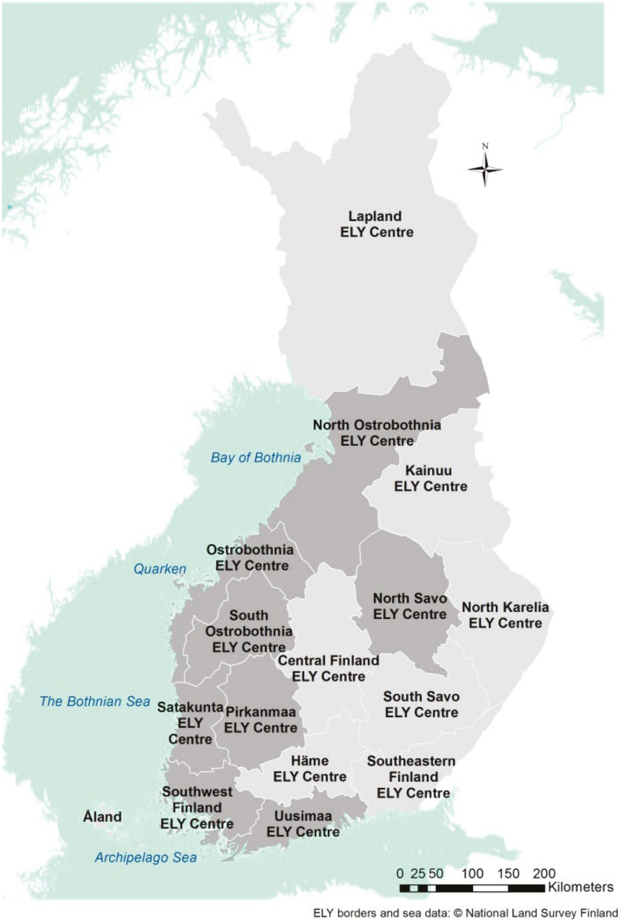

Figure 1. Areas sensitive with regard to water systems divided according to the borders of the Centres for Economic Development, Transport and the Environment (ELY Centres).

Fertilisation determined by crop needs

In fertilisation determined by crop needs, phosphorus and nitrogen are administered as indicated by crop growth responses, taking the legacy nutrients in the soil into account. Phasing out unnecessary phosphorus fertilisation is a precondition for a gradual reduction in soil soluble phosphorus content and phosphorus load into the surface waters. More accurately dosed nitrogen fertilisation is also a prerequisite for reducing nitrogen leaching risks.

The estimate of phosphorus fertilisation determined by crop needs in this report is based on summaries of Finnish fertilisation experiments, in which crop yield responses achieved by applying phosphorus fertilisation on cereals and grasslands were analysed (Valkama et al. 2009, 2011, 2016a). It is unlikely that yield response is achieved in cereals and grassland when the P level is over 6 mg/l in clay soils (soil fertility class passable/satisfactory), over 10 mg/l in coarse mineral soils (soil fertility class passable/satisfactory) and over 15 mg/l in organic soils (soil fertility class good/high) (Valkama et al. 2011). It should be noted that with the current prices, the economically optimised level of phosphorus fertilisation for cereals and grasslands calculated on the basis of crop yield responses is lower than the maximum fertilisation levels under Finnish agri-environmental scheme. The Natural Resources Institute Finland has published a phosphorus calculator[1], which farmers can use to optimise their phosphorus fertilisation. Similar summaries have been produced for nitrogen fertilisation of cereals and grasslands (Valkama et al. 2013, 2016b), but no fertilisation optimisation calculator is available for nitrogen as yet.

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[1] https://portal.mtt.fi/portal/page/portal/kasper/pelto/peltopalvelut/fosforilaskuri

Photo: Tapio Tuomela / Natural Resources Institute Finland’s archive

3. Limitations

This report focused on examining the state-of-the-art in phosphorus (P) and nitrogen (N) recycling, especially in food production and consumption, where the nutrient streams are the largest. This includes agriculture, the food and feed industry, fish farming as well as municipal biowaste management and sewage treatment. Forestry has been included in the examination to the extent that it can produce nutrients for food production and forest fertilisation. The report looks at biomasses which are generated in significant quantities and which contain high volumes of nutrients. They include livestock manure, surplus grass in agriculture (incl. currently underused grass biomasses in riparian zones, fallow fields and nature management fields), municipal sewage sludge, municipal biowaste, food industry side streams and pulp and paper industry sludges (including fibre, coating, sewage and de-inking sludges). Ash is examined in connection with fertiliser product use. Unless otherwise stated, both phosphorus and nitrogen refers to their total contents. In terms of policy instruments, the main emphasis was on discussing regulatory and economic instruments.

Photo: Yrjö Tuunanen / Natural Resources Institute Finland’s archive

4. Phosphorus and nitrogen use in different sectors

The largest quantities of phosphorus and nitrogen are used in agriculture to fertilise crops (Table 1). Of all phosphorus and nitrogen fertilisation in agriculture, 65% and 35% respectively is based on manure or fertiliser products containing recycled nutrients, while the remainder comprise conventional inorganic fertilisers. The majority of recycled phosphorus and nitrogen used for fertilisation originates in manure. The phosphorus in agricultural feeds is mainly passed on to manure and fertiliser products produced from manure and is thus included in their usage volumes. Smaller quantities of phosphorus and nitrogen are also used in landscaping, forestry and fish farming (Table 1). In forestry, the proportion of recycled nutrients is 56% of the total phosphorus used and 0% of the total nitrogen, while these figures for fish farming are 24% and 15%. In landscaping the same inorganic fertilisers are used as in agriculture, and it was not possible to itemise them reliably in the data. For this reason, the volume of inorganic fertilisers used in landscaping is not included in Table 1, and it was not possible to calculate the proportion of recycled nutrients. For more details on the data sources used and the uncertainties associated with them, see Appendix 1.

Table 1. Estimated total volumes of phosphorus and nitrogen use (t/a) and the proportions of recycled nitrogen and phosphorus (%) in different sectors in Finland (situation in 2014–2016, see footnotes; for data sources, see Appendix 1).

	Phosphorus use	Nitrogen use
Agriculture		
- inorganic fertilisers[1]	11,300	148,000
- manure[2]	19,300	76,000
- fertiliser products containing recycled nutrients[3]	1,700	4,000
Total (t/a)	*32,300*	*228,000*
Proportion of recycled nutrient (%)	*65*	*35*
Forestry		
- inorganic fertilisers[1]	113	3,560
- ash-based fertilisers[4]	146	0
Total (t/a)	*259*	*3,560*
Proportion of recycled nutrient (%)	*56*	*0*
Landscaping		
- fertiliser products containing recycled nutrients[5]	1,050	1,470
Fish farming[6]		
- conventional feeds	160	1,360
- feeds containing recycled nutrients ('Baltic Blend')	50	240
Total (t/a)	210	1,600
Proportion of recycled nutrient (%)	*24*	*15*

[1] Finnish Food Safety Authority Evira 2017a and product labels. Includes both products manufactured for use in Finland and imports. Data from 2016.
[2] Table 2 of this report. Data from 2014–2016.
[3] Finnish Food Safety Authority Evira 2017a and product labels. Contains the type designation groups soil conditioners, organic fertilisers and ash-based fertilisers. Data from 2016.
[4] Finnish Food Safety Authority Evira 2017a and product labels. Ashes used for further processing not included. Data from 2016.
[5] Finnish Food Safety Authority Evira 2017a and product labels. Contains the type designation groups soil conditioners and organic fertilisers. The notified quantities used for landscaping purposes and further processing were included. Data from 2016.
[6] Vielma 2017. Data from 2015.

5. Biomasses as raw materials for nutrient recycling

5.1. Biomasses and their nutrient content

Nearly 20 million tons of livestock manure, some 1.5 million tons of biomass from surplus grass in agriculture and a total of over 2 million tons of different organic municipal and industrial sludges and side streams are generated in Finland every year (Table 2). Due to their large volume and high nutrient content, these biomasses play a key role in nutrient recycling. Each biomass type contains materials that are very different regarding their properties and biochemical consistency. Food industry side streams, for instance, contain both animal and plant based materials ranging from liquids to solid masses. The quantities and properties of the materials are partly based on estimates, as there are no systematical statistics on this data. For more details on the data sources used and the uncertainties associated with them, see Appendix 1.

Table 2. Total quantities of biomasses and their phosphorus and nitrogen content (t/a) in Finland (situation in 2014–2016, see footnotes; for data sources, see Appendix 1).

	Biomass quantity	Phosphorus	Nitrogen	Soluble nitrogen
Livestock manures[1]	17,300,000	19,300	75,600	32,400
Surplus grass[2]	1,510,000	2,540	7,060	420
Municipal and industrial wastewater sludges[3]	667,000	2,880	3,740	670
Municipal and industrial biowaste[4]	809,000	730	5,340	320
Food industry sidestreams[5]	259,000	360	2,070	830
Pulp and paper industry sludges[6]	578,000	230	1,160	30
Total	**21,100,000**	**26,000**	**95,000**	**34,700**

[1] The livestock numbers (cattle, pigs, poultry, goats and sheep) are based on statistics from 2014 (Official Statistics of Finland 2017a), the number of horses in 2014 is based on information provided by the Finnish Trotting and Breeding Association Hippos, and the number of fur animals in 2016 is based on information provided by the Finnish Fur Breeders' Association STKL. Manure generation and nutrients: Cattle, pigs, poultry, horses and goats based on the Finnish Normative Manure System (Luostarinen et al. 2017a), sheep based on the minimum manure storage volumes and table values in the Nitrate Decree (government decree 1250/2014), estimate for fur animals based on minimum manure storage volumes and Viljavuuspalvelu statistics from 2005-2009.

[2] The volume of grass biomass is based on the surface area of fallow fields, nature management fields as well as riparian zones in 2016 (Official Statistics of Finland 2017b) and a crop yield of 3,000 kg of dry matter/ha. Crop yields and nutrients: Niemeläinen et al. (2014).

[3] Volume data from VAHTI information system from 2014, complemented with the sludge volumes from Helsinki Region Environmental Services Authority and Turku wastewater treatment plants. Nutrients: Biokaasulaskuri (2014), Kahiluoto & Kuisma (2010), Rasi et al. (2012).

[4] Biowaste quantities from housing and services based on biowastes produced per individual resident (Salmenperä et al. 2016) and population data from Statistics Finland on 31 December 2016, industrial biowastes based on volume data in VAHTI information system from 2014. Nutrients: Biokaasulaskuri (2014), Kahiluoto & Kuisma (2010), Rasi et al. (2012), Tampio et al. (2016).

[5] Volume data in VAHTI information system from 2014. Nutrients: Biokaasulaskuri (2014), Kahiluoto & Kuisma (2010), Rasi et al. (2012).

[6] Includes fibre, coating, sewage and de-inking sludges in 2015. Volumes: Finnish Forest Industries Federation (2017). Nutrients: Apila Group (2013), Biokaasulaskuri (2014), Rasi et al. (2012).

The biomasses examined in the report contain approximately 26,000 tons of phosphorus and 95,000 tons of nitrogen annually (Table 2). At the same time, conventional inorganic fertilisers used annually in Finland contains about 11,000 t of phosphorus and 152,000 t of nitrogen. Notably, the phosphorus and nitrogen contents in manures were at least one order of magnitude greater than in the other biomasses examined.

The quantity of soluble nitrogen indicates the availability of nitrogen for crops. Of the examined biomasses, the proportion of soluble nitrogen in total nitrogen is the greatest in manures and food industry by-products (Table 2). In these materials, nitrogen is highly available, which also increases the risk of nitrogen leaching after field application. Data on the quantity of soluble phosphorus in different biomasses is not available.

Table 3 shows manure quantities and nutrient content by animal category and manure type. While the greatest quantities of manure are generated on cattle farms, pig and poultry farms are also significant. Of the manure generated, 58% is slurry, 35% is solid manure (farmyard manure, deep litter, dung) while the remainder is separately collected urine. Of the phosphorus in manure, 53% is found in cattle manure, 14% in pig manure, 12% in poultry manure and 17% in fur animal manure. The majority of nitrogen contained in manure is found in cattle (72%) and pig (15%) manure. These figures were mainly calculated using the Finnish Normative Manure System[2] of the Natural Resources Institute Finland and the Finnish Environment Institute. Up-to-date manure data can be checked from the Finnish Normative Manure System.

Table 3. Livestock manure quantity and nutrient content estimated for stored manure, situation in 2014–2016. For the sources, see Table 1.

	Quantity (t/a) (volume of manure produced while grazing deducted)			**Total of manure (t/a)**			
	Slurry	Solid manure	Urine	Total quantity	Phosphorus	Nitrogen	Soluble nitrogen
Cattle	6,770,000	4,680,000	1,010,000	12,500,000	10,300	53,600	23,400
Pigs	3,320,000	166,000	125,000	3,610,000	2,680	11,100	6,770
Poultry	18,000	257,000	0	275,000	2,390	5,400	1,110
Sheep and goats	0	82,000	0	82,000	190	720	170
Horses and ponies	0	686,000	1,000	687,000	510	2,490	330
Fur animals	0	200,000	0	200,000	3,200	2,260	580
Total	10,100,000	6,070,000	1,140,000	17,400,000	19,300	75,600	32,400

5.2. Geographical distribution of biomasses and nutrients

The areas which generate the largest volumes of biomass are found on the southwest and west of Finland and in North Savo in regions with high livestock densities (Figure 2). The largest quantities of municipal sewage sludges are produced in Uusimaa and Southeast Finland. The quantity of biowaste created in Uusimaa is more than three times the quantity produced in other areas. The largest quantities of food industry side streams, on the other hand, are generated in South Ostrobothnia. Regarding pulp and paper industry sludges, regional data is only available for 60% of the total biomasses shown in Table 2.

The majority of recycled phosphorus and nitrogen originates in livestock manure almost everywhere in Finland (Figure 3). Sewage sludge produced in Uusimaa and Southeast Finland contains an equal quantity of phosphorus as the manures generated in these regions. In addition, the share of biowastes in the quantity of phosphorus and nitrogen is significant in Uusimaa. These numbers reflect the high population density compared to animal density in Southern Finland.

[2] http://www.luke.fi/projektit/normilanta

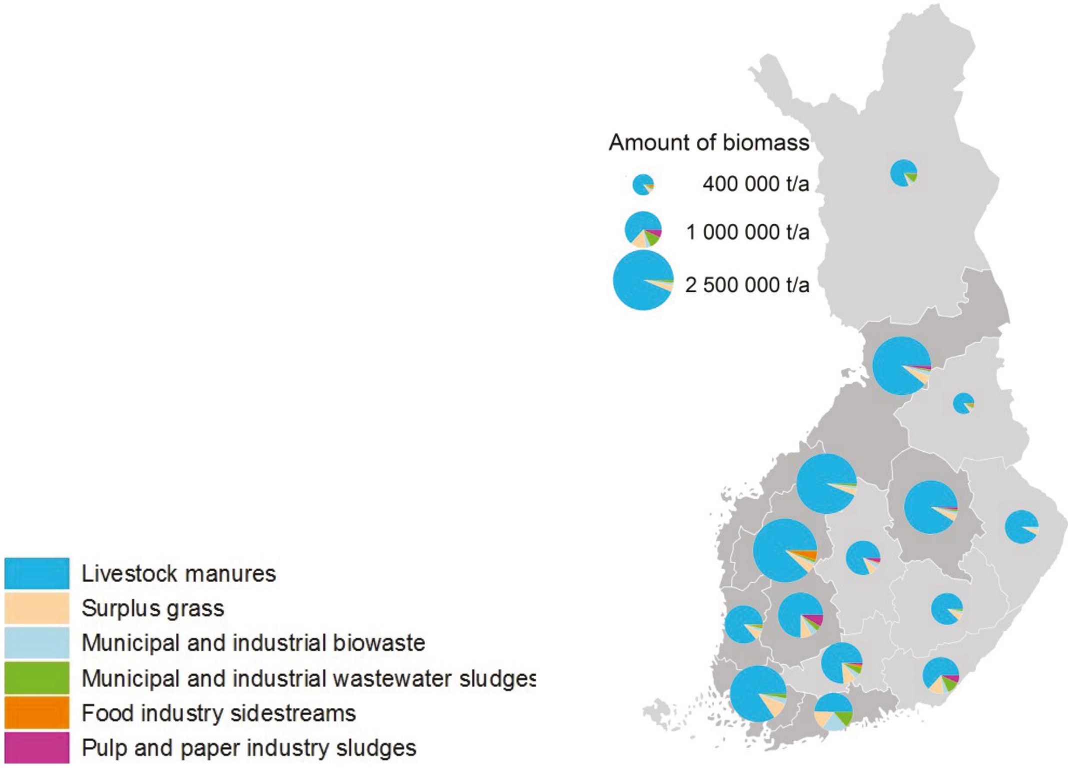

Figure 2. Regional distribution of biomasses in Finland divided according to the borders of the regional Centres for Economic Development, Transport and the Environment (ELY Centres)(for calculation principles, see Appendix 1).

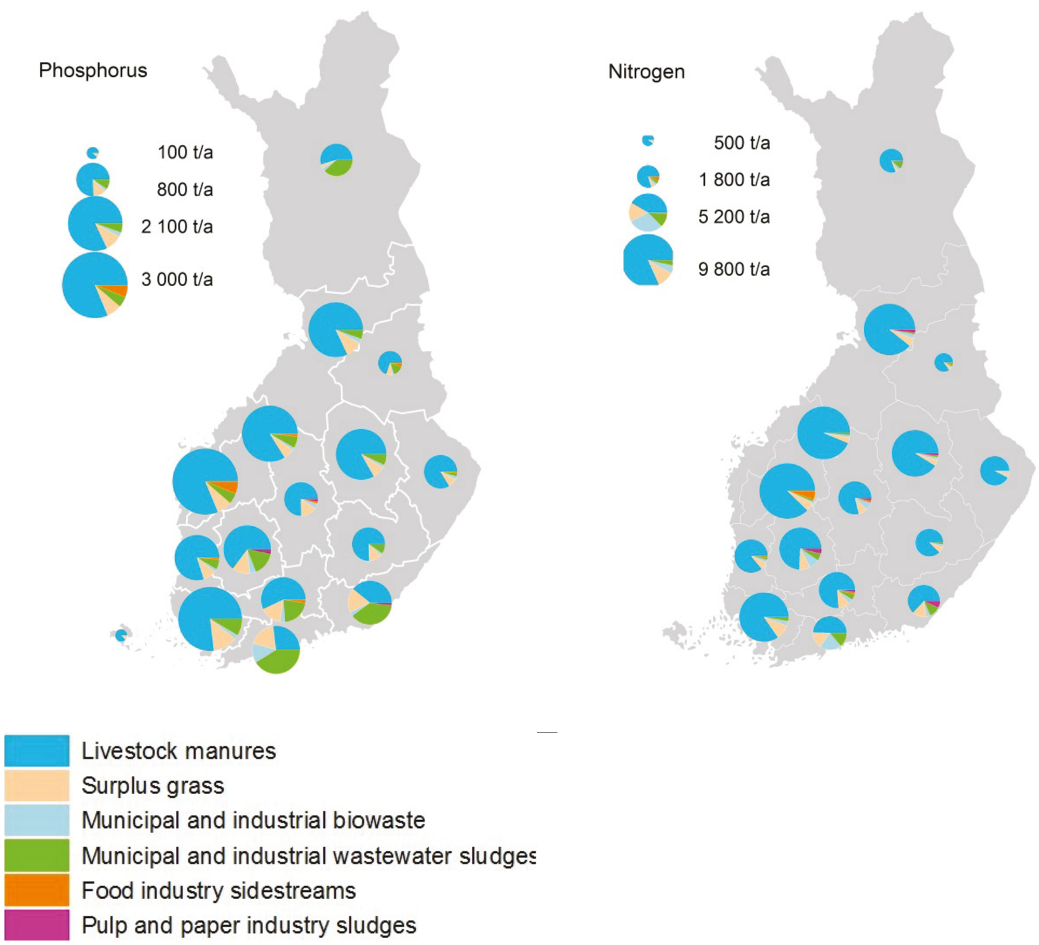

Figure 3. Annual regional distribution of recycled phosphorus (left) and nitrogen (right) divided according to the borders of the regional Centres for Economic Development, Transport and the Environment (ELY Centres). Note the different scales of the figures. The same information sources were used as for Table 1, except that the data on pulp and paper industry sludges are based on VAHTI information system data from 2014 (geographic information on pulp and paper industry sludges is only available in VAHTI for 60% of the total biomasses in Table 1).

Manure has always played an essential role as a fertiliser in crop production, but the geographical dissociation of livestock farming and crop production that has taken place in recent decades and the increasing unit sizes have resulted in a concentration of nutrient streams to certain regions and imbalances between nutrient volumes and crop needs.

By combining regional data on soluble phosphorus content in soil (Ylivainio et al. 2014), the phosphorus requirements of the most important crops (cereals and grass) (Valkama et al. 2009, 2011, 2016a) and the manure quantity, we can assess the regional nutrient situation and the quantity of excess manure phosphorus produced in comparison to crop requirements in the region (Figure 4). The Figure 4 shows that in regions with high concentrations of livestock farming, the nutrient content in manure exceeds crop needs. Nutrients in other biomasses further increase the local nutrient surplus. Also conventional inorganic fertilisers are used in the same regions. At national level, manure based phosphorus alone would be sufficient to satisfy the needs of cereals and grasslands (Lemola et al. 2013, Ylivainio et al. 2014). A precondition for this, however, would be transporting part of manure phosphorus out of the excess regions by processing it into a form that is easier to transport and store.

No similar assessment has been carried out for nitrogen. However, local imbalances of the nitrogen content in manure and crop needs are not as great as compared to phosphorus. It is thus more likely that the nitrogen content in livestock manure can be used for crop fertilisation locally, without any need for long transport distances. In the simplest form, the proportion of recycled nitrogen in all nitrogen use could thus be increased by reducing the nitrogen losses from manure in all phases of manure processing and by optimising the use of nitrogen in other biomasses as well.

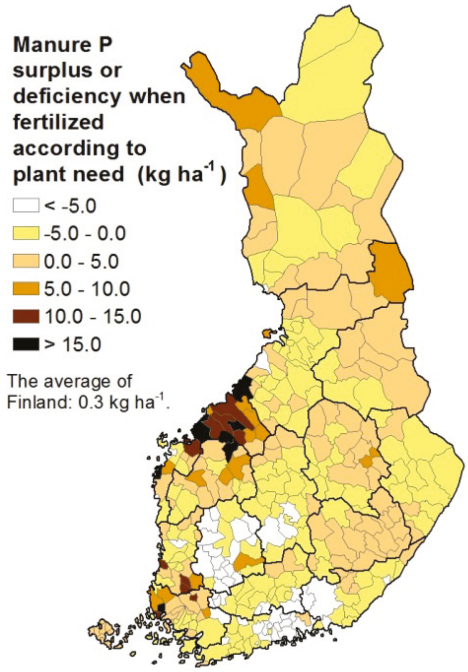

Figure 4. Adequacy of manure phosphorus by municipality for fertilisation according to crop requirements (Ylivainio et al. 2014). A positive value indicates a surplus of manure phosphorus, while a negative value indicates a deficit in terms of crop needs in a municipality.

In addition to the calculation based on arable land area discussed above, it is useful to look at the total quantity of manure phosphorus in different regions, for example at the level of regional Centres for Economic Development, Transport and the Environment (ELY Centres). The surplus of manure phosphorus in the area of an ELY Centre can be roughly calculated as the difference between the generated quantity of manure phosphorus and the fertilisation needs in the municipalities of the area based on information in Ylivainio et al. (2014). Of the fifteen ELY Centre areas in Finland, nine areas produce manure phosphorus in quantities that exceed the needs of crop fertilisation in that area (Table 4). The total quantity of manure phosphorus that exceeds the fertilisation needs (3,500 tons) corresponds to some 20% of the annual manure phosphorus quantity in Finland. Of this surplus, 91% is produced in the coastal areas of the Bay of Bothnia, Quarken, the Bothnian Sea and the Archipelago Sea. One half of the surplus is generated in the area of the Ostrobothnia alone, which has a high number of fur farms. For ELY-centres and coastal areas, see figure 1.

Table 4. Finnish ELY Centres in whose areas the phosphorus volumes in manure exceed the need for phosphorus fertilisation (based on information in Ylivainio et al. 2014, for ELY Centres, see figure 1).

ELY Centre	Total quantity of manure phosphorus (t/a)	Excess of manure phosphorus (t/a) in proportion to requirement in the ELY Centre area	Excess of manure phosphorus (%) in proportion to requirement in the ELY Centre area
Ostrobothnia	3,075	1,775	58
South Ostrobothnia	2,518	761	30
Satakunta	1,063	287	27
Southwest Finland	1,932	250	13
North Savo	1,427	181	13
North Ostrobothnia	1,835	130	7
South Savo	613	106	17
Lapland	417	33	8
Kainuu	282	12	4
Total	13,161	3,535	27

5.3. Biomass processing technologies

The type of processing required to recycle nutrients is determined by the properties and location of the biomass as well as the uses of phosphorus and nitrogen. While the largest quantities of phosphorus and nitrogen are used in agriculture, they also have industrial uses.

In order to use recycled nutrients in crop production as indicated by the crops' nutrient requirements, in many cases the nutrients have to be transported to areas with fertilisation needs. For this purpose, the biomass must be processed to form products that are easy to transport, store and handle and safe to use as fertiliser products. The first requirement for end-products to be transported for long distances is a low water content. It is also important that the nutrient contents and proportions as well as their availability for crops are known for optimising the application rates from economical and environmental point of view. Processing may also be needed to reduce the contents of harmful substances and hygiene risks.

The processing of biomasses into different products also enables business based on recycled nutrients. To ensure that the products are competitive compared to conventional inorganic fertilisers, the processed products must not only have the aforementioned properties but also be consistent in quality and competitively priced, their availability must be predictable, and it must be possible to produce them in sufficient quantities. The carbon contained in biomass-based fertiliser products may have added value in agricultural use compared to conventional inorganic fertilisers. Recycled nutrients may also be combined into the same products with conventional inorganic fertilisers. Recycled nitrogen or phosphorus may be added to inorganic fertilisers during the manufacturing process, and similarly, the nutrient content of fertiliser products based on recycled nutrients can be complemented by adding conventional inorganic fertilisers to them. In industrial applications, the requirements placed on product properties are case specific.

Manure may be used in an unprocessed form in crop production when restrictions placed by legislation are considered. However, this may result in excessive fertilisation quantities regarding crop requirements, and in that case, the conditions for nutrient recycling are not met (see section 2. Terms). Depending on the regional situation, simple solid-liquid separation may be sufficient as a processing method: it divides the most of manure nutrients into a liquid fraction that is high in nitrogen and a solid fraction rich in phosphorus. This way phosphorus, which usually limits manure application due to high soluble phosphorus concentration in agricultural soils, can be transported slightly further. If the manure cannot be spread sustainably in the local area, for example due to a high soil phosphorus content, the processing of manure and nutrient recovery must be taken a step further.

In the processing of municipal and industrial wastes and side-streams, the objective often is converting the material into a form that allows the waste producer either to hand the mass over to another actor for further processing or process it into a product that is suitable for their own use. In the case of sewage sludge, in particular, nutrient recycling today often is of secondary importance, and the most important objective is making the material harmless and improving its transportability by removing water.

Biomass processing technologies can be roughly divided into four categories. Separation techniques (separation, drying/concentration and membrane technologies) are used to separate biomasses into fractions, either physically or mechanically. Biological techniques break biomasses down by microbiological means, thermal methods reduce the mass quantity to be processed and concentrate the selected compounds using a high temperature, and chemical methods separate and concentrate biomasses through different chemical reactions (Table 5). Processing may also result in new side streams, and their utilisation and further use must be addressed. For a more comprehensive review of the processing techniques, see Appendix 2.

Table 5. Biomass processing technologies for nutrient recovery that are on the market or being developed. For a more comprehensive review of the processing techniques, see Appendix 2.

Technology	Principle	Nutrients	Level of technological maturity
Separation techniques			
Separation	Separation into a solid and liquid fraction or water removal. The processing changes the nutrient proportions but does not significantly affect their availability.	Nitrogen is mainly found in the liquid fraction and phosphorus in the solid fraction	Commercial
Drying and concentration		Some of the nitrogen may evaporate during the process (recovery possible), phosphorus remains in the dried product	Commercial
Membrane technologies		Precise separation of nutrients	A commercial technology for water treatment, techniques for nutrient recovery are being developed
Biological techniques			
Composting	The treatment stabilises the biomass and makes it easier to process	Some of the nitrogen evaporates (recapture possible with certain techniques). Phosphorus is retained in the composted biomass	Commercial
Anaerobic digestion (mesophilic/ thermophilic)	The treatment stabilises the biomass and makes it easier to process, thermophilic treatment also sanitises it. Energy production	Nutrients are retained and nitrogen solubilises. Phosphorus availability changes little	Commercial
Thermal techniques			
	Heating the biomass reduces its quantity and makes it easier to transport. Incineration produces ashes. Energy production	Increase in temperature reduces the availability of phosphorus for plants and slows down the decomposition rate of carbon in soil. Nitrogen capture must take place already during the biomass drying step. Incineration breaks down organic compounds and phosphorus is retained in the ashes	Commercial technologies are available for processing. Techniques for wet biomasses in particular are being developed
Chemical techniques			
	Different techniques, some of which aim for reconditioning the biomass and making it easier to process	Others aim for an inorganic nutrient product, the properties of which are similar to those in conventional fertilisers	Commercial and developing technologies

When processing biomasses, different technologies can also be combined into a processing chain. For instance, the separated fractions can be channelled to other suitable treatments with the aim of processing them further into products. The choice of the processing technique and processing chains always is specific to individual cases, however. Some large biogas plants, for example, separate the digestate and process especially the liquid fraction further into more concentrated nutrient products. Similarly, solutions for processing the solid fractions separated from the digestate are being sought in pyrolysis technology. In addition to agriculture, the end-products of advanced processing can also be channelled to such sectors as the industry (nutrient products and chemicals, including ammonium sulphate or phosphoric acid).

Other possibilities for nutrient recycling and biomass processing include different integrations with other functions, including microalgae production or fish farming, which may use the liquid nutrient solutions produced when processing biomasses. Consequently, a number of different routes can be used to direct the nutrients found in biomasses to food production, and different symbiotic relationships can be seen as an important part of the future for nutrient recycling.

5.4. State-of-the-art in biomass processing and recovery

The degree to which biomasses are processed varies greatly depending on the material (Table 6). Manure is mainly used in agriculture without further processing. Surplus grass biomasses are not processed at all in practice. Municipal and industrial wastes and sludges are processed using different techniques, but the primary objective of the treatment is most commonly something else than nutrient recycling and recovery. Nutrients may also be intentionally lost during processing, or their availability is not optimal after the process. The choice of processing techniques can thus have a significant impact on the properties and availability of nutrient fractions if the actors are willing or obliged to invest in this. For details of the information sources and calculation principles used in Table 6, see Appendix 1.

Table 6. State-of-the-art in biomass processing in Finland. The data is based on total biomass quantities in Table 2 as well as processing data from 2013–2017; see footnotes.

Processing technique, % of total biomass quantity	Separation	Composting[1]	Anaerobic digestion	Incineration	Ethanol production	Direct agricultural use	Use as feed	Others[2]
Manures[4]	0.6	3.3	1.1	0.16	-	95	-	0.02
Surplus grass[5]	-	-	-	-	-	100	-	-
Municipal and industrial wastewater sludges[6]	-[3]	40	51	-	-	-	-	9
Biowaste[7] from housing, services and industry	-[3]	30	19	-	1	-	-	50
Food industry side-streams[8]	-[3]	7	4	6	7	47	16	12
Pulp and paper industry sludges[9]	-[3]	32	-	66	-	-	-	2

[1]Composting also includes use for landscaping purposes.
[2]The category Others includes drying of manures, final disposal in landfills, other processing techniques (Kemicond and lime stabilisation of sludges among other things) and biomasses whose processing technique could not be traced in VAHTI information system.
[3]Separation is almost always part of such processes as sewage sludge treatment and anaerobic digestion.
[4]Processing of livestock manures: surveys of manure processing conducted by the National Resources Institute Finland and the Finnish Environment Institute in 2012, the Finnish Biogas Association's map of biogas plants from 2017, Finnish Food Safety Authority Evira's annual notification data from 2016 (Evira 2017a) as well as environmental permits issued to biogas and composting plants. Data on centralised composting of fur animal and poultry manure for 2017 obtained from operators. Data on composting for 2013 provided by equestrian enterprises (Luostarinen et al. 2017b); the data on incineration concern 2016 (information provided by Fortum Oyj).
[5]No statistical data on processing, mainly not processed, expert assessment. The nutrients are returned to the field, but there is no methodical recycling.
[6]VAHTI information system data from 2014.
[7]Contains biodegradable waste collected separately and biowaste ending up with mixed municipal solids waste (MSW); processing of biowaste from housing and services in 2014 and 2015 (Pirkkamaa 2014, Evira 2017a); processing of industrial biowastes in 2014 (VAHTI information system).
[8]Processing in 2014 (VAHTI information system).
[9]Processing of pulp and paper industry fibre, coating, sewage and de-inking sludges in 2015 (Finnish Forest Industries Federation 2017).

Manures and surplus grass

At the moment, approximately 5% of manures are processed (including separation, composting and anaerobic digestion), while the remainder is used in agriculture without processing (Table 6). The availability of phosphorus in unprocessed manure for plants is mostly similar to phosphorus in conventional inorganic fertilisers (Ylivainio et al. 2008, Ylivainio et al. 2017, Ylivainio et al. 2018a), and the availability of nitrogen is also good. Nutrient availability also remains at a good level in the most common processing techniques used today. Processed manure is mainly used for crop production, while some of it ends up in landscaping projects and gardens.

Surplus grass is mainly not processed. Grass in riparian zones is cut and usually spread on other fields either directly or after windrow composting. Grass in fallow fields and nature management fields is cut and left in the field. Some of the grass is used as feed. The main reason for the low utilisation rate of these grass biomasses is the poor feed quality and/or location in areas with little livestock farming needing the feed. Grass is also rarely processed into fertiliser products at the moment as the economic feasibility of such operations is poor.

Sewage sludges

The majority of sewage sludges are processed into different fertiliser products by anaerobic digestion or composting, or combinations of these processes (Table 6). The number of biogas plants has increased and the processing of sludges by anaerobic digestion has expanded since data for Table 6 were collected, with a simultaneous decrease in the share of composting. Dried sewage sludges are also processed chemically by means of Kemicond treatment, and lime stabilisation is used, for example to treat septic tank sludges in rural areas. Some biogas plants process the digestate further using different techniques, including separation, stripping or evaporation. In this case, the same biomass goes through a number of different treatment processes. Various biomasses are also often treated together at centralised plants, and the nutrient-rich fractions produced thus contain nutrients from several different biomasses.

One challenge for the use of sewage sludges lies in the poor availability of chemically precipitated phosphorus for crops (Ylivainio et al., 2017, Ylivainio et al. 2018b, manuscript). The most common technique for removing phosphorus from waste water in Finland is simultaneous precipitation, in which phosphorus is bound into a low solubility compound using iron salt and is separated from waste water together with the sludge. The quantity of nitrogen contained in the sludges is usually low in relation to wastewater it origins, as in the nitrification-denitrification process today commonly used for removing nitrogen from waste water, nitrogen evaporates into the atmosphere. The remaining nitrogen mainly is organic nitrogen, which must be converted into ammonium nitrogen or nitrate either in a process or in the soil in order to be available for plants. Of the sludge processing techniques, anaerobic digestion to some extent converts organic nitrogen into ammonium nitrogen.

Another factor that hampers the reuse of sludges is harmful substances contained in them. The heavy metal content of sludges has decreased in recent years, and in general, they are below the national limits (Olofsson et al. 2012, Ministry of the Environment 2014, Sarvi et al. 2017). Small quantities of organic contaminants and pharmaceuticals occur in sewage sludges, biowastes and livestock manure alike (Fjäder 2016, Marttinen et al. 2014, Vieno 2015, BONUS PROMISE project[3]). The load of organic contaminants carried to the fields in digestate-based fertiliser products, for example, is of similar magnitude in the case of many compounds as the loading from atmospheric deposition, but greater loading levels may also occur depending on the compound (Marttinen et al. 2014). Finnish legislation does not currently set limits to the content of organic contaminants. The occurrence of pathogens, pharmaceuticals and antibiotic resistant strains of microbes as well as the significance of exposure to low concentrations both in manure based and sewage sludge based products is currently

[3] Phosphorus Recycling of Mixed Substances (BONUS PROMISE) 2014-2017. Implemented by the Natural Resources Institute Finland, Julius-Kühn Institut (JKI), National Veterinary Institute (SVA) and Outotec GmbH & Co. KG

being evaluated (NAMI project[4], BONUS PROMISE project[3]). Different processing techniques, of which incineration is an extreme example, may reduce the share of contaminants.

Due to inadequate statistics, no exact data on the end use of sewage sludge based fertiliser products is available. However, the most significant sector in which sludge-based products have been used in the 2000s is landscaping (Ministry of the Environment 2014). According to Statistics Finland (2017), as little as approx. 3% of sewage sludges were used in agriculture in 2014, but this figure has been growing in recent years (Evira 2017a). At the time of the writing of this report, the use of sewage sludge based fertiliser products in agriculture was again declining, as some food companies refused to buy cereals on which these products had been applied. The backdrop to this situation is concern over the potential risks of harmful substances in sludge products when carried to the fields and the consequent risk to good reputation, which is why some foreign cereal buyers have set limits to sewage sludge use.

Biowaste

The majority of biodegradable wastes collected separately are processed by anaerobic digestion or composting, or combinations of these processes (Table 6). Since the data for Table 6 were collected (in 2014 and 2015), the share of composting has decreased, whereas the share of anaerobic digestion has seen a corresponding increase with the establishment of new digestion plants that process biowaste. According to Statistics Finland (2016), 93.6% of separately collected biowaste was recycled as materials, 5.7% was used as energy, and 0.7% was disposed of in landfills in 2015. The biodegradable waste considered in Table 6 contains not only separately collected biowaste but also biowaste that, in 2014 and 2015, ended up mainly in landfills and incineration plants together with mixed municipal solid wastes (MSW). Regulations that entered into force in 2016 today prohibit the disposal of organic and biodegradable waste in landfills, which has contributed to the introduction of alternative processing techniques for MSW and the processing of biowastes separated from MSW in other ways. According to the Finnish Solid Waste Association (2017), approximately 33% of MSW produced by households is biowaste, which can be separated from MSW mechanically. Due to impurities contained in it, however, this fraction cannot be used as raw material for fertiliser products or in biogas or composting plants without further treatment (Salmenperä et al. 2016).

Food industry side streams

The food industry produces both animal and plant based side streams, which can either be used as such in the industry's own processes, or channelled to the processes of other operators. The biomasses examined in this report are side streams that are reported as waste and are, for example, used in the feed industry or as agricultural fertilisers, or processed to produce energy or nutrients and organic matter.

Due to their diversity, food industry side streams have a number of different processing options and end uses. However, almost 50% of the side streams looked at in this report were used in agriculture without further treatment in 2014 (Table 6). The biomasses used directly in agriculture mainly consisted of potato fruit juice generated as a by-product of potato starch manufacturing, and they also included small quantities of feed and sewage sludges. Situation has changed dramatically since the year of scrutiny, as new potato fruit juice processing plants have been commissioned.

Approximately 16% of the side streams classified as food industry wastes, including slaughterhouse and vegetable wastes, are used as feed. This way, the nutrients contained in these biomasses mostly end up in livestock manure and become recycled. According to information available to the

[4] Resistance to antimicrobials and residues on cattle farms – impacts on the environment and human health 2015–2017. Implemented by the Finnish Food Safety Authority Evira, the Natural Resources Institute Finland and the Finnish Environment Institute

Finnish Food Safety Authority Evira, some of these side streams are used in feed industry, both in Finland and abroad. Biomasses of animal origin are processed to make livestock feeds and pet foods, and vegetable wastes are mainly used as raw materials for livestock feeds (Evira 2017b). Some of these side streams also end up in agricultural and landscaping use through composting, anaerobic digestion and ethanol production, and according to an estimate provided by the Finnish Food and Drink Industries' Federation, anaerobic digestion of side streams is still increasing (Berg 2016). Only a very small part of food industry side streams is disposed of in landfills, and the category 'Others' for side streams in Table 6 thus mostly comprises reuse of materials in other ways or disposal of waste water to a waste water treatment plant.

Pulp and paper industry sludges

The most important techniques for processing pulp and paper industry sludges (including fibre, coating, sewage and de-inking sludges) currently are incineration and composting (Table 6). Besides sludges, other fractions from the pulp and paper industry also end up in energy production. In total, approximately 20% of ashes from incineration are used as fertilisers. In this report, biomasses used in fertiliser products and as soil conditioners, whose probable processing technique is composting or ageing, were included in the composted biomasses in Table 6. Examined by fraction, 10% of sewage sludges and 4% of fibre and coating sludges from pulp and paper industry ended up as fertiliser products, while 15% of sewage sludges, almost 60% of fibre and coating sludges and approx. 50% of de-inking sludges were used in earthworks, for example in road structures. At the time of writing of this report, a biogas plant is being built in connection with the bioproduct factory constructed in Äänekoski. This biogas plant will increase the processing of pulp and paper industry sludges (especially biosludges from treatment plants) by anaerobic digestion.

5.5. Fertiliser products containing recycled nutrients

The end-products of biomass processing and post-processing must meet the requirements of fertiliser product legislation if they are to be marketed and used as fertiliser. Fertiliser products are a group of products of different types intended to promote the growth of plants, or to improve crop quality or the physical or biological condition of the soil or growth medium (www.evira.fi). They may contain both recycled nutrients and conventional inorganic fertilisers, as well as other ingredients. Unprocessed livestock manure is not classified as a fertilising product, and its use is not regulated under the fertiliser legislation.

Table 7 shows the volumes of fertiliser products containing recycled nutrients, and the distribution of their use, in different sectors in Finland in 2015. The classification of fertiliser products is based on a national type designation list (Evira 2016). However, meaningful comparisons between the significance as nutrient sources of fertiliser products under different type designations cannot be done, as the biomass quantities give no indication of the products' nutrient content.

Various types of fertiliser products containing recycled nutrients are used in different sectors (Table 7). The majority of organic fertilisers (93%), organic mineral fertilisers (80%) and soil conditioners (64%) are used in agriculture. Soil conditioners that are almost exclusively used in agriculture include digestate and used food industry growth mediums (used mushroom growing mediums and peat growth mediums) as well as food industry by-products used as organic fertiliser without treatment (molasses extract, vinasse and vinasse extract, potato fruit juice). 60% of reject water is used in agriculture, whereas the majority of cover materials (65%) and growth mediums (98%) are used in landscaping. As a terminological point, it should be noted that only some of the digestates produced by biogas plants, for example, fall under the type designation "digestate". As the type designation is determined by the entire treatment chain and the end product, more highly processed digestates fall under other type designations.

Of the pulp and paper industry ashes, ash volumes reported by operators referred to in the Fertiliser Product Act (Ministry of Agriculture 539/2006) are included in Table 7. In addition to ashes produced from sludge incineration shown in Table 6, this quantity also includes other ashes. The ash volumes delivered by other operators to such sectors as earthworks are not included in the Table. The majority (37%) of ash-based fertilisers are used in forestry, whereas their agricultural use is significantly more limited (19%). Of ash-based fertilisers, 11% are channelled to further processing.

Products classified as fertiliser products are also used for other purposes. According to operators' reports, in particular fibre sludge (72%), reject water (40%) and ash-based fertilisers (31%) end up in other uses.

Table 7. Use of fertiliser products containing recycled nutrients in Finland in 2015 (Evira 2017c). The quantity of conventional inorganic fertilisers used was 590,000 t/a.

Fertiliser product (type designation)	Total quantity used 1 (t/a)	Quantity of fertilising products containing recycled nutrients (t/a)	Use of fertiliser products containing recycled nutrients2				
			Agriculture (%)3	Forestry (%)	Landscaping (%)4	Further processing (%)5	Other than fertiliser product use (%)6
Ash-based fertilisers	150,000	150,000	19	37	3	11	31
Total of organic fertilisers	149,000	149,000	93	-	-	-	7
By-products used as organic fertilisers without treatment (from food industry)7	119,000	119,000	100	-	-	-	-
Reject water	24,500	24,500	60	-	-	-	40
Others	6,020	5,970	98	-	-	-	-
Organic mineral fertilisers	1,360	1,360	80	-	19	-	-
Total of soil conditioners	875,000	872,000	64	-	7	20	9
Digestate	425,000	425,000	94	-	-	6	-
Composts	300,000	300,000	25	-	18	41	15
Fibre sludge	37,000	37,000	18	-	2	8	72
Cover materials	11,400	11,400	24	-	65	12	-
Used food industry growth mediums8	6,840	6,840	99	-	1	-	-
Others	94,700	91,400	76	-	1	21	2
Total of growth mediums9	1,370,000	705,000	2	-	98	-	-
Soil from root vegetables	13,000	13,000	37	-	58	-	5
Others	1,360,000	692,000	1	-	99	-	-

1Includes imports.
2In addition to the purposes listed here, fertiliser products are also used for packaged growth mediums and the fertilisation of potted plants and planters. They are also exported.
3Agricultural use includes application in fields and gardens and professional use in greenhouses.
4Landscaping also includes golf courses and other lawns.
5For example, further processing means granulation of ashes or composting of digestate.
6The fertiliser product has been used for other purposes, for example in landscaping.
7Contains type designations 1B41 Molasses extract, 1B42 Vinasse and vinasse extract and 1B43 Potato cell sap.
8Contains type designations 3A55 Used mushroom house medium and 3A56 Used peat growth medium
9Growth mediums in which compost can be used as one of the raw materials have been included in growth mediums containing recycled nutrients.

6. Assessment of biomass processing needs

Prime Minister Sipilä's Government Programme set the objective of increasing the recovery of nutrients especially in areas that are sensitive with regard to the Baltic Sea and other water systems so that at least 50 percent of the manure and municipal wastewater sludge will be covered by advanced processes by the year 2025. If advanced processing refers to techniques that address efficient nutrient recycling, we can say that the current situation is nowhere near achieving this objective.

Manure

The processing of livestock manures can be stepped up, as only 5% of them are currently processed. Manure processing is not a value in itself when it comes to recycling its nutrients, as depending on the local situation, manure can often also be used efficiently as such by optimising farm-level manure treatment. Consequently, it is not necessary to reach the target of 50% by 2025 set in the Government Programme in all regions.

The minimum need for advanced processing of manure regarding phosphorus can be roughly assessed based on the figures presented in section 4.2. If a quantity of manure exceeding crop requirements is generated at the regional level, this probably also means that at least the surplus share of manure should be processed into a form that could be transported to locations outside the region. Based on this estimate, at minimum 20% of the phosphorus quantities found in manure produced in the entire area of Finland at the time of writing should be processed using advanced techniques that facilitate subsequent transport. The greatest needs for processing are experienced in Ostrobothnia (58% of the manure phosphorus produced in the region), South Ostrobothnia (30%), Satakunta (27%) and Southwest Finland (13%). In these regions, farm-specific processing solutions will no longer significantly promote nutrient cycles, and there would thus be a demand for more centralised manure processing and the associated contracting services. In order to improve the profitability of processing, support for the development of a market for recycled fertilisers will be needed, for example by removing legislative barriers.

Regarding nitrogen, in particular, the efficiency of recycling and recovery of nutrients can also be improved locally by reducing nitrogen losses in conventional manure processing. Well-known nitrogen saving methods include intensified manure removal, covering manure storages and spreading manure only before sowing or during growing season and incorporating spread manure into the field soil. In addition, cooperation between livestock and crop farms with the aim of distributing manure across a wider area and transporting it away from parcels with high phosphorus levels is possible when it is economically feasible for both parties.

When setting targets, the different needs regarding manure processing between individual farms and regions should be noted. Even if an area has been identified as having a nutrient surplus (Table 4), it may contain a great number of livestock farms that do not experience challenges with manure use. The farm's arable land area and operating methods may support their own utilisation of manure without processing. On the other hand, farms needing to either process manure or hand it over to other operators in order to ensure that it can be used sustainably may also be found in areas where no nutrient surplus has been identified at the regional level. Manure may be processed not only to facilitate the transport of surplus nutrients but also for other reasons, including increasing the self-sufficiency in energy and nutrients of a farm or a group of farms. Rather than getting rid of the nutrients, the objective in that case is intensifying their recovery compared to traditional modes of manure handling.

Municipal sewage sludge

The efficiency of sewage sludge utilisation can be improved, as only approximately 3% of these sludges are used for crop production according to Statistics Finland (2017). Higher numbers, however, has been reported after writing of the original version of this report (Vilpanen & Toivikko 2017).

While all sewage sludges are processed, the methods used were not originally planned with nutrient recycling in mind. Rather than using the processing target set for municipal wastewater sludges in the Government Programme, the target could be formulated better. It should refer to nutrient recovery in wastewater, which can be enhanced by means of changes in the wastewater or sludge processing.

In wastewater treatment, advanced processing may, for example, mean phosphorus removal by methods that preserve its good availability for crops, and nutrient recovery using methods in which nutrient streams are kept separate from sludges. A precondition for advanced processing of sewage sludge is either the introduction of completely new techniques, or expanding the current treatments by post-treatment techniques in which fractionation and concentration of nutrients are performed to produce more transportable fertiliser products.

There is also need for evaluating the reuse of sewage sludge nutrients if their use risk the image of the crops and hamper marketing. One option is incinerating the sewage sludge, which would eliminate organic contaminants, so that phosphorus in the ashes could be reused. Germany, for instance, is moving towards incineration as the solution, and after transition periods of different lengths, sludges from the greatest urban centres must be incinerated and the ashes used as fertiliser or stored for future use. A handful of operators in Finland are currently investigating the possibility of processing sewage sludge digestate with pyrolysis technology (Rasa et al. 2015).

The use of advanced processing methods in the treatment of wastewater and sewage sludge is restricted by its costs. Some sewage treatment plants and sludge processing plants are currently pursuing research and development projects aiming to develop processes that promote nutrient recycling. Preconditions for achieving the objective for municipal wastewater sludges set in the Government Programme include developing new processes, conducting experiments and introducing new methods. There is also a need for a common forum of various stakeholders to formulate national policies on solutions for recycling nutrients in sewage sludge.

<u>Other biomasses</u>

While the Government Programme only sets specific objectives for the processing of manure and municipal wastewater sludge, the efficiency of using the nutrients in other biomasses could also be improved.

The annual phosphorus content of riparian zones, nature management fields and fallow fields is in the same range, and their nitrogen content is more than double, the contents in municipal sewage sludges. Only a small part of these nutrients is within the scope of methodical nutrient recycling. Processing of grass into fertiliser products could enable the transport of nutrients, for example from riparian zones near water bodies to areas where nutrients are needed. A prerequisite for this would be developing cost-effective harvesting and recovery chains. Grass biomasses could potentially also be available from feed production surplus, intensified grassland cultivation and crop rotation in cereal production.

Recovery of nutrients in municipal biowastes could be promoted by means of more efficient separate collection of biowaste and the processing of biowaste so that the end-products are suitable for nutrient recycling. Biogas and composting plants should ensure that the mixing of biomasses of different types will not hamper the use of the fertiliser products they manufacture.

Food industry side streams are used as raw materials for livestock feeds, for example, which is at a higher level in the waste hierarchy than recycling as fertiliser products. The use of these side streams as feeds should thus be promoted further. The processing of potato fruit juice generated as a by-product of potato starch manufacturing into different products has already been launched, considerably reducing the volume of fractions that are used in agriculture without treatment. What was said above about biowastes also applies to the fractions processed at biogas and composting plants.

Phosphorus from pulp and paper industry sludges and other fractions is used as ash-based fertilisers, especially in forestry, and in small quantities also as fertiliser products of other types. A significant part of the sludges are used for purposes in which the nutrients are not recovered, including earthworks. By developing the processing of pulp and paper industry sludges, especially fibre sludges and biosludges from treatment plants, the recycling of their nutrients can thus be promoted significantly. At the same time, the organic matter and fibres contained in these materials can be used as a soil conditioner.

7. Policy instruments

7.1. Objective and methods

One objective of this report was to provide a review of policy instruments used to promote recycling of nutrients, assess their effectiveness and identify needs for improved policy measures. The commission also called for an analysis of potential new policy instruments.

In the first phase of the work, a literature review was carried out to study the current policy instruments and to identify potential new ones. The project group supplemented the analysis of the policy instruments on the basis of expert feedback. For a summary of this work, see Tables in Appendix 3.

The assessment of the effectiveness and impacts of the policy instruments rested on literature reviews and expert evaluations. Above all, information was collected at a workshop for 27 participants organised on 3 April 2017 as well as a meeting of a more limited number of experts on 18 April 2017, which discussed the needs to improve policy instruments and their environmental effectiveness.

7.2. Classification of policy instruments

Policy instruments can be classified in several different ways (Similä 2007). This report draws on a basic division between regulatory and economic instruments. The examination relies on the conceptual tools offered by policy evaluation studies, economics and jurisprudence. The literature in these fields points out that *policy instruments* do not work or create impacts in a deterministic manner. In other words, the impacts of a statute, for example, do not solely depend on how the statute is worded and what is required under it. Implementation practices shape the effectiveness of a policy instrument. Policy instruments do not work in isolation from each other. The type of 'policy mix' the different instruments make up is crucial. Fragmentation of policy instruments can easily result in a 'policy mess', in which transparency is poor and which may contain overlapping and even conflicting regulations or incentives.

The policy instruments have both desirable impacts and, potentially, positive and/or negative side effects. At best, policy instruments are evaluated broadly through a number of criteria, which typically include consistency, clarity, predictability and transparency; impact in proportion to different policy objectives; targeting of impacts at different groups and actors; dynamic effectiveness, or incentive for innovation and business renewal; impacts on the public economy; and the regulative burden placed on operators and the administration. While the examination in this report was guided by these criteria, as the evaluation was based on synthesising existing information, it was not possible to produce an analysis incorporating all the criteria.

In public debate, instruments specifically created to promote the achievement of the objective in question are frequently seen as relevant. When examining a policy as a whole, however, it is important to also account for any factors that may hamper the achievement of its objectives. In the Tables of Appendix 3, an effort has been made to identify such potential bottlenecks created by policy instruments.

7.3. Policy instruments relevant to nutrient recycling

7.3.1. Steering nutrient use in agriculture

The examination of policy instruments in this report (Appendix 3) has a strong emphasis on the agricultural sector. On the one hand, this is due to the fact that farms are key actors in nutrient recycling (see the nutrient stream tables at the beginning of the report), as livestock manure and its nutrients are needed to produce grass, cereals and special crops. On the other hand, the emphasis on agricultural policy instruments in this report reflects the highly regulated nature of this sector. The public authorities control the preconditions for nutrient recycling, above all through regulating agricultural production. Policy instruments that target other sectors or operators have a considerably smaller role[5].

The analysis showed that the regulation of nutrient use in agriculture has become an incoherent and unstructured. This form of public steering results in a considerable regulatory burden, but fails to have much significance for the promotion of sustainable recycling of nutrients. The identified problems stem from the contents of the statutes and support scheme conditions as well as from the complicated relationships between different policy instruments. The control system is a patchwork of several different policy instruments, making it difficult to perceive the whole and the relationships between the different instruments. The patchwork also has unnecessary components: for example, the phosphorus fertilisation limit set in the fertiliser product legislation is so high that it usually is devoid of practical significance (Ministry of Agriculture and Forestry decree 24/11, section 11).

The most stringent restrictions on manure and fertiliser use are set in the terms and conditions of the EU agri-environmental scheme. The scheme thus strives to provide an incentive for sustainable use of manure as fertiliser. However, the current scheme provides significantly less incentive for using manure than before, and the payment amount is not necessarily high enough to compensate for the costs caused by nutrient recycling and payment bureaucracy. The significance of the agri-environmental scheme in guiding nutrient recycling thus has decreased in recent years, especially because fewer farms than before have committed to the scheme. The rate of commitment is the lowest among large pig and poultry farms (Kauppila et al. 2017). As farm sizes grow and the concentration of livestock farming increases, the rate of commitment may decrease further. On farms that remain outside the scheme, the use of manure and fertilisers is only directed through the Fertiliser Product Decree and the Nitrate Decree. In the expert feedback, the environment payment system was also criticised for supporting the recycling of mild nutrient products and thus failing to provide an incentive for innovations and investments that could improve the efficiency of recycling and expand its geographic scope. The exceptions incorporated in the scheme also enable phosphorus fertilisation that exceeds crop requirements.

Sometimes the low impact of a policy instrument – especially compared to the regulatory burden caused by it – is only revealed when attention is paid to how the instruments are translated into practices and operating methods. The permit system for livestock installations under the Environmental Protection Act includes the obligation of preparing a manure application plan. The purpose of the plan is to promote the sustainable use of manure produced on the farm, ensuring that manure spreading is guided by the nutrient requirements of the fields and the crops cultivated in them. However, expert interviews and previous studies indicate that the plan has little impact on manure spreading. The plan does not necessarily promote sustainable recycling. Especially in areas with high livestock densities in Southwest Finland and Ostrobothnia, manure ends up in fields that already are nutrient rich, regardless of application plans prepared for them. While the manure application plans may have some steering functions, their role is modest compared to the costs their compilation causes to farmers and authorities.

In expert feedback, shortcomings related to audit and monitoring practices were also highlighted as policy problems. Follow-up of soil nutrient content and nutrient use is based on labour-intensive

[5] In addition to the processing of livestock manure, the use of industrial and municipal organic by-products and wastes in biogas production and the processing of digestate is at the core of promoting nutrient recycling. In addition to the general preconditions for the development of this sector, it is important to pay attention to the use of different inputs and solutions for processing nutrients fractions. In this report, the regulation and support forms of biogas production are only discussed from the viewpoint of digestate reuse.

sampling and recording practices. However, no attention has been paid to the quality assurance and reliability of the knowledge base. Another problem is that the information produced is only used little or not at all in the guidance of nutrient recycling.

7.3.2. Innovation policy and promotion of market creation a recycled nutrient market

When effective, restrictions placed on nutrient use may guarantee that manure spreading, for example, always qualifies as recycling rather than mere disposal. Obligations operate also as innovation policy instruments. It is unlikely that systemic changes, including a transition from the use of inorganic fertilisers to recycled fertilisers, will take place without them. For instance, restrictions and obligations imposed on the application of manure may provide an incentive for innovations and investments that will improve the transportability and nutrient proportions of the materials.

However, restrictions and prohibitions cannot catalyse change alone. Both carrots and sticks will be needed to pave the way for new technologies and practices. The investment support of the Rural Development Programme are instruments tailored to promote the renewal of rural businesses. The allocation of funding to nutrient recycling related investments can tell about the role the funding scheme has in the field. . Little information of this type was available for the needs of this report. Whether or not making investments is attractive depends on farm profitability and future outlook, and there are differences in the uptake of support between lines of production. On the other hand, interviews with experts also brought up a need for active provision of advisory services and facilitation related to the support schemes.

During the current government term, the development of nutrient recycling technologies and business concepts as well as experiments are supported with EUR 30 million as part of the key project ‘bioeconomy and clean solutions’. The impact of this and previously granted funding is difficult to assess. No systematic follow-up data is available on the significance of the funds already spent and the lessons learned from experiments.

Nutrient recycling may be based on cooperation between farms or, for instance, networking of biogas, composting or industrial companies with farms. Contractors that transport and spread biomasses, and sometimes also process them, are important mediators and coordinators of activities. The creation of nutrient recycling entrepreneurship may be supported by means of investment support, for example, but also by providing more training in the sector. At the same time, it is important to ensure that farms can trust the products and services provided for them.

A well-functioning market of recycled nutrients could also efficiently promote a good match between production and demand. The EU Regulation on Fertilisers, which is being updated, aims to improve the classification of fertiliser products. It lays a foundation for development of products that can be placed on the common market. The regulation sets requirements regarding raw materials, product performance and product safety. The legislative reform will create preconditions for generating a European market for recycled nutrients. This means that while the export opportunities of Finnish products will be increased, imports of recycled nutrients may also grow considerably.

The literature review carried out showed that discussion on measures through which the creation of a recycled fertiliser market can be promoted is relatively active. Separate reports are currently being produced on many policy instruments (see Appendix 3).

8. Recommendations

A comperensive policy reform is needed

Efficient promotion of nutrient recycling demands that the problems identified in this report will be solved. This calls for a comprehensive policy update. In its current form, the steering of nutrient use places a considerable regulatory burden on both operators and the administration. This burden is heavy, particularly when compared to the gained benefits in nutrient recycling and environmental protection. The imbalance also extends to the EU agri-environmental scheme, which has been considered a key policy instrument for promoting nutrient recycling. The lower payment amounts and reduced commitment to the scheme have undermined its importance.

The timing for a policy reform would be optimal. Preparations of a new programme period for the EU agri-environmental scheme are currently under way. In addition, a reform of the permit system for livestock installations under the Environmental Protection Act is currently being drafted by the so-called deregulation working group. In the context of the EU's circular economy package, possible needs to review the Nitrate Decree have also come up in discussions. An overall reform drawing on different processes could result in an outcome that will support nutrient recycling sustainably. Problems associated with the synchronisation and timing of legislative amendments should not be an obstacle to the reform. If the amendments cannot be carried out at the same time, the reform should progress one statute at a time.

1. A general statute applicable to all cultivation/fertilisation that addresses both differences in crop nutrient needs in individual plots and the objectives of water management should be drafted. The guidance of nutrient use in its current form through the EU agri-environmental scheme should be abandoned. The Nitrate Decree, which could become a statute that applies to all nutrient use, provides a feasible basis for regulatory development. The reform would improve the predictability of regulatory instruments, release environment payment scheme funds for new measures, and anticipate a situation where commitment to the scheme is reduced further. Increasing the share of arable land fertilised with manure and manure-based fertiliser products and reducing the use of conventional inorganic fertilisers should be set as the objective of the entire guidance system.

2. The role and relationship with general regulatory instruments of the environmental permit for livestock installations will be clarified. It is important to consider if the manure application plan in its current form has a genuine role in steering, and if the use of manure for fertilisation could be guided exclusively by the statute referred to in the previous section. The environmental permit system for livestock installations could, for example, be developed through the Nutrient calculator tool[6] that is being created for the authorities. This tool makes it possible to check if an area can receive more nutrients or not. If not, the environmental permit conditions may require the producer to present a solution for processing the manure or transporting the nutrients away from an area with a surplus.

3. To support the development of policy instruments, a field plot specific nutrient database for authorities and researchers should be created, starting with regional experiments. Objectives will include verifying and monitoring the phosphorus status of fields. Based on the data, manure and other fertilisers can be applied sustainably and as determined by crop needs. This system would make the surveillance of policy instruments more efficient, streamline permit processes, make it possible to evaluate the effectiveness of the steering system, and improve the transparency and impact of the policy instruments. The new system would not necessarily bring further regulatory costs compared to the current situation, as up till now, soil samples have been collected as an obligation

[6] Tool for planning regional nutrient recycling project, 2016–2018. Implemented by the Natural Resources Institute Finland and the Finnish Environment Institute.

under the agri-environmental scheme. The proposal does not have direct effects on the evolution of nutrient loading, but it is a precondition for the effectiveness of all other instruments. The database may also have an informative role.

Other proposals for developing policy instruments

4. The objectives and targeting of funding for experiments will be developed. The projects to be funded should be based on clearly identified and well-justified experiment or trial designs. Experiences and lessons learned through experiments will be collected systematically. The impact of funding mechanisms should be assessed regularly, and their content should be developed based on the assessment results.

5. Investment support should be more clearly targeted at solutions that promote nutrient recycling, taking regional differences into account. The investments and procurements of the central government, municipalities and counties may also indirectly support nutrient recycling.

6. Research relying on public-private partnerships should be stepped up to support the development of competitive recycled nutrients and their quality assessment. Large companies engaging in agricultural, foodstuff and input production will play a key role in taking up new solutions.

7. Finland will continue its active participation in the reform of the EU fertiliser legislation and see to the effectiveness of national legislation in the nutrient recycling sector, taking the requirements of Union legislation into account.

8. A well-functioning market, entrepreneurship and safe use of recycled nutrients will be supported by developing quality systems and standards and through training targeted at operators in the sector.

Proposals for developing the knowledge base and goal-setting

9. A comprehensive information system will be created that encompasses the locations where nutrient-rich biomasses and ash are produced as well as their volumes, properties, processing techniques and end uses. Compatibility of data collections between the environmental administration and the Finnish Food Safety Authority will be ensured. The traceability of data will be ensured.

10. The recommendations on phosphorus and nitrogen fertilisation for different crops will be updated as indicated by the latest research results.

11. Regional targets for processing livestock manure will be produced, drawing on the Tool for planning regional nutrient recycling that is being prepared for the authorities.

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Appendixes

APPENDIX 1.

Calculation principles

Chapter 4. Phosphorus and nitrogen use in different sectors

The estimates given in Table 1 are mainly based on information provided by operators subject to the notification obligation under section 11 of the Fertiliser Product Act (Ministry of Agriculture and Forestry 539/2006) to Evira for 2016 and the product labels. The quantity of inorganic fertilisers includes both products manufactured for use in Finland and imports.

For the information sources used to estimate the manure and nutrient quantities, see Table 2. The data were collated from sources for 2014–2016. The figure describes the quantity of manure generated on farms. In practice, a small share of the manure is processed into organic fertiliser products, and it is thus also included in the quantities of fertiliser products containing recycled nutrients.

In the fertiliser products containing agricultural recycled nutrients, the quantities of soil conditioners, organic fertilisers and ash-based fertilisers used for agricultural and horticultural purposes have been included. The fertiliser products containing recycled nutrients from the forest industry are mainly ash-based fertilisers. Ashes used for further processing are not included. In landscaping, the quantities of soil conditioners and organic fertilisers used in landscaping and further processing have been included. Kangas and Salo (2010) previously estimated that the quantity of phosphorus and nitrogen recovered exclusively from sewage sludge used in landscaping was 1,500 and 2,600 t a year. Compared to these figures, the figures presented in this report are low and also contain other raw materials besides sewage sludge.

Regarding fish farming, the phosphorus and nitrogen quantities given in Table 1 are expert estimates based on the masses of fish produced for human consumption and the nutrient content of feeds (Vielma 2017). In recycled nutrients are included those in the so-called Baltic Blend produced by a Finnish fish meal factory. This fish meal produced from fish caught in waters near Finland partly replaces the fish meal previously used in feeds made with fish caught in oceans. Its proportion of fish feed used in Finland was estimated based on the production figures of companies operating in the market (Vielma 2017).

Chapter 5.1 Biomasses and their nutrient content

The data given in Tables 2 and 3 as well as Figures 2 and 3 are based on a number of different sources depending on the type of biomass. The data on manure are estimates based on livestock numbers. These numbers (cattle, pigs, poultry, goats and sheep) are based on the Natural Resources Institute Finland's livestock statistics from 2014 (OSF 2017a). The number of horses in 2014 is based on information obtained from the Finnish Trotting and Breeding Association Hippos, and the number of fur animals in 2016 is based on information provided by the Finnish Fur Breeders' Association (STKL). The quantities and properties of manure from cattle, pigs, poultry, horses and goats were estimated based on animal numbers and the Finnish Normative Manure System (Luostarinen et al. 2017a). Manure quantities from sheep were estimated based on animal numbers as well as the minimum manure storage volumes and table values in the Nitrate Decree. The manure generated from fur animals is based on, besides the animal numbers, an estimate of minimum volumes of manure storage facilities and Viljavuuspalvelu statistics on manure properties in 2005–2009.

The quantities of surplus grass (fallow fields, nature management fields and riparian zones) were estimated based on areas under cultivation and crop yields. The areas under cultivation in fallow fields, nature management fields and riparian zones in 2016 were obtained from the available statistics on agricultural land (OSF 2017b). The crop yield and property data are based on the results of the project Biogas from managed uncultivated fields (dry matter crop 3,000 kg/ha, dry matter content 37%, nutrient contents in fresh weight 4.7 gN/kg, 1.7 gP/kg, 0.3 g soluble N/kg, Niemeläinen et al. 2014).

The principal data source for recyclable municipal and industrial biomasses was the data in the environmental administration’s oversight and loading information system (VAHTI) for 2014. Other studies and statistics were also used as information sources if the data were not available in VAHTI information system with the desired accuracy and reliability. The data in VAHTI are based on outgoing biomasses, or the volumes of biodegradable materials generated in production reported by operators liable to have an environmental permit. The data of plants with permits issued by municipalities are not included in the figures, as they are not recorded in the VAHTI system. The nutrient contents of sludges, wastes and sidestreams are based on previous studies and expert estimates of biomass consistencies (see Table 2).

The quantities of sewage sludges as well as industrial wastes and sidestreams were gathered from the VAHTI system and complemented by adding the data of any plants that were found to be missing (sludge volumes of Helsinki Region Environmental Services Authority and Turku treatment plants). Sewage sludges were defined as including both treated and untreated municipal and industrial sludges (including septic tank sludges). The dry matter content of sludges varies depending on the treatment method, and the VAHTI data contained both undried sludges (dry matter content 1–5%) and dried and processed sludges (dry matter content 10–35%). To estimate the total quantity of sewage sludges, the sludge quantity with the dry matter content recorded in the VAHTI system was used. The mass of anaerobically digested and composted sewage sludges was corrected to correspond to the pre-treatment mass, presuming that the original mass was 10% higher for digested sludges and 30% higher for composted sludges. To estimate the nutrient quantities, the average dry matter content of the sludges was presumed to be some 16% based on VAHTI data and literature. The nutrient contents of sewage sludges (5.6 gN/kg, 4.3 gP/kg, 1 g soluble N/kg in fresh weight) are based on prior studies (Biokaasulaskuri 2014, Kahiluoto & Kuisma 2010, Rasi et al. 2012).

The volume of biowaste produced from housing and services was estimated based on the average biowaste quantity per resident determined in the KEIKKA project (146.9 kg/a, Salmenperä et al. 2016) and population data from Statistics Finland on 31 December 2016. The biowaste quantity per resident contains not only separately collected biowaste but also an estimate of biowaste contained in mixed municipal solid waste (MSW). Biowaste mainly consists of biodegradable food waste, excluding such materials as paper or cardboard. Industrial biowaste quantities that end up being processed together with municipal biowaste were gathered from the VAHTI system and combined with biowaste quantities from housing and services. The data on biowaste properties (dry matter content 30%, nutrient contents in fresh weight 6.6 gN/kg, 0.9 gP/kg, 0.4 g soluble N/kg) are based on prior studies of municipal biowaste consistency (Biokaasulaskuri 2014, Kahiluoto & Kuisma 2010, Rasi et al. 2012, Tampio et al. 2016).

Food industry sidestreams consist of different food industry and livestock production sludges and wastes, data on which are reported to the VAHTI system. A high number of small food sector companies that do not report their data are missing from the VAHTI system. Particularly significant uncertainty is caused by the wide range of materials with different properties in food industry sidestreams. The dry matter content of different materials may vary from 2 to 100% (VAHTI information system, Kahiluoto & Kuisma 2010), which sets a particular challenge to estimating the properties of the total sidestream quantity. The nutrient data used in this report are based on average properties of food industry sidestreams used in prior studies (dry matter content 20%, nutrient contents in fresh weight 8 gN/kg, 1.4 gP/kg, 3.2 g soluble N/kg) (Biokaasulaskuri 2014, Kahiluoto & Kuisma 2010, Rasi et al. 2012).

The pulp and paper industry sidestreams accounted for in this report consist of fibre, coating, sewage and de-inking sludges. The sludge quantities are based on data for 2015 obtained from the Finnish Forest Industries Federation, as the sludge quantities reported to the VAHTI system were not comprehensive regarding these sidestreams. Regional data in Figures 2 and 3 are based on the VAHTI system, however (data for 2014), which only contains about 60% of the total sludge volumes reported by the Finnish Forest Industries Federation. There are also great variations in the properties of pulp and paper industry sludges depending on the sludge type. The property data used in this report are based on average sludge properties used in prior studies (dry matter content 25%, nutrient contents in fresh weight 2 gN/kg, 0.4 gP/kg, 0.1 g soluble N/kg) (Apila Group 2013, Biokaasulaskuri 2014, Kahiluoto & Kuisma 2014, Rasi et al. 2012).

When looking at the waste and sidestream data, we must note that due to the uncertainties associated with many of the input data, the figures are indicative and do not necessarily contain all possible biomass fractions that could be recycled. The greatest uncertainties are related to data in the VAHTI system that do not contain plants to which municipalities have issued environmental permits, which means that small actors, in particular, are missing. Not all large plants are necessarily included, either, if the plant data have been reported by other means than the VAHTI system. No waste data from the Åland Islands are included in the VAHTI system. Data gathering was also hampered by the fragmented nature and poor traceability of data recorded in the database. Additionally, data on the properties of several waste and sidestream fractions were not readily available.

Chapter 5.4. State-of-the-art in biomass processing and recovery

The data on biomass processing were collated by combining the available data in the VAHTI system and data from Evira as well as earlier reports and surveys concerning the techniques used by plants processing different biomasses. The plants' environmental permits were also used to find data that were not otherwise available. The quantity of biomasses processed using different techniques varies depending on the availability of the masses and, for example, waste and sludge processing contracts, which adds its own challenges to assessing the-state-of-the-art in biomass processing.

The current state of the art in manure processing was studied by means of manure management surveys conducted by the Natural Resources Institute Finland and the Finnish Environment Institute, based on environmental permits issued to biogas plants, through interviews with Natural Resources Institute Finland's experts and by contacting different operators directly. A survey of manure management on all livestock farms was carried out in 2012, including for horses in 2014 (Luostarinen et al. 2017b). Data on the incineration of horse manure were obtained as a communication from Fortum Oyj. The share of centralised composting of manure from fur animals was estimated for 2017, and the situation of centralised composting and drying of poultry manure in 2017 was obtained directly from the operators. The quantities of manure processed at biogas and composting plants were estimated based on data from annual notifications to Evira in 2016 (Evira 2017a), the Finnish Biogas Association's map of biogas plants from 2017, and the environment permits issued to plants. The current status of surplus grass processing is based on expert estimates.

The state of the art in the processing of sewage sludges, industrial biowastes and food industry side streams is based on data for 2014 in the VAHTI system. The processing of biowastes from housing and services is based on estimates of the Finnish Association for Biological Waste Treatment concerning biowaste processing (data for 2013, Pirkkamaa 2014) and on annual notifications to Evira for 2016 (Evira 2017a). The data on the processing of pulp and paper industry sludges are based on data produced by the Finnish Forest Industries Federation for 2015 (Finnish Forest Industries Federation 2017).

APPENDIX 2. Biomass processing technologies

Technology	Biomass	Principle	Separation efficiency of nutrients, % of process input content			Special features and requirements of the technology	Suitability		Level of technological maturity	Scale	References
			N	P	OM		Pros	Cons			
Separation techniques		Separation into a solid and liquid fraction or separation of water. The processing changes the nutrient proportions but does not significantly affect their availability.									
Set-tling/sedimentation	Manures, sludges	Separation based on gravity and particle density. The solids settle at the bottom and the liquids are collected from the surface.	30-80	20-65	55	Gravity-based separation in sludge tanks for manures. Efficiency depends on dry matter content and the use of additives	Simple and inexpensive. Suitable for sludges with a low DM content	Separation efficiency often rather poor	Commercial. Separation efficiency need development	Farm, large-scale	[1]
Screen separators	Sludges	Operation is based on using a sieve or a sieve fabric that separates solids from liquids. The separation may be gravity-based, or its efficiency may be increased e.g. by pressing. Press separators have more efficient DM separation.	30	35-40	50-55	Works best with biomasses with a low DM content		Tendency to get blocked	Commercial	Farm, large-scale	[2]
Belt press	Sludges		5-50	5-60	20-60	Improving the process efficiency with additives		Rather poor separation efficiency without additives	Commercial	Farm, large-scale	[1]
Screw press	Manures	Separation using a screw press that pushes the material towards a sieve under pressure. The liquid is filtered through the sieve and solids are separated.	5-35	5-45	25-50	Improving the process efficiency with additives	Simple and relatively inexpensive	Phosphorus separation rather poor without additives	Commercial, commonly used for slurries	Farm, large-scale	[1,3,4]
Centrifuga-tion	Manures, sludges	Separation is based on the centrifugal force caused by a spinning cylinder.	10-50	50-85	50-70	Efficient for biomasses with a high DM content. Additives make separation more efficient with low DM contents	Efficient separation of phosphorus and DM	Suitability of additives for manures, which tend to increase the mass. Impacts of additives on soil need to be studied.	Commercial	Farm, large-scale	[1,2,4–6]
Drying	Sludges	Removal of water by heating the mass. Depending on the process, the DM content of the dried sludge may be up to 100%.	n.k.	>95	90	Nitrogen evaporation can be reduced by decreasing the pH. Possibility for nitrogen recovery	Dried biomass easier to handle (incl. hygiene) and transport. Can be used as pre-treatment for thermal treatment/pelletizing	Nitrogen evaporation. Need for treatment of drying gases and condensate	Commercial	Large-scale	[7]

Concentration	Manures, sludges, wastes	Increasing the temperature to evaporate water, leaving the concentrated fraction (concentrate). The evaporated water is condensed and the condensate is collected.	80-99	85-100	>90	Decrease of pH to prevent nitrogen evaporation	Efficient concentration of nutrients and water removal	Requires pre-treatment. Fouling of surfaces	Commercial	Large-scale	[8-10]
Ultra-filtration, micro-filtration	Manures, sludges, wastes	Separation through a porous semi-permeable membrane based on differences of pressure, temperature, concentration or electric potential. The liquid is separated into two fractions: the retentate that remains on the input side of the membrane and the permeate that goes through the membrane i.e. the filtered/treated fraction.	95-100	70-100	98-100	The separation range of a porous membrane is 0.01-0.1 µm. Requires pre-treatment of the biomass. Membrane regeneration.	Efficient separation and water removal	Fouling	A commercial technique for water treatment, techniques for manures under development	Large-scale	[8.11-13]
Nano-filtration, reverse osmosis	Manures, sludges, wastes		95-100	70-100	98-100	Separation of soluble compounds (e.g. NH_4-N) through a solid membrane. Requires pre-treatment. Potentially requires decrease of pH and increase of temperature. Membrane regeneration	Accurate separation and water removal	Fouling. Operation requires high pressure	A commercial technique for water treatment, techniques for manures under development	Large-scale	[8,10,12,14,15]
Electrodialysis	Manures, sludges, wastes	Separation of positively and negatively charged molecules through an ion-exchange membrane using electric current.	100	>90	0	Requires pre-treatment. Suitable for solutions with a low nutrient concentration	Accurate separation and water removal	High energy consumption. Membrane fouling	In development and demonstration phase	Large-scale	[8,11,12]
Membrane distillation	Manures, sludges, wastes	Separation of volatile compounds (e.g. NH_3) from liquid (pH>9) through a porous hydrophobic membrane based on differences in vapour pressure.	>90[a]	0	0	Requires pre-treatment. Potentially requires decrease of pH and increase temperature. Membrane regeneration	Accurate separation and water removal	High energy consumption, membrane fouling	In development phase	Large-scale	[12.13]
Forward osmosis	Manures, sludges, wastes	A separation and concentration method based on osmotic pressure and a semi-permeable membrane.	50-80[a]	90	n.k.	Requires pre-treatment. Suitable e.g. for enhancing struvite precipitation process	Accurate separation and water removal. Less problems with fouling than in reverse osmosis		In development phase	Large-scale	[12]

Biological techniques											
Composting		A microbiological process in which biodegradable (organic) raw materials form humus-type compost as well as carbon dioxide in aerobic conditions. The biomass is considered to be sanitised once its temperature has exceeded 55 °C for at least two weeks. Treatment efficiency depends on the material to be processed and the selected technique (incl. aeration, process water circulation and nitrogen recovery). The treatment stabilises the mass and makes it easier to handle, but sludges require mechanical pre-drying.									
Widrow composting	Manures, sludges, wastes	Composting in a heap or surface sealed widrows. The widrows may be turned or otherwise aerated to promote composting.	30-90	60-100	50	Often the only treatment for manures. For other biomasses mostly used to mature of compost or digestate	Simple to implement, no infrastructure investments required Reduces odours and (partly) sanitises the biomass	Control of emissions, nitrogen losses, odour	A well-known commercial technology	Farm, large-scale	2.16
Tube composting	Manures	The biomass to be composted is packaged into a plastic wrap using a feeder. Aeration through an aeration pipe.						Control of emissions, nitrogen losses	A well-known commercial technology	Farm	
Tunnel composting	Manures, sludges, wastes	A continuous, mechanically aerated widrow composting in an enclosed space. Technology enables nitrogen capture from the gases. Aeration from below the widrow. Duration usually from 2 to 3 weeks, after which the biomass is moved to open widrows for secondary treatment.				Need for maturing	Reduces odour and sanitises the biomass, makes it easier to handle	Nitrogen loss/recovery. Often needs maturing. Unevenness of the process and variable quality of the product, long processing time	A well-known commercial technology	Large-scale	
Drum composting	Manures, sludges, wastes	An industrial-type treatment where the biomass is composted in a rotating drum. The biomass is fed in at one end of the drum and unloaded at the other. The process duration is 5 to 7 days, after which the biomass is moved to open widrows for maturing.				Need for maturing		Nitrogen loss/recovery. Often needs maturing.	A well-known commercial technology	Farm, large-scale	

Biogas process		A microbiological process in which biodegradable (organic) raw materials form biogas and digestate in anaerobic conditions. Treatment efficiency depends on the material to be processed, conditions and the technique. Preservation of nutrients in a process where nitrogen is solubilised. The availability of phosphorus is also considered to improve.									
Wet-type anaerobic digestion	Manures, sludges, wastes	A biogas process where the DM content of the feed is less than 15%.	100	100	20-70	Either a mesophilic (35-40 °C) or a thermophilic (50-55 °C) process. A mesophilic process offers better stability than a thermophilic process, while the thermophilic process may be more efficient and also enables the hygienisation of the material	A well-known and effective technology for different raw material mixes. Can be located close to areas where biomass (e.g. manure) is generated. Reduces odours	DM content limits increases reactor volume. Diluting water may be required. A N-rich input may disrupt gas production	A well-known commercial technology	Farm, large-scale	2,3,17-20
Dry-type anaerobic digestion	Manures, sludges, wastes	A biogas process where the DM content of the feed is 20 to 40 %.					May be suitable for dry biomasses without dilution, but masses with DM contents of >40% often need to be diluted. Potentially reduces odours	Digestate properties and need for secondary treatment. Emissions not known and depend on the technology. A N-rich input may disrupt gas production	Different technologies being developed, first commercial technologies available	Farm, large-scale	
Thermal techniques		Heating of the biomass reduces its volume and makes it easier to transport. Increase in temperature reduces the availability of phosphorus for plants and slows down the decomposition rate of carbon in soil. Nitrogen capture must take place during biomass drying.									
Slow pyrolysis	Manures, sludges, wastes	Heating organic matter in anaerobic conditions at a temperature exceeding 300 °C. The process produces a fraction containing carbon and nutrients (biochar) and gases. During the condensation of gases also a liquid fraction is produced. Product properties greatly depend on process conditions and the raw material.	30-70	75-100	45-70	Requires drying of the biomass (input DM content >70 %)	Transportability of the product. (bio)char is preserved in the soil for a long period. The energy content of the produced gas can be used to dry the biomass, or as process energy. A scalable technology. The biochar yield is higher than in a fast pyrolysis	Legislative restrictions, utilisation of liquid fraction, nitrogen recovery (cf. drying technologies)	Pilot and demonstration scale plants. Also mobile units with continuous operation	Farm, large-scale	21.22

Fast pyrolysis	Manures, sludges, wastes	Heating organic matter in anaerobic conditions at temperatures of 450 to 600 °C. The process produces a liquid fraction (40%), bio-char (40%) and gases (20%). Product properties greatly depend on process conditions and the catalyst.	25	95	40	Requires drying of the biomass (input DM content >70 %)	The energy content of the produced gas can be used to dry the biomass, or as process energy. A scalable technology.	Legislative re-strictions, utilisation of the liquid fraction, nitrogen recovery (cf. drying technologies), corrosive effects of ashes	A commercial technology only for wood biomasses. Pyrolysis of ma-nure has not been demonstrated.	Large-scale	[23]
Hydrothermal carbonisation	Sludges	In hydrothermal carbonisa-tion, organic matter in the sludges is broken down under pressure (<50 bar) and at a high temperature (180 to 250 °C) to form biochar (+ reject water and gas). Biochar can be dried mechanically to reach a DM content of 70%.	25	95	n.k.	Input material DM content 5-15%	Suitable for wet sludg-es	Material pumping under high pressure is a costly technology	Commercial batch-based equipment for sludges, under development for manures	Large-scale	[24]
Hydrothermal liquefaction	Manures, sludges, wastes	In hydrothermal liquefac-tion, organic matter in the sludges is broken down under pressure (100 to 250 bar) and at a high tempera-ture (280 to 370 °C) to form bio-oil.	25	95	n.k.	Input material DM content 5-20 %	Suitable for wet sludg-es	Material pumping under high pressure is a costly technology	POC for biomasses and sludges. Not demonstrated due to the require-ments set by the high pressure	Large-scale	[25]
Gasification	Sludges, wastes	Heating organic matter at a temperature exceeding 700 °C in anaerobic conditions. The process produces synthesis gases and ashes.	25	95	0	Requires drying of the input material (input DM content >70 %)	The energy in the gas product may be used for drying the sludge or as process energy, or as a fuel. Only two products, gases and ashes. A scalable technology.	Requires the drying of the sludge, corro-sive effects of the ashes, possible for-mation of PAH com-pounds	Commercial tech-nology for wood biomasses and wastes. Gasifica-tion of manure has not been demon-strated.	Farm, large-scale	[26]

Incineration	Manures, sludges, wastes	Conversion of organic matter into energy in a thermal oxidation process at a temperature exceeding 900 °C.	0	100	0	Requires drying of the input material (input DM content >70 %)	Significant reduction in mass	Drying of the material before incineration. Corrosive effects of chlorine etc. Management of emissions from small-scale processing. Organic matter is lost, and the availability of phosphorus to crops is reduced	Development needs in small-scale incineration of manure regarding emissions management. On power plant scale there are well-functioning applications for mixed fuels.	Farm, large-scale	
Chemical techniques		Different techniques, some of which aim for reconditioning the biomass and making it easier to process. Others aim for producing an inorganic nutrient product which contains properties similar to those in mineral fertilisers.									
Acidification	Slurries	Lowering the manure pH to level 5.5-6, which increases the proportion of ammoniacal nitrogen and reduces ammonia emissions (potentially also odours).	80-100	100	100	Use of sulphuric acid to lower the pH. Can be excecuted either in the livestock installation, manure storage or during fertilisation	A simple technology, reduces nitrogen emissions compared to untreated manure	Occupational safety. The required acid quantity depends on the pH buffering capacity of the manure	A commercial technology	Farm	27
Kemicond treatment	Sludges	A sludge conditioning method developed by Kemira, in which the sludge is acidified and oxidised. During acidification the sludge pH is decrased by adding sulphuric acid. In oxidisation, hydrogen peroxide is added to the sludge. Kemicond treated sludge is composted after drying.	n.k.	100	n.k.	Sludge drying after treatment is required	The treatment enhances water removal. Reduces odours	Requires several chemicals and requires separation after treatment. Occupational safety	A commercial technology	Large-scale	28.29
Lime stabilisation	Manures, sludges	Increase of pH (pH>10) and temperature by using either quick lime or slaked lime. Quick lime is used to increase the pH, which raises the temperature to 55 °C for two hours. Using slaked lime, the pH is raised to over 12 degrees for 48 hours or to over 11 degrees for at least 14 days.	20	100	10	Requires secondary treatment, e.g. composting	A fast process. The use of quick lime enables hygienisation and dries the biomass. Improves the availability of phosphorus in sewage sludge	Evaporation of nitrogen as ammonia. CO_2 emissions	A commercial technology	Large-scale	8.30

Ammonia stripping and scrubbing	Manures, sludges, wastes	A nitrogen recovery technique in which ammonium nitrogen (NH_4-N) is separated from the liquid phase in the form of gaseous ammonia (NH_3) using pH and temperature regulation. Ammonia can be recovered by stripping it from the air flow, for example with sulphuric acid, producing ammonium sulphate ($(NH_4)_2SO_4$).	65-98	0	0	Requires pre-treatment. Need for chemicals (pH decrease and nitrogen recovery)	The product has a high ammonium nitrogen content	Fouling. Phosphorus recovery step before/after stripping needed	Used on an industrial scale, high costs on a small scale	Farm, large-scale	8.31-33
Crystallisation (struvite)	Manures, sludges, wastes	Crystallisation of nitrogen and phosphorus in liquid to form magnesium-nitrogen-phosphate salt ($MgNH_4PO_4.6H_2O$).	20-65	70-99	0	The process requires a low DM content, pH regulation (>9) and addition of Mg	Easy-to-transport nutrient product	The P content of manure limits crystallisation, Ca ions cause the formation of other crystals	A commercial technology for sludges, for manure in piloting phase	Large-scale	8.34
Ion exchange / absorbents	Manures, sludges, wastes	Attachment of ions (e.g. ammonia) to the surface of a porous inorganic material (e.g. zeolites). Further use of the material, e.g. in fertilisation, or absorbent regeneration.	37-99[a]	>90	n.k.	Requires pre-treatment and a low material DM content	A nutrient product for field use	Blockages, chemicals used for absorbent regeneration and cleaning, absorbent self-life	A commercial technology for water treatment, techniques for manures are being developed	Large-scale	11.13
[a]NH_4-N											
OM=organic matter, DM=dry matter, n.k.=not known, POC=proof of concept, report on suitability and feasibility											

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APPENDIX 3. Key current and proposed policy instruments on nutrient recycling

Table 1: Current regulatory instruments.

Policy instrument	Operating mechanism	Significance for directing the nutrient cycles	Essential for effectiveness; side effects	Development perspectives
Permit system under the Environmental Protection Act	Safeguards the reuse of manure nutrients (manure application plan) and prevention of water pollution: requirement of the necessary field area for spreading manure in proportion to livestock numbers; permit regulations concerning the storage, management and application of manure. BAT requirements for manure nutrient composition Channelling of side streams from the forest and energy industries: (relatively detailed) regulation of requirements for further use	Ambiguous, in some cases obstructs the introduction of new recovery methods (inflexible permit conditions) A bottleneck or an enabler: regulation enables use and opens markets, while also acting as a bottleneck for previously unregulated use. Bottleneck: cumbersome permit processes of biogas and processing plants.	Labour-intensive, costs for the operator Environmental permits for livestock installations: the guiding impact of the manure application plans is unclear, as is its role and relationship with other policy instruments in the regulation of manure application. Indirect guidance extending beyond the 'operative unit' (livestock farm) that the permit concerns when manure production and ownership of arable land are dissociated.	A reform is being drafted under which permits for livestock installations would to a great extent be replaced by an extended notification procedure, and competence would be shifted to municipalities. Permit procedure for livestock installations: the role and relationship with general regulatory instruments should be clarified. Relaxation of guidance by permits should be considered regarding manure reuse: *in the future, no manure application plans*, focus on managing the other negative impacts caused by a livestock farm. The manure application plan overlaps with the annual cultivation plan. *Above all, manure use could be regulated by evolving legislative instruments*. On the other hand: the increasing importance of water management plans may result in more stringent guidance by permits with enhanced impacts. Potential of guidance by permits in regulation specific to "hot spots". General regulation offers no flexibility based on an area's special features.
General regulatory instruments: Government Decree on the restriction of discharge of certain emissions from agriculture (1250/2014); (so-called Nitrate Decree)	Safeguards the reuse of manure nutrients: restrictions and prohibitions applicable to the use of manure and other fertilisers to limit emissions to water and guarantee that application comprises genuine reuse.	Obligations under the Nitrate Decree hamper/prevent losses of nutrients and force operators to consider ways of using them; on the other hand, a bottleneck: some of the regulations obstruct the storage of biomasses. The significance of fertilisation limits in fields with a high P level is low.	Do all the requirements have a guiding impact in practice? Are the requirements correctly dimensioned? Special regulations on using manure as a raw material. Bottleneck of nutrient recycling	Fertilisation limits should be examined in terms of lightening the permit system, the fertiliser legislation, the EU agri-environmental scheme and centralisation of production. *The Nitrate Decree could be developed into a clear statute that applies to all nutrient use*. Nitrogen limits under the Nitrate Decree only for manure-based fertilisers. Use of processed manure as an ingredient in fertilisers should not weaken the status of these fertilising products: the Nitrate Decree should be discussed as part of the EU circular economy package?

Policy instrument	Operating mechanism	Significance for directing the nutrient cycles	Essential for effectiveness; side effects	Development perspectives
Fertiliser legislation: The Act on Fertiliser Products (539/2006); The Decree on Fertiliser Products (Ministry of Agriculture decree 24/11) as well as the Decree on Activities Concerning Fertiliser Products and Their Control (Ministry of Agriculture decree 11/12)	The type designations of organic fertilising products work as the basis of productisation and market creation Requirements of effectiveness and safety placed on the products; requirements and restrictions concerning permitted raw materials in recycled nutrients, the way nutrient biomasses are used and the quantities used	The type designation system describes the requirements for the products' fertilisation effects and use and the management of harms and hazards, also directing the products to suitable uses. Bottleneck in its current form: A precondition for getting new types of products into the market is applying for a type designation, and the application must include information on the functioning and safety of the product The fertiliser product legislation is an unsystematic and complex entity which is difficult to comprehend. Inflexibility of administrative process as a bottleneck	Pros and cons of standards: support market creation but may inhibit small companies Cost-sharing when applying for a new type designation: how can unfair treatment of operators and creation of obstacles to innovation be avoided? Creation of a European market will provide export opportunities but may also increase the imports of fertiliser products	The problems have been identified, a new EU Fertilising Products Regulation is forthcoming, by-product criteria in connection with the Fertilising Product Regulation are being developed. National exemptions permitted under the By-product Regulation have been used in full. Streamlining regulation on type designations and on applying for designations is important. No general quantitative targets for recycling, focus on product quality. The point is the suitability as a fertiliser, rather than staying below the regulatory limits. Support for market development is needed: advice and information for farmers related to the use of new products; a register of products and producers.
An amendment to the EU Fertilising Products Regulation is being drafted	Marketing requirements: the EU Fertilising Products Regulation extends to cover organic fertilisers			
The Animal By-products Regulation	Limits for phosphorus fertilisation		The limits for phosphorus fertilisation are high. So-called facade instruments, no practical impacts.	Is environmental protection legislation the right place for restrictions on phosphorus use (Nitrate Decree). In any case, the phosphorus limit must be made more stringent and tailored: how can it be made effective? Which general fertiliser limits could work, and how variations in individual field plots could be addressed?

Table 2. Current economic instruments.

Policy instrument	Operating mechanism	Significance for directing the nutrient cycle	Essential for effectiveness; side effects	Development perspectives
EU agri-environmental scheme	a) An economic incentive for using manure as fertiliser; b) Fertilisation limits represent an attempt to prevent excessive fertilisation	A significant role in guiding the nutrient cycle, but lower payment levels and, on the other hand, growing farm sizes reduce its significance; volume EUR 1.6 billion/7 years (EUR 225 million/year) Under the current programme, there is less incentive to use manure than before; on the other hand, the criteria for fertilisation use are stricter Fertilisation limits have also been blamed for being a bottleneck in nutrient recycling. The target of nutrient recycling is not integrated in the agri-environmental payment scheme	Declining rate of commitment to agri-environmental scheme; the funds available for the scheme have also dwindled A lot of bureaucracy and paperwork No data on the cost-effectiveness of support forms. Criticism has been levelled at the scheme as a whole: inefficiency, role of income support, expensive supervision and credibility of the knowledge base have come up in discussions. Does it encourage innovation and investments? According to critics, the system supports the recycling of mild nutrient products. Especially concentrated, low-phosphorus nitrate fractions: does spreading them on fields with a high phosphorus play a role in environmental protection; is a total ban justified? The fact that no phosphorus can be spread on fields with a high STP level may have excluded some farms from the scheme. If a small quantity could be spread, separating the manure, spreading the liquid, nitrogen-rich fraction onto the field and transporting the solid phosphorus rich fraction away might be feasible. Always permitting a certain P level could promote investments and still reduce P accumulation in soil in the long run	1) <u>New measures and emphases</u> Attention to increasing organic matter (target at 4%) and carbon sequestration; field plot specific (recycling) fertilisation plan and a field reconditioning programme based on an extended soil analysis; efficient identification of loading risk areas; paying for ecosystem services (carbon sequestration, nutrient retention). Support for transport (used in the first environment payment period). Would it distort the existing market for recycled nutrients? Which biomasses would be within the scope of the support? Increasing the payment amounts to correspond with more stringent limits on manure use. Applying slurry in the field and recycling nutrients and organic matter should not be mutually exclusive. The support for spreading slurry only covers part of the costs incurred. 2) <u>Updating the operating model</u> Dropping detailed guidance regarding nutrients should be considered (replaced by general regulatory instruments that would address the P status of field plots); would free up funds for new measures and anticipate a situation where commitment to the scheme is reduced further. The target should be increasing the proportion of field surface area fertilised with manure and manure-based fertilising products.

Investment support	Rural Development Programme: - Support for farm investments (key); - Biomass production and distribution chains; - Innovation groups - Business start-up aid - Techniques that promote energy savings and improve the status of the environment Support rate of investments in the storage and use of manure is approx. 10% higher in the target area.	Important, e.g. remote storage Volume approx. EUR 80 million /year for all farming investments The current investment rate is enough to keep the production volume at the current level, or the volume will decrease slightly.	Support levels (e.g. separation solutions): are they high enough? Support conditions and their significance? Facilitation and use of support forms on farms? In livestock farming, investments focus on certain lines of production	Links to other investment incentives, including restrictions and obligations? Could the link be stronger? It should be noted that some of the large livestock farms (pigs and poultry) that remained within the scope of the support in 2015 did so just in case. They thought that future investment support forms might be linked to participation in the agri-environmental scheme. Targeting of support: should nutrient recycling investments be double deductible in taxation? Evaluations or studies of the impacts of support forms and their targeting → support system development
Innovation policy: (in this context: R&D support, including RaKi programme, Government key project, TEKES)	Support for the development and testing of nutrient recycling technologies and business concepts Project funding approx. EUR 6.9 million in 2016 (Raki programme, Government key project and separate funding); for the entire government term EUR 30 million	Innovations are an important precondition for the development of the sector and for maintaining its competitiveness in the future	Cost-effectiveness of funding? High quality of projects; viability and reproducibility of measures and solutions	”Support measures should be targeted more clearly, rather than following the principle of giving a little to everyone” (Mikkonen, 2014, 9) Evaluations are needed. What is a good experiment/test funding mechanism like? How can the lessons learned through experiments be collected and used? Innovation policy is based on individual projects and discontinuous. While the funds are intended for developing nutrient recycling, it appears that they are spent on general activity. Only later (i.e. now) efforts are made to perceive where we are and what we should spend money on. Project follow-up is poor.

Table 3. Proposed new openings.

Policy instrument	Operating mechanism	Essential for feasibility and effectiveness	Impacts
Targeted processing obligation	The environment permit could contain an obligation to process manure (and transport it away from the area) if there is a shortage of arable fields in which to spread manure in the area	Links to compensating support forms? Technological standards of processing? Use of process products? Must be economically feasible for one of the parties; requirements under the fertiliser product legislation must be fulfilled.	Investment costs for actors, demand for equipment and contractors If successful, will reduce the demand for conventional inorganic fertilisers Impacts on end product price?
Obligation to recover phosphorus, a separate project of the Government analysis, assessment and research activities is under way (Recovery and recycling of phosphorus in sewage/Aalto University, Tyrsky-Konsultointi Oy)	Improving the availability of phosphorus and product safety		If successful, will reduce the demand for conventional inorganic fertilisers
Obligation to mix/distribute	An obligation will be imposed to mix organic biomass in mineral fertilisers or to ensure the availability of organic fertiliser products	Technical possibilities, product safety Which mixes will it be applicable to? Where would the organic fractions come from (imported)? Poultry manure, for example, also comes from the Netherlands, not only from Finland Balancing out nutrient streams between different regions: will it promote this objective, and on what terms could it do so?	Expands the market/creates a new market If successful, will reduce the demand for conventional inorganic fertilisers
Promotion of experiments and 'innovation agreements' with the EU	If it turns out that EU regulation is a bottleneck in the introduction of a useful innovation, its testing should nevertheless be possible		Supports productisation and reduces the risk included in innovation inputs. Administrative costs? Supports the adaptability of legislation.

Fertiliser tax, a separate project of the Government analysis, assessment and research activities is under way (Economic policy instruments for the circular economy/VTT Technical Research Centre of Finland, Finnish Environment Institute, Motiva Oy)	A materials tax to reduce the price competitiveness of mineral fertilisers compared to recycled fertilisers	Recycled fertilisers must be available Nitrogen or phosphorus – or both – should be taxed? The tax rate should be considerably high to have an impact (nitrogen fertilisation) Measures that compensate for the rising costs: what and how?	The price of production inputs will increase the end product price and undermine the competitiveness of domestic production Societal costs Safety risks of own importation and production; the cadmium limits of P fertilisers may push up the price of mineral phosphorus, whether or not the phosphorus needs to be purified (Fertilising Product Regulation). The fertiliser tax is fraught with problems: taxing imported products, taxing the N and P content of recycled fertilisers, mismatch depending on whether or not organic recycled fertilisers are available in the area.
Standards	End products and their manufacturing practices	In Sweden, a standard related to sewage sludges is applied	Regulatory burden
Quality systems, self-regulation, undertakings	Certificates/accreditation for nutrient fractions, technologies, contractors A label ('resource-wise') for the end products (foodstuffs, biogas, electricity); producer organisations', companies' etc. common undertakings, e.g. concerning the phosphorus value chain	The more complex the market becomes, the more information and commitment will be needed. 'Farmers are not familiar with organic fertilisers', and service concepts are thus needed. A quality system could help competent actors stand out. Training and continuing training programmes to support competence development.	Costs of an accreditation system

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